A Conceptual GIS Vulnerability Model for Unsafe Drinking Water in Relation to Hydraulic Fracturing: A Southwestern Manitoba Case Study

by

Glen Robert McDonald

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Department of Environment and Geography

University of Manitoba

Winnipeg

ABSTRACT

Fracking has become a major fossil fuel source providing $37 billion to the Canadian economy in 2016 and $15 billion in taxes and royalties from 2013 to 2015. By current estimates, if annual reserves of 207 billion barrels are used up every year North America will only be energy self-sufficient for the next 10-15 years. There is substantial political and industry pressure to develop these reserves. However, hydraulic fracturing has potential environmental impacts from sub-surface contamination of aquifers from fracking fluid, surface and groundwater contamination, noise and air pollution, possible seismic instability, and long-term chronic health effects related to drinking water. The geologic, geographic and social-spatial context where fracking development occurs is important in determining risk and therefore any mitigative measures that might be undertaken. The literature suggests that water contamination may be the primary risk posed by fracking, but hydrology is a spatially complex phenomenon. Water quality is the most serious issue facing communities, such as Virden Manitoba, that are spatially adjacent or within oil and gas production fields. The objective of this study is to develop a conceptual model for Ground Water Protection in GIS that will inform future environmental mitigation policies.

GIS allows for the layering and analysis of a wide range of social, economic, and spatial variables in order to determine their spatial relationships as well as discover unforeseen variables and phenomena that give insight into how future studies and mitigation policies are conducted. It allows areas of vulnerability to be identified and resources directed to the community in question in order to mitigate future health risks.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

Canada is a water wealthy nation reliant on its clean drinking water for the safety of public health. 884 million people lack access to clean drinking water worldwide (World Health Organization, 2017, July). Hydraulic fracturing (fracking) accounts for half of U.S. crude oil production (U.S. Energy Information Administration, 2016, March 16) and over two-thirds of natural gas production (U.S. Energy Information Administration, 2016, May 5). It is the method of hydrocarbon extraction for nearly 90% of the natural gas wells in the United States (U.S. Department of Energy, 2013). Adoption of this technology has made North America the single largest hydrocarbon-producing region in the world (U.S. Energy Information Administration, 2016, May 23), accounting for $1.2 trillion in gross production as of 2014 (Perryman Group, 2014). While Canada has yet to achieve the same level of production as the United States, it holds 8% (compared with the United States' 9%) of the world's supply of shale gas (Natural Resources Canada, 2016), and projections state that 80% of natural and tight gas production by 2035 will be extracted using fracturing technologies (Natural Resources Canada, n.d.-a). The significant economic and political inducements to support fracking have not been counterbalanced with needed research into fracking's environmental impacts (American Chemical Society, 2016).

Hydraulic fracturing, an industry technique used in oil and natural gas production, mixes water and sand with chemical additives, such as fracking fluid or HFF, and injects it at high pressures into geological formations. This creates microfractures in the rock and releases shale gases and otherwise irrecoverable resources from specific geological formations. Hydrocarbons can then flow through these fractures into a well for extraction. The horizontal drilling technique is used once a gas-bearing shale deposit has been found from drilling straight down. In horizontal drilling, the drill is then turned sideways and can continue for kilometers through the middle of a deposit. Multiple wells drilled in this manner can fan out underground in all directions, allowing for the fracturing of hundreds of hectares of shale from a single well pad. Injection fluid is then collected at a separate collection site, stored in tailing ponds or tanks, and either reused or disposed of (Boudet et al., 2014). Fracking fluid is composed of up to a thousand different possible constituents (Wattenberg et al., 2015), and most oil and gas companies have patents protecting the exact mixture that they use (see Appendix H for a short list). The environmental impact of fracking has been downplayed by the industry, but several recent seismic events have been linked primarily to disposal fracking practices, in which waste fluid is injected into disposal wells.

Considerable public controversy surrounds hydraulic fracturing's impact on the quality of drinking water (Canadian Council of Ministers of the Environment [CCME], 2014). While unsafe drinking water has been modeled and analyzed from the standpoint of fracking on the physical and chemical environment, research literature that addresses the human health and social risk of fracking with regard to drinking water is severely lacking (Vengosh et al., 2014). According to Cromley and McLafferty (2012), the health effects of approximately 80% of the constituents of HFFs are unknown, and only a few of the thousands of potentially hazardous chemicals in HFFs are regularly monitored by environmental health systems. This is not to say that the effects of singular chemicals are unknown; it is the effects created by the combination of these chemicals that create a new hazard to ground, surface, and drinking water that has not been adequately researched (Gatrell & Elliott, 2015). Over 1,000 chemicals are employed in creating HFFs, and each company's completely unique formula is a protected trade secret (United States Environmental Protection Agency [EPA], 2015). Given that there are over 3,600 wells in Manitoba at the time of this study (the majority of which use fracking techniques) and approximately 2,000 of those wells employ horizontal drilling (Council of Canadians, 2013), there is plausible cause for concern for the quality of drinking water in communities adjacent to oil and gas development regions.

Within the field of environmental studies, social vulnerability is defined as the inability of an individual or group to withstand the adverse effects of exposure to a natural hazard because of their capacity to anticipate, cope with, or resist and recover (Mahmud, 2015). Quantitative risk assessments are the standard research methods, and they seek to establish acceptable thresholds or risk levels in the general population. In the process, these "acceptable" levels quickly become the baseline for normative environmental exposure, but these baselines ignore the chronic effects of the mere presence of certain organic chemical compounds, natural elements, and synthetic chemicals. This situation effectively removes the human health factor from the equation, shifting the research premise toward attaining federal regulation and guideline thresholds for safe drinking water, regardless of long-term human health effects. The literature rarely discusses the acute and chronic effects of such combinations of chemicals in drinking water, because these chemicals and the efficacy of the policies created by the studies are mostly undocumented.

The European approach to environmental acts and policies differs in that it follows the "precautionary principle of European Law" (Cromley & McLafferty, 2012).In brief, this principle states that a lack of specific scientific evidence of causality cannot excuse any failure to act on a potential threat to environmental or human health. This has led to the banning of many fracking fluids and chemical substances that are still being used in North America despite their lack of research and supporting toxicity data. In short, the European industry alone does not drive policy; public opinion also drives policy by pressuring the government to regulate the industry.

Most water quality research literature lacks a multivariate perspective and is dominated by a primarily one-to-one relationship approach to modeling (Cromley & McLafferty, 2012).

Researchers tend to concentrate on the biofootprint of the chemicals and the quantitative nature of reporting the presence of specific chemicals rather than the spatial environmental and health geography ramifications of a spill or release into the environment (Plog & Quinlan, 2012). Wattenberg et al. (2015) address the health impacts of high benzene levels in drinking water, identifying, weighing, and classifying hazardous materials according to their toxicity and acute versus chronic effects.

The present study asserts that the literature on drinking-water safety omits human health concerns from the equation, and this is because of the problematic nature of potentially alarmist statements or conclusions that might negatively affect gas and oil extraction through fracking operations. This study further asserts that in-depth study of the chronic health effects of injecting fracking fluids into the groundwater supply would be too expensive and would ultimately force public health policy makers and regulatory bodies and the petroleum and gas industries to radically change their methods of operations—or perhaps abandoning them altogether and enforcing moratoriums.

Linking environmental exposure to health hazards and issues is no easy or definitive task, as evidenced by the lack of research in the field. Clinical studies are ethically limited to short-term reversible human effects (Interagency Secretariat on Research Ethics, 2005), so studies rely on animal testing that results in toxicity thresholds not suitable for human health considerations. In addition, the geographic locations of participants' places of residence are not necessarily considered in such clinical trials, thus completely ignoring the spatial aspects of exposure. Most data in this study are restricted by access to government-collected data, and the results from water treatment plants do not reliably represent true water quality. An accurate measure of the water's exposure to other sources of contamination en route to the consumption point can be determined only at the tap. Without this data, epidemiological studies can only be employed to determine possible patterns of contamination sources.

Many epidemiological studies of unsafe drinking water, and the socioeconomic and spatial variables associated with vulnerability, assume a one-to-one or one-to-many multicriteria approach. This study offers a more multivariate modeling approach by presenting a comparative spatial vulnerability model to determine unsafe drinking water zones in the township and adjacent municipalities of Virden, Manitoba, compared with that of the city of Brandon, Manitoba, and its adjacent municipalities. The town of Virden was selected because of its proximity to hydraulic fracturing operations in the southwestern corner of the province, which lies within the Bakken Shale deposit region and has attracted increased natural gas extraction by the oil and gas industry in the recent decades. Brandon was selected as a comparison settlement because of its remote distance from said operations and for its similar regional geographic, geological, and geomorphological characteristics. It also shares common watershed characteristics, and the socioeconomic composition of both communities is very similar.

This study does not aim to discern one-to-one epidemiological relationships of causation attributable to specific chemicals or environmental exposures to any specific health concerns. Rather, it aims to establish the relationships that submodel variables associated with the overall multivariate model and identify spatial unsafe drinking water vulnerability. The results of each of the submodel processes will be synthesized into visual displays in the form of maps and graphs to reveal the spatial correlation of variables to geographies of vulnerability. A final analysis will be conducted using geographic information system (GIS) software to combine the spatial attributes of all relevant variables, and the results of the intersection of the top-weighted variables will be revealed and geographic health disparities discussed.

The oil and gas industry practice of fracking provides economic benefits, but comes with costs not yet clearly identified. HFFs can impact water quality and human health, and existing physical measures of these tend to be bivariate. The risk to human health should incorporate social vulnerability. Fracking, like all environmental impacts, is multivariate, multispatial, and geographic. The fracking problem juxtaposes physical, health, and social factors within the geographic context, requiring a new way of thinking. Addressing this juxtaposition with GIS allows for the development of holistic models and for enhancing models such as the DRASTIC parameter model (Aller, 1987).

Fracking's risk to human health from contaminated drinking water combines the extent of the contamination (as a function of proximity, number of wells, fracking fluid constituents, mobilization of fluids, etc.) and the social vulnerability of the population (socioeconomically disadvantaged, gender, demographics, etc.). Some of these factors can be measured, and some cannot. The objective of this thesis is to develop a comprehensive multivariate model to determine the risk to human health from drinking water potentially contaminated from fracking, and to demonstrate, in principle, by applying the analytical hierarchy process (AHP) the merits of pair-wise ranking that incorporates human judgement in assessing risk (Saaty, 1981). Ideally the latter would be done with stakeholder groups, and with monitoring data, but here a tangible demonstration is provided based on extensive review of the literature and physical and social parameters (many of which are provided in the Appendices). This model will be spatially explicit and geographic and use the physical environment and social vulnerability as part of the estimation of risk. This study employs urban and industrial infrastructure locational data along with environmental data and uses geographic information technology to determine which socioeconomic variables are sensitive to variables contributing to drinking water vulnerability.

CHAPTER TWO

LITERATURE REVIEW

Fracking and Water Quality Effects

Public concern regarding the health threat of contaminated drinking water as a direct result of fracking operations is rising worldwide (World Health Organization, 2012). The health risks of methane gas and other fracking fluid contaminants in drinking water are real and widely reported (EPA, 2015). Groundwater contamination has been the focus of many studies about the leaching of fracking fluids into drinking water sources. However, surface spillage at drill well operation sites along with wastewater holding sites is also a source of concern. Gross et al. (2013) published a study in the *Journal of the Air & Waste Management Association* in which Weld County, Colorado, c (BTEX) components of crude oil were analyzed. They analyzed groundwater samples collected from the spill excavation area and on the first reported date of sampling. The BTEX measurements exceeded the U.S. national drinking water maximum contaminant levels (MCLs) in 90%, 30%, 12%, and 8% of the samples, respectively. Leakage of BTEX and other fracking fluid contaminants into groundwater sources from lined holding ponds designed for temporary storage of "flow back" or production water (water that flows back to the surface with the oil and gas during hydraulic fracturing operations) can contaminate the groundwater through failures in the lining. The tailing ponds used to contain flow back and wastewater consist of a mixture of gas, oil, metals, and fracturing fluids, with the possibility of naturally occurring radioactive materials (Gross et al., 2013). Although BTEX measurements indicate they biodegrade quite rapidly, soil type and aquitards play a role in the speed at which this process occurs. BTEX compounds are mixed with thousands of other variable additives depending on the extraction company's particular patented concoction. These additives cause the particularly harmful BTEX compounds to remain on the surface of aquifers. The long-term biodegradability of these concoctions is largely unknown because of the lack of research in this field. An example of the pretreatment groundwater BTEX concentration levels can be found in the Weld County study from 60 test sites found in Appendix A. Ongoing monitoring of this sort is necessary in gaining a temporal perspective of the human health effects of fracking fluid contaminants in drinking water sources. Most studies addressing the issue of groundwater contamination conclude that the lack of public engagement, education, and disclosure of fracking operation practices on behalf of the industry are the major sociopolitical factors in unsafe drinking water vulnerability. More public engagement is required, allowing for public education. Most Americans know very little about fracking and therefore do not know if they support or oppose the practice (Boudet et al., 2014).

In a recent analysis of groundwater quality in the Barnett Shale region in north central Texas, chemical contamination can result from casing failures and in fact do in approximately 3%–12% of new gas well operations within the first year of operation (Hildenbrand et al., 2015). The Barnett Aquifer supplies metropolitan Dallas–Fort Worth, Texas, with its entire drinking water supply. Employing a multicriteria analysis modeling approach concluded that the depth of groundwater source was more positively correlated to improved water quality than distance to well site operations (Hildenbrand et al., 2015). The direction of movement of groundwater also played a large role particularly when large concentrations of well sites were located in the direction from which groundwater flowed. Consider the following figure delineating groundwater movement in southwestern Manitoba.

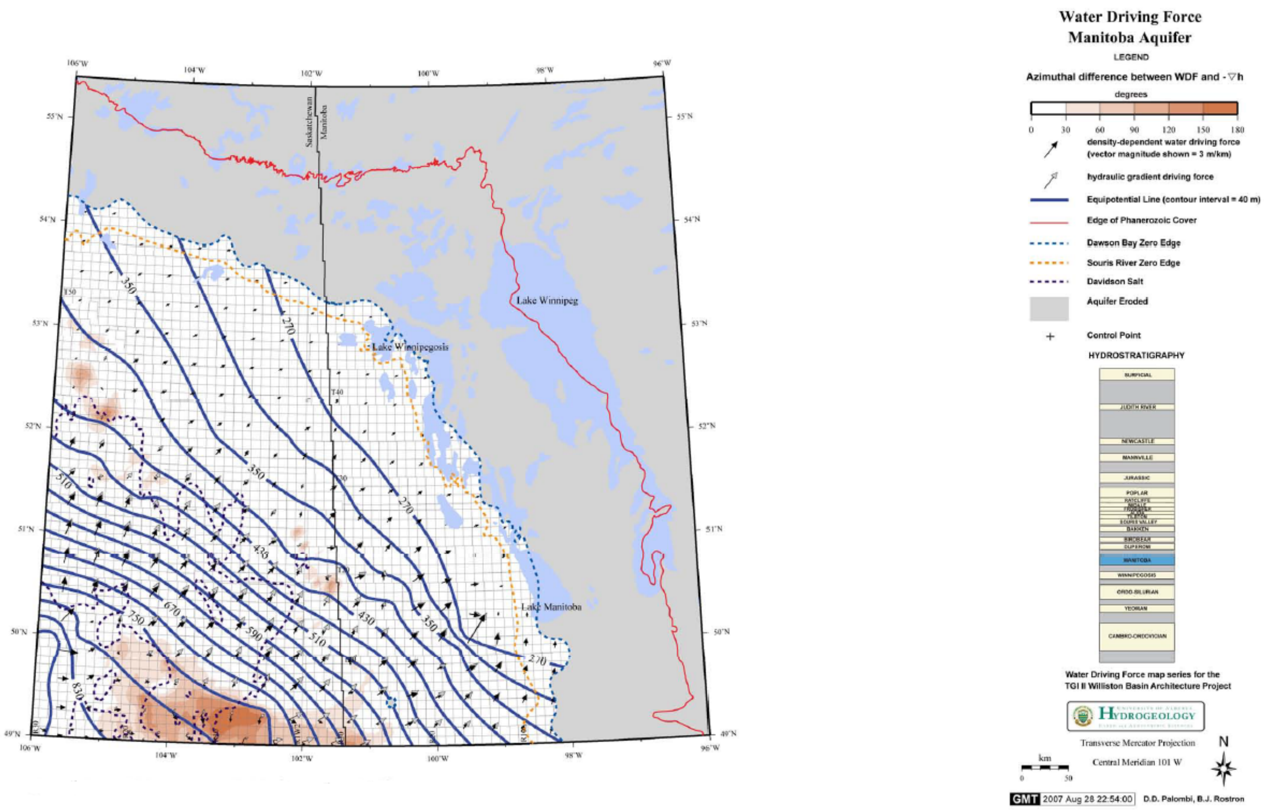

Figure 2.1. Water driving force in the eastern Prairie Provinces influencing western Manitoba aquifers. Source: D. D. Palombi and B. J. Rostron, *TGI II Williston Basin Architecture Project*.

The abovementioned figure clearly illustrates the general and consistent flow of groundwater in southwestern Manitoba from the Bakken Shale region of gas and oil development toward the lower elevation northeast region of the province. Given the conclusions of the Barnett Shale region study, some serious concerns regarding the safety of drinking water in the southwest portion of the province should be raised given the high arsenic levels in the Virden water supply (ALS, 2016) and its geographic vicinity to the flow of groundwater originating from the epicenter of the Bakken oil and gas fields of operation. The following figure further illustrates the Manitoba escarpment groundwater discharge toward the northeast using a cross-sectional view.

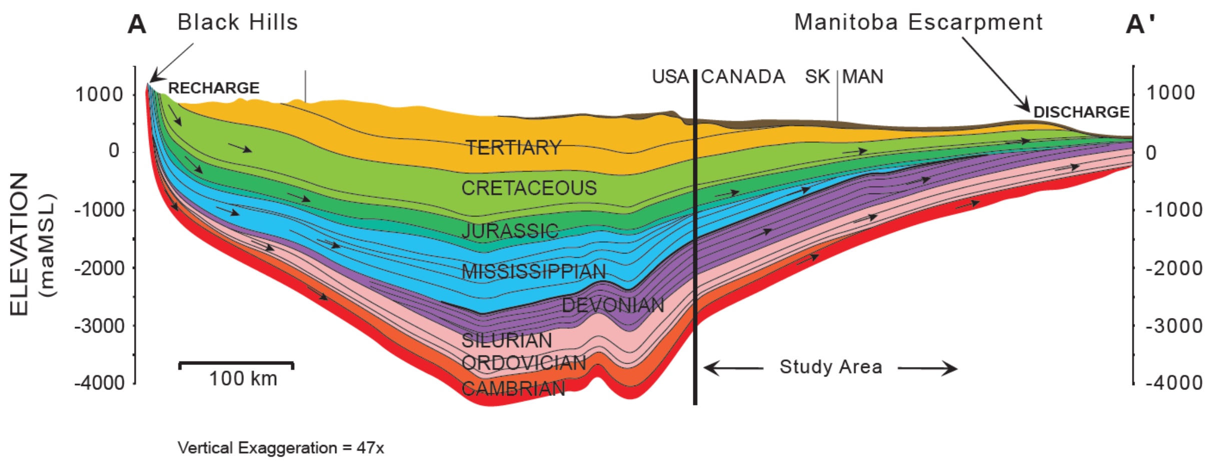

Figure 2.2. Structural cross-section A to A' through the line of section shown in Figure 2.1 (modified after Benn and Rostron, 1998). The hydrogeological characterization includes rocks from the Cambrian to uppermost Cretaceous systems. This study spans from the USA-CANADA border and continues to the edge of Phanerozoic deposition (beyond this section). Recharge is thought to enter the basin in the Black Hills of South Dakota and up-dip discharge to the northeast of the Manitoba Escarpment. Source: D. D. Palombi and B. J. Rostron, *TGI II Williston Basin Architecture Project*.

According to Ridlington and Rumpler (2013), the Barnett Shale region of North Texas indicated elevated levels of arsenic, selenium, and strontium in drinking water wells in the vicinity of fracking sites. They suggest that the operation of fracking the substrata opens fissures that allow the free flow of naturally occurring chemicals and metals into the groundwater at higher concentrations and at a faster rate than would normally occur. Again, they attributed this to faulty well construction. The study also indicates a 6%–7% well failure rate in Pennsylvania because of such structural failures in well construction. This result is supported by DiGiulio and Jackson (2016) in their Wyoming study of fracking well injection, stating that anomalies in major ion concentrations in two monitoring well sites were recorded, which prove the upward migration of solutes. Furthermore, by comparing current level to those recorded in the mid 1990s, they found impact from wastewater injection practices on domestic wells.

The practice of fracking releases natural chemicals and metals into groundwater sources through the physical act of creating fissures to release oil and gas deposits. It also introduces synthetic chemicals and other contaminants, the long-term health effects of which on the public are unknown due to the ethical constraints on human studies (Canadian Institutes of Health, Natural Sciences and Engineering Research Council of Canada, Social Sciences and Humanities Research Council of Canada, 1998). Those that have been studied are examined singularly and not as HFFs. Animal studies do not reflect the same tolerances when attempting to establish threshold limit values (TLVs). When used in combination, these HFF ingredients create a completely new health hazard. The Ashland Oil Company spill in 1988 on the Monongahela River in Pennsylvania resulted in the mixing of bromide and chlorine into the local drinking water supply, resulting in a population of 23,000 people bereft of drinking water for over a week (Miklaucic & Saseen, 1988). The combination of the two chemicals results in the production of trihalomethanes, cancer-causing chemicals that also affect mammalian reproduction and endocrine systems (Kassotis et al., 2016). Fracking also consumes valuable freshwater resources at a rate of hundreds of thousands of gallons for each well drilled, dependent on the depth, distance, and time the drill requires to complete (Council of Canadians, 2014). This freshwater is permanently removed from the natural water cycle and must be stored, mainly in tailing ponds until permanent solutions are employed. This also creates a competition for local water sources between the oil and gas industry and agriculture.

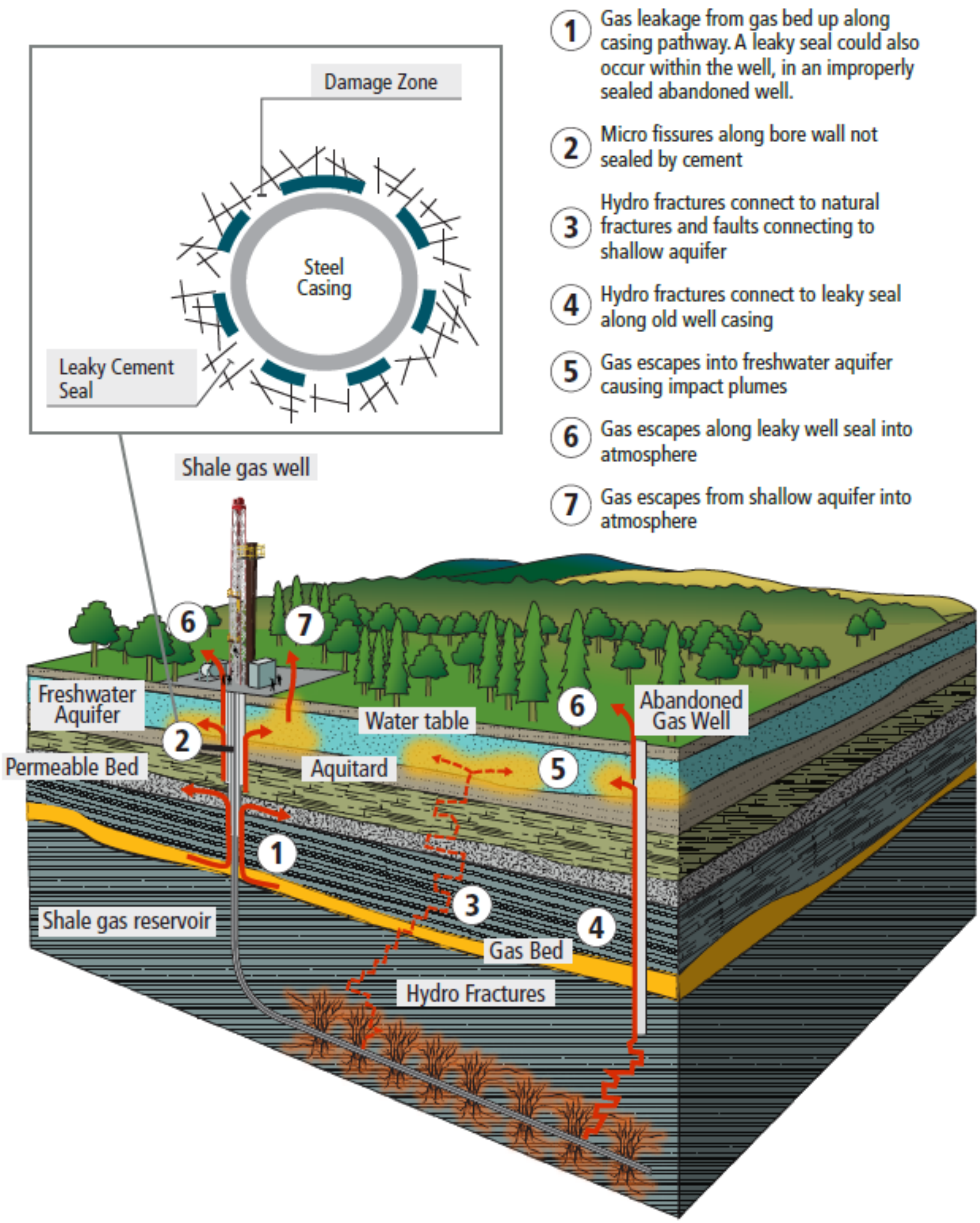

Figure 2.3. Cross section of a shale gas reservoir identifying possible locations where groundwater contamination can occur during hydraulic fracturing. Source: Council of Canadians, *Environmental Impacts of Shale Gas Extraction in Canada.*

The following (Figure 2.4) illustrates fracking fluid ratios and the specific constituents of fracking fluid that are generally found in a typical HHF.

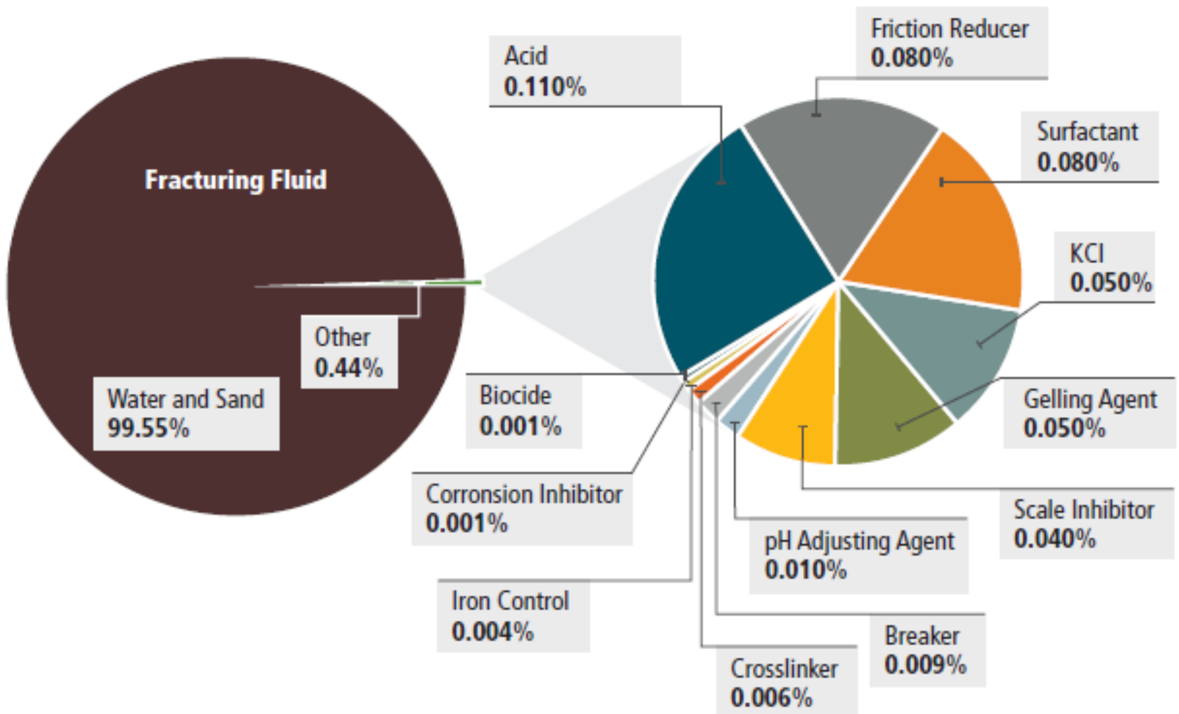

Figure 2.4. Breakdown of hydraulic fracturing fluid ingredients by function. Source: Council of Canadians, *Environmental Impacts of Shale Gas Extraction in Canada.*

The most common fracking fluid constituents and their purposes can be found in Appendixes C and D, respectively. These do not include volatile organic compounds (VOCs). Studies such as DiGiulio and Jackson's (2016) study of the impact of the vicinity of wells to drinking water sources in Wyoming identify potential contamination sources such as holding ponds and fracking fluid injection sites as having a direct effect on groundwater organic and inorganic anomalies.

Ogneva-Himmelberger and Huang (2015) employed primarily socioeconomic data to indicate how clusters of low-income populations adjacent to the Marcellus Shale region of the

United States were disproportionately vulnerable to environmental pollution as a direct result of adjacent fracking operations. The methods used spatial buffers to determine vulnerability with the conclusion that the poor are disproportionally exposed to pollution from oil and gas wells.

The lack of studies dedicated to the determination of the health effects of fracking fluid ingredients is emphasized by Stringfellow, Domen, Camarillo, Sandelin, and Borglin (2014). The study identified 81 commonly used fracking fluid ingredients according to the purpose they serve during the drilling process (e.g., friction reducer, biocides, etc.). Each constituent was further identified as organic, inorganic, and biodegradable and whether the compounds created by the mixture of these chemicals were treatable environmentally. Of the chemicals studied, twelve were considered volatile five of the chemicals were carcinogens, and a large disparity in the researched toxicity data for one-third of the 81 chemicals included in the study. The long-term effects of fracking on the groundwater supply are largely unstudied. According to the Council of Canadians (2014), the effect of fracking on groundwater resources should be studied in terms of decades and centuries due to the potential for widespread contamination and the slow flow of groundwater.

Human Health Effects

In a study that reviewed papers discussing the environmental health impact of natural gas development, Werner, Vink, Watt, and Jagals (2014) ranked 121 papers based on their relevancy and contribution to human health effects. Highly relevant papers illuminated the subject based on primary/secondary data, direct evidence of causality, and evidence collected directly or reviewed directly from the source. Lastly, the papers were ranked based on their contribution to literature in the field. Papers were weighted highly relevant, relevant, not very relevant, and irrelevant accordingly. Of the 39 papers reviewed that dealt directly with water quality, 20 were considered grey literature with little or no relevance to the field. Three out of six papers that dealt with risk and vulnerability were considered irrelevant in their contribution.

The human health effects of many chemicals in fracking fluid are largely unknown. (Bamberger & Oswald, 2016). Wild and domesticated animals are used as surrogates to monitor the potential impacts of fracking on human health because their breeding cycles are shorter and they are in more close and frequent contact with the environment. Kassotis et al. (2016) claim that oil and gas wastewater in a Virginia oil field exhibited endocrine disruptive effects on local wildlife because of the presence of fracking fluid wastewater and flow back. Their study measured the concentrations of the chemicals upstream and downstream from the operations site, revealing the presence of antagonist chemicals to hormonal activity receptors. The study concluded that substantially higher concentrations of antagonist chemicals were present downstream of the operations than upstream. Cattle and deer populations have been shown to be affected by the presence of gas flaring. Deer populations move away from oil and gas operations while cattle are confined, and the effects of the operations have been shown to increase stillbirths in cattle over a three- to four-year study (Bamberger & Oswald, 2016).

Predictions have stated that by 2035, 80% of all natural and tight gas wells in Canada will use fracturing (Natural Resources Canada, n.d.-a). A more common practice than the exception, studies are increasingly susceptible to what Gatrell and Elliott term “sensitization bias” (Gatrell & Elliott, 2015), whereby the acceptable normative levels of environmental toxin threshold levels rise insidiously and become the acceptable datum for the guidelines and standards set by governing bodies. This tendency, whether intentional or not, blurs the positivist conclusions of science because it changes the yardstick against which conclusions are drawn and public health policies are set. For instance, how is one to find a control group when the entire populace has been exposed in some measure to the presence of aluminum? Studies have suggested that aluminum is a major contributor to the development of dementia and Alzheimer's disease; levels of aluminum in modern populations are believed to be as high as five times that of previous generations in preindustrial times (Gatrell & Elliott, 2015). Yost, Stanek, and Burgoon (2016) state that a tremendous amount of gap exists in the toxicity threshold values in chemicals in HFFs.

Discerning the source of certain elements that may be naturally occurring within the soil is problematic. Arsenic is a naturally occurring chemical element in the soil in many parts of the study region (Town of Virden, 2014). However, arsenic and other heavy metals that are not part of the constituents of fracking fluid have been found to be abnormally high in regions conducting fracking operations. This could be explained by naturally occurring heavy metals being released by the fracturing of the substrata (Betcher, Grove, & Pupp, 1995).

Wattenberg et al. (2015) assessed the top 30 known hazardous constituents of HFFs to establish a list of acute and chronic toxicity health hazards using MSDS TLVs and the cumulative percentages found in wells in a given area. This provides a baseline for determining the health hazard risks associated with well density. However, no spatial data such as comparative soil samples, substrata characteristics, or geomorphology or hydrology data were used in this health-based study of HFFs and drinking water. The study concluded that many of the known toxins in HFFs, and in particular the simultaneous exposure to HFFS, have not been studied from the public health safety perspective. The study indicated that lack of access to information and industry nondisclosure agreements have led to inadequate policies and monitoring contrary to the public interest (Wattenberg et al., 2015).

Social Vulnerability

The adaptive capacity of a group or subset of a group is an extremely important consideration to the discussion of vulnerability, whether the cause be global warming or access to safe drinking water (Madajewicz et al., 2005). Often the ability of a group to adapt relies heavily upon its socioeconomic status. Access to alternative drinking water sources, education, testing facilities, and choice of residence are all crucial variables when creating a vulnerability model. Indeed, the adaptive capacity (or lack thereof) of individuals and groups largely determines their vulnerability.

Exposure and vulnerability to environmental factors are variables that may or may not be within the control of the individual, but how they choose to adapt and their available choices of adaptation are crucial to the level of vulnerability. All things being equal, it is often the available social structures and safety systems that allow individuals to avoid the effects of unsafe drinking water. In every system, the variables most affecting vulnerability will differ, so each variable must be weighted and considered for each observation site under the auspices of the environmental circumstances (Madajewicz et al., 2005). Every variable concerning the ability to adapt must be considered from every applicable scale of reference that affects it. Smit and Wendel (2005) approached human vulnerability from the perspectives of human, environment, community, groups, households, sectors, regions, and countries in their study of adaptation and vulnerability. This approach permitted a look at the issue from multiple social scales and not merely from an environmental or ecological causal perspective as has been done in the past. Smit and Wendel (2005) also support the notion that adaptive response is often a function of individual or household choices that are influenced and constrained by social, political, and economic influences at higher levels of society. All variables in the consideration of vulnerabilities are related, even though they may be considered uniquely and weighted differently among their covariates throughout different portions of a model (Cromley, McLafferty, 2012).

Any drinking water vulnerability model should be adaptable to any circumstance whether it may be acute disaster relief or chronic water shortages. This begins with the ability to spatially map out the affected area. In a conflict and humanitarian assistance report based from a relief case in the Philippines, Cannon, Twigg, and Rowell (2001) stated that the ability to map out affected areas was a crucial tool in the ability to gather data and establish control over a situation. The mapping of such variables as topography, houses, land use, hazards, elements at risk, and safe areas can provide fast and easy reference to local resources and indicate the flow of resources in and out of households and neighborhoods as well as identify who controls resources (Cannon et al., 2001).

First Nations communities in Canada are extremely vulnerable to unsafe drinking water environments (Spence & Walters, 2012). Many of these communities often do not have access to alternative sources of drinking water, and certain genetic sensitivities among the populace may exist that do not exist in the larger populace. An isolated community's perception plays a large role in the modeling of vulnerability (Madajewicz et al., 2005). One's socioeconomic standing in the community, organoleptics (taste, odor, smell), community access in and out of the area, perceived control over water resources, and past experiences are all examples of social perceptions that play a role in vulnerability (Spence & Walters, 2012). If a perception of little or no choice exists, then apathy may lead to poor decisions made at an individual, household, or community level. In their study of First Nations perceptions of safe drinking water, Spence and Walters (2012) asked as part of the 2001 Canada Census if people felt their drinking water was safe; their answer was "yes" or "no." They noted that those people living in houses in need of repair tended to have negative perceptions as to the safety of their drinking water. Age, income, and marital status were not correlated to the answer, but gender was, as women were more concerned than men with health concerns, as were families with children under 15 years of age. Mobility had no effect, but perceptions significantly varied across regions both east to west and north to south.

Similar factors of social perception played a role in a study by Mosler, Blochliger, and Inauen (2009) addressing the personal, social, and situational factors that influenced the consumption of drinking water in Bangladesh. The study concluded that social norms and attitudes played a larger role in women (whose role it is to gather water) deciding whether or not to use the deep tube wells that were arsenic free. Location of the wells is a factor in that when women required help to collect and transport the water, they felt inhibited to ask because of social norms. The time to fetch the water was a major factor, and crowded areas were avoided as well because of social norm factors such as returning home in time to prepare evening meals. The study concluded that social factors were responsible for the most variance at 47%, then situational factors such as distance at 38.4%, and finally personal factors at 34.6%. This study revealed that vulnerability is a social, as well as a spatial and environmental, construct and that social norms are a point of consideration when applying any spatial model to a study of vulnerability.

Modeling Approaches

When designing a new model the idea is not to test any specific hypothesis; rather, the driving purpose behind the exercise is to test the utility of the model itself (Gatrell & Elliot, 2015). Does the overall model lend itself to alteration with regard to unique circumstances? Do the submodels address most or all possible situations and scenarios whether acute or chronic? Does the flow of the model lend itself to providing an accurate and definitive answer to the question(s) posed? Does it allow for reiteration where required? Is the model scalable? These are a few of the questions one is required to ask when designing spatial models.

The category of variables within each submodel will determine how they are weighted, classified, and processed, as well as which procedure will be utilized. For instance, the particular weighting method proposed in this paper for qualitative data is AHP, which allows one to independently prioritize variables based on structured but intuitive means based on smaller hierarchical decisions. AHP may be employed using both discrete and continuous data from which it is used to derive ratio scales. It is a method most commonly applied in multivariable resource management models (Saaty, 1980).

AHP has been used in industrial engineering applications in integrated manufacturing, commercial buildings, and in technology investment decisions such as layout designs, and final investment decisions. In manufacturing an example is choosing a computer system for a manufacturing facility from a number of manufacturer choices in order to determine the best case scenario. Criteria such as software reliability and cost, maintenance, contracts, and performance would be taken into consideration in this scenario (Triantaphyllou & Mann, 1995). An example of the commercial use of AHP is the selection of store and commercial building sites worldwide. The choice of an optimal location directly impacts the competitiveness and performance of a company. Various criteria such as shipping and supply logistics, business environment, customer appeal, transportation cost, availability of scaled labour will all affect administrative issues and profits. The use of AHP assists in the complex decision making process of spatial decision analysis (Koc & Burhan, 2015).

GIS can also be used to model investigative studies to determine the sources of environmental degradation. In 1992, the EPA used GIS to locate possible industrial sources of toxicant releases throughout seven states in Pennsylvania. Using locational data of 14 types of industrial facilities and data from sewer databases, the sources were successfully identified (EPA, 1992).

GIS can also be employed to create dispersion models. Generally used in environmental disaster modeling, it is utilized to temporally predict future dispersions of known substances using historical or scientifically predictive data of a known substance or phenomenon (Cromley & McLafferty, 2012). Substrata groundwater dispersion of HFFs may not be easily mapped. However, best guess estimates may be made given groundwater direction and relative lithographic porosity and most importantly water source proximity to the oil field. As a closely related example, in 2006 the state of Ohio used spatial modeling and a tool called Soil and Water Assessment Tool to simulate patterns of suspended sediments and nutrients in the Sandusky Watershed (Tetra Tech Inc., 2013).

Despite this study using singularly sampled data to test the proposed vulnerability model, it is noteworthy to mention sampling patterns and frequencies. Consistent data is not always possible to secure. However, good sampling techniques need only be randomly performed temporally and by location in order to perform reliable extrapolations. Very few sampling sites are required to accurately represent an environmental attribute such as groundwater quality (Cromley & McLafferty, 2012).

The use of multiple criteria decision analysis (MCDA) is widely known; MCDA has emerged as the modeling technique used in GIS modeling of seemingly conflicting or unrelated objectives and so is suitable for use with multiple submodels (Huang, Keisler, & Linkov, 2011). When multiple variables are considered in making complex spatial decisions, this modeling technique has proven quite useful. It may be utilized to decide between a number of optimal locations for final decisions or it can be used to search for spatial locations for any number of reasons using desirable or undesirable criteria. In their 2013 study, Demesouka, Vavatsikos, and

Anagnostopoulos (2013) utilized this modeling procedure to locate optimal landfill sites in Thrace, Greece, espousing the advantages of using MCDA methodology for culling out the most suitable sites using a multilayer approach that utilizes GIS.

Maps are quite often looked upon by both professionals and laypersons as true and accurate representations of reality. It is therefore the responsibility of the spatial analyst to ensure that accurate sampling and modeling techniques are as robust as possible to be utilized as a reliable tool for optimal public health policy formation (Cromley & McLafferty, 2012).

Policy

The U.S. federal government laws and regulations concerning fracking cover procedures and standards for offshore, coastal, onshore, agricultural, and wildlife areas (U.S. Government Publishing Office, 2017) and require minimal reporting of some spills but not all (Patterson et al., 2017). The regulation and monitoring of oil and gas industry proper procedures, technology, and licensing is the responsibility of the individual states. Under the U.S. 2005 Energy Policy Act, the industry qualifies for several exemptions under federal environmental statutes with regard to HFF ground injection for the purposes of storage and fracking operations (Brady, n.d.).

The Canadian constitution divides legislative jurisdiction and ownership of resources between First Nations, the Crown, and provincial legislatures. Provincial authorities have more specific local mandates; however, the roles of both overlie one another concerning all natural resource development (Natural Resources Canada, 2017). Natural Resources Canada holds broad overseeing powers of authority in matters of resource development and future energy policies. However, the majority of the responsibility falls on the shoulders of the provinces. At least eight main federal acts in Canada are related to regulating fracking operations, including the Canadian Environmental Protection Act (Mining Association of Manitoba, 2015). The other acts include the Hazardous Products Act, Hazardous Material Information Review Act, Dangerous Goods

Act, Species at Risk Act, Fisheries Act, Environmental Enforcement Act, and Health Act. The provinces are responsible for establishing and enforcing laws and regulations specific to fracking operations within their jurisdiction. The federal government regulates frontier territories and a portion of offshore areas (Petroleum Services Association of Canada, 2016).

Table 2.1. Suggested components necessary for a comprehensive (holistic) assessment of overall vulnerability for communities in a region with active fracking operations. Available data source and type identifies spatial sources as well as monitoring information where possible (MLI is Manitoba Land Initiative http://mli2.gov.mb.ca). Data gap indicates where data or other information are unavailable (with emphasis on Manitoba), and literature source provides a primary reference.

Component of a holistic model	Available Data Source/Framework	Data Gap	Literature Sources
Chemical Contaminants	• BTEX[†] • Municipal water reports • Additional metals including arsenic	• Health effects of all fracturing fluid constituents unavailable. • Constituents protected by patents and not available • Insufficient investigation from lack of information and proper technology	Hume, 2014 Mall, 2014 [*]Vengosh et al. 2014 Gross et al., 2013 Wiseman, 2010 [*]Municipal water reports
Industrial Contaminant Sources	• BTEX • MLI and CanVec • Municipal inventories	• All sites and all relevant attributes unavailable	[*]Rahm et al. 2013 Vidic et al. 2013
Urban at-risk Infrastructure	• BTEX • MLI and CanVec • Municipal inventories	• Lack full inventory of infrastructure • All relevant site attributes not available • Potential health effect	[*]Vengosh et al. 2014 Gross et al., 2013 Rahm et al. 2013
Socio-Economic Factors	• Canada Census (GIS) • Agriculture Canada	• Individual data unavailable, rural census units large. • Impacts to local agricultural production unknown	Short et al., 2015 Ong, 2014 Sohel et al., 2010 [*]Morrow, 1999.
Environmental Factors	• DRASTIC[††] Model • MLI Hydrology • MLI Soils	• Ground water level (vadose zones) missing in MB • Pre-development baseline unavailable • Monitoring limited or unpublished	[*]Babiker et al., 2005 [*]Maloney et al., 2001 Aller et al., 1987 [*]Municipal water reports

[*] Indicates source useful in ranking or evaluating vulnerability factors.

[†] BTEX is benzene, toluene, ethylbenzene, and xylene.

[††] DRASTIC stands for **D**epth to groundwater, Annual **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of vadose zone, Hydraulic **C**onductivity.

CHAPTER THREE

METHODOLOGY

Study Area

The submodel criteria is arrived at through careful consideration of the data gap shown in Table 2.1. As seen in figure 3.1, the two urban locations selected for this comparative study are the township of Virden, Manitoba, Canada, located at 49°51′03″ N, 100°55′54″ W with an elevation of 440 m, and the city of Brandon, Manitoba, Canada, located at 49°50′54.5″ N, 99°57′33″ W with an elevation of 400 m. The Virden oil field patch is approximately 600 km^2 in area. Given that the source of drinking water for the town of Virden is drawn from two wells of undisclosed location adjacent to the Souris River watershed (which lies within the Bakken Shale oil and gas field region of southwest Manitoba), the town was selected as a comparison to the city of Brandon, which lies approximately 80 kilometres (km) east outside the oil and gas (petroleum production) region. The rural municipalities of Wallace, Elton, and Cornwallis adjacently associated with the two communities are included in the delineation to display and compare the level of vulnerability outside the urban spaces. The Souris River meanders from Saskatchewan Canada into North Dakota United States of America and back into Manitoba Canada for 700 kilometres (Natural Resources Canada, 2016). Abandoned wells are a source of known contaminants in the Souris River (Government of Manitoba, 1992).

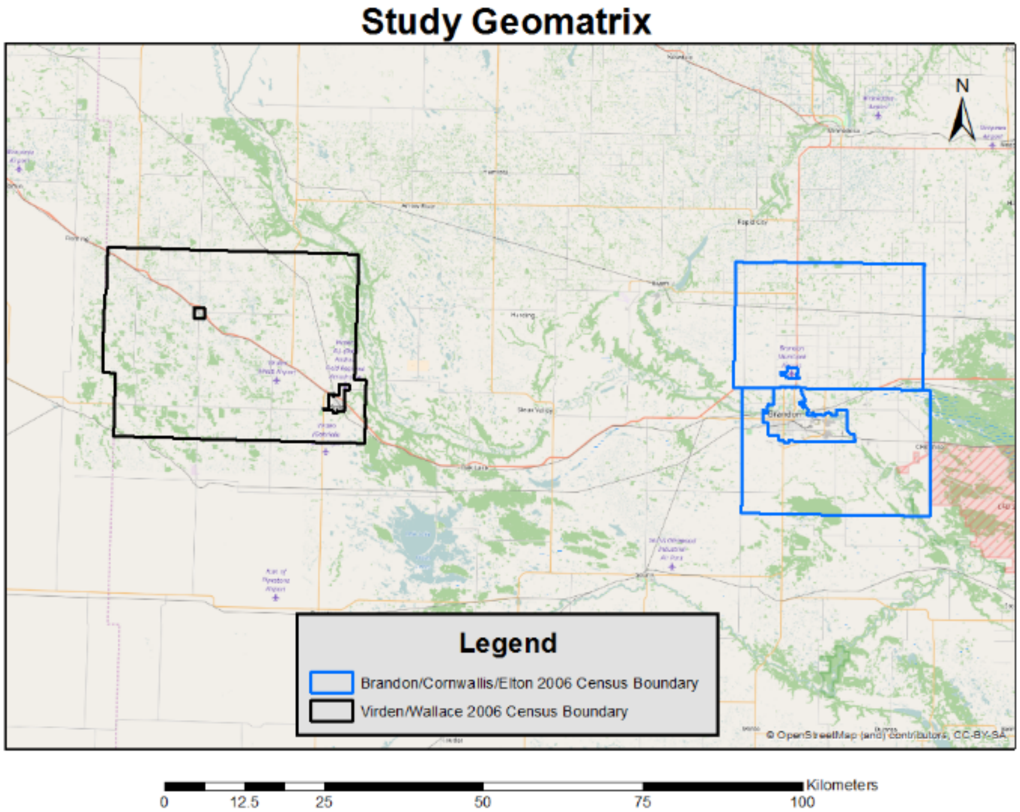

Figure 3.1. Study area boundary in Manitoba, Canada, showing the two principal census areas used in developing the model. Source: G. R. McDonald, 2017.

The scale of the model was arrived at based on a comparative construct of a petroleum based community versus an adjacent non-petroleum based community. The reason for including the adjacent census municipalities is that the smallest census boundaries available for both the communities encompass the entire urban setting. The surrounding rural community of Wallace adjacent to Virden is included in the matrix, and the rural census boundaries of Cornwallis and Elton are included with Brandon's boundary.

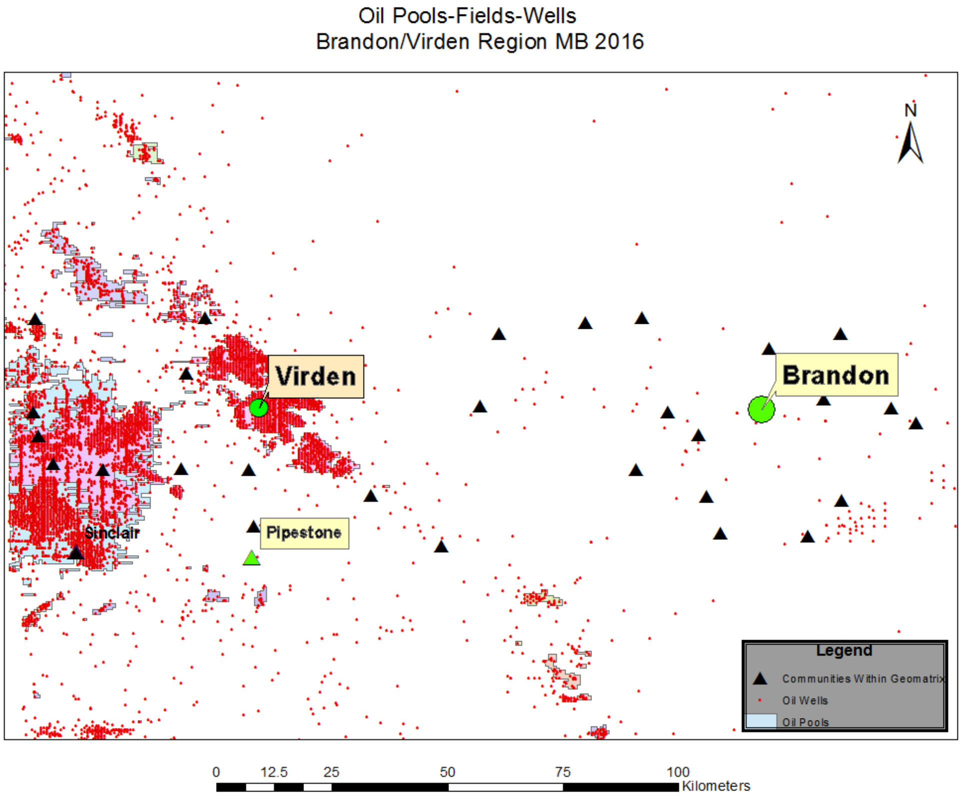

Figure 3.2. Example of the oil pools-fields-wells within the Brandon and Virden regions, Manitoba, from the 2016 MLI data set. Source: G. R. McDonald, 2017.

The centers share similar geomorphology, geologic history, substrata, and elevation as well as ground hydrology characteristics (Betcher et al., 1995). Both settlements have similar Stats Canada socioeconomic and infrastructure data (Statistics Canada, 2016). Brandon drinking water sources originate from two aquifers, namely, the Assiniboine River Valley Aquifer, which lies approximately 11 km west of the city near where the Little Saskatchewan River enters the Assiniboine River Valley, and the Brandon Channel Aquifer, which is a separate aquifer used only for industrial purposes (Little & Smith, 2015). It is for the aforementioned similarities, along with the exception of the presence of oil and gas drilling operations in Virden, that the two locations were selected for the purposes of this study to analyze and ascertain the potential application of the proposed unsafe drinking water vulnerability model presented. Both Virden and Brandon fall within the Prairie Mountain Regional Health Authority administrative area (Allan et al., 2015).

The region is considered part of the Manitoba Uplands and lies within the Assiniboine River Basin. Drainage is considered medium to low and somewhat poor in certain areas toward the Manitoba escarpment to the east. The general drainage flow pattern of the area is directed through Lake Winnipeg then on to the Nelson River and eventually discharges into Hudson's Bay (Natural Resources Canada, 2017). The area lies within the central North American continental climate typology with annual precipitation averaging 400 mm to 600 mm. Evapotranspiration tends to be highest in the southwestern portion of the province (Palombi, 2008).

The regional geology can be historically characterized as lying within the lower Cambrian to the upper Cretaceous periods, the depth of which tapers off from the southwest portion of Manitoba toward the northeast drainage basin (see Figure 2.2). The bedrock consists of Mesozoic and Cenozoic shales and sandstones with some limestone and evaporates (Betcher et al., 1995). Black to brownish-black organic shale forms much of the upper and lower levels of the Bakken Formation and the middle portion of siltstone and sandstone. (Nicolas, 2012). The lower level of the formation consists of black, siliceous, radioactive, massive, blocky to fissured organic shale and sparse disseminated pyrite (Nicolas, 2012). The soils mainly consist of black chernozemic subtype (Michalyna, Podolosky, Gardiner, 1976). For an illustrated view of Manitoba's geologic column along with lithology and oil and gas shows, see Appendix B.

The Bakken aquifer TDS ranges from 25 g/L to 280 g/L and increases toward the discharge basin in the northeast region of the province with brackish waters dominating toward the northern portion of the Bakken aquifer (Palombi, 2008). This is considered medium- to high-risk drinking water according to Health and Welfare Canada (Betcher et al., 1995).

Map collation and most spatial analyses were performed using ArcMap 10.4.1 GIS software (described below as part of level-7 analysis). Analytical Hierarchy Process (AHP) was performed using OncoLogic 8.0 software, the relevant spatial relationships between environmental conditions and health vulnerability as it pertains to unsafe drinking water. The more recently developed approach of Environmental Public Health Tracking is increasingly being utilized to temporally track hazards to the environment and human health, an approach that lends itself well to the use of GIS tracking, collection, analysis, and dissemination of spatial health data. It involves the collection, analysis, and public dissemination of environmental hazards. Unfortunately, no such database is available yet in Canada.

The AHP method provides decision making problem analysis using a framework to weight multiple criteria based on the comparative importance of each criteria by employing an underlying statistical mathematical theory. However, results can be challenged because the process uses relative comparisons without a consideration of the true range of scale of each criteria. Because of this the objectives must be clearly identified along with the criteria. Criteria groups should be complete sets non-redundant and minimal if using spatial analysis to represent criteria within a map layer in GIS. As no single method exists to identify criteria; evaluation literature, studies and consultation is used once the criteria are set. Hierarchical relationships are identified and evaluated through the use of a pairwise comparison matrix. The weighting is accomplished through establishing the relative importance of each criteria when compared to all other criteria. This thesis employs sensitivity modeling to weight the criteria. By utilizing a reciprocal square matrix where the number one represents, those criteria of highest importance are identified with all subsequent numbers indicating sequential levels of importance (Saaty, 1980).

Proposed Unsafe Drinking Water Vulnerability Model

Employing the proposed theoretical model, this study will extrapolate several epidemiological variables that will include trends of increased presence of hazardous chemical constituents in water supplies within the multiple geomatrices of the study. These trends (if identified) will be used to weigh and classify the top four variables of concern in each of the five submodels, namely, Chemical Analysis, Industrial Infrastructure, Urban Infrastructure, Environmental Factors (Geomorphology and Geology), and Socioeconomic Factors, using an MCDA modeling approach as employed by Logan et al. (2015). All variables are weighted, classified, and identified in the same manner under the auspices of geomorphological and geological characteristics of the region to illuminate a comprehensive environmental health picture of the spatial considerations that may affect vulnerability to unsafe drinking water geographies. The proposed model attempts to illustrate how the five submodels may be combined into one MCDA model in a positivist approach. It is approached from a physical infrastructure viewpoint on the spatial plane to gain a much clearer perspective on spatial vulnerability for the purpose of future policy recommendations and possibly for the use of epidemiological studies.

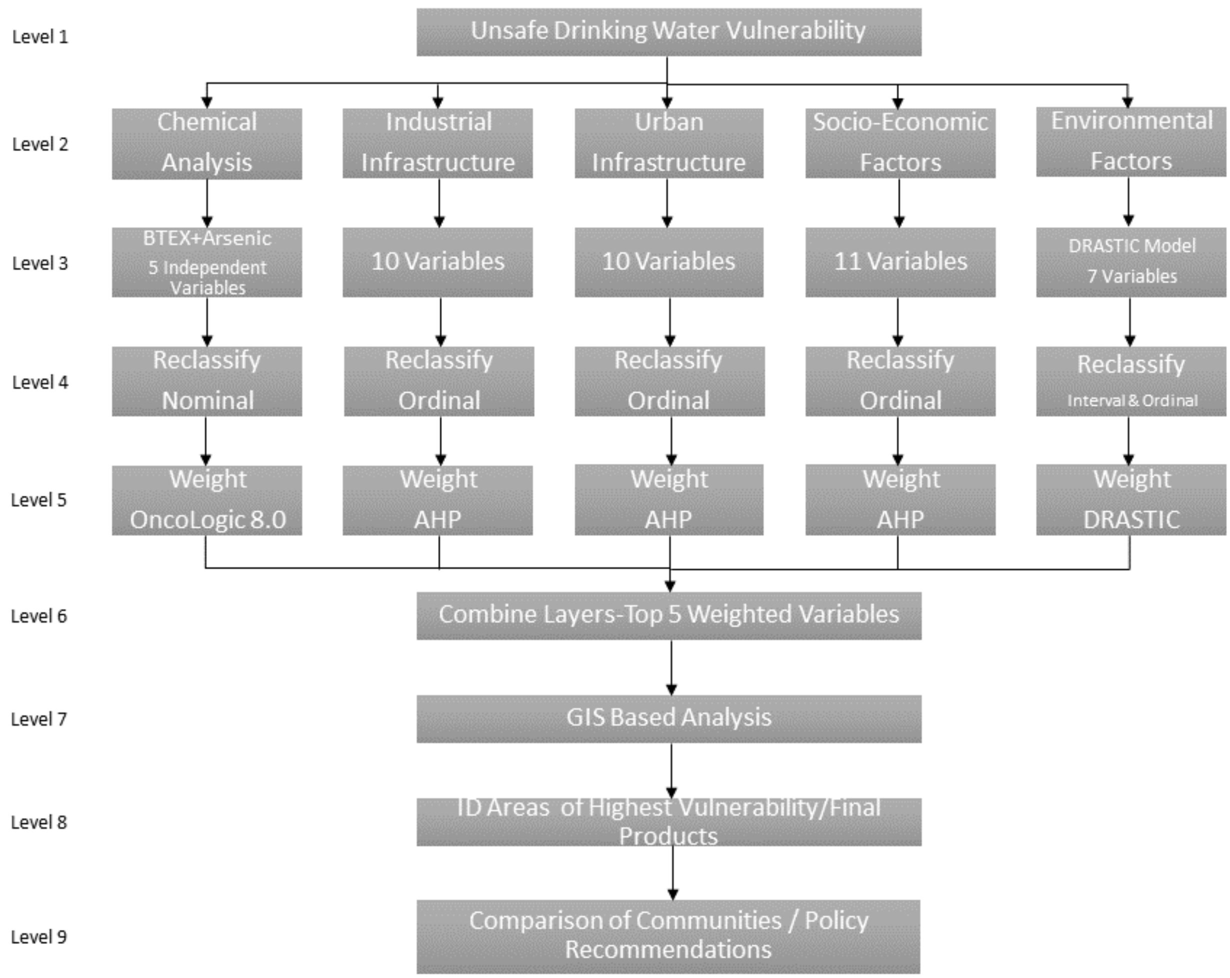

Figure 3.3. Proposed drinking water vulnerability model. Source: G. R. McDonald, 2017.

Level 1: This involves defining the problem or formulating the question to be answered. This model is designed to answer a specific spatial question but could be modified to any scale and spatial construct such as a specifically defined geographic region or a predefined space such as capital cities with a population base of more than a million people.

Levels 2 and 3: *Chemical Analysis* involves acquiring the levels of BTEX in the drinking water source. In this case, they form the baseline for the toxicology of the drinking water source. They are the hydrocarbon chemicals most commonly tested for within the geographic region in question. As has been mentioned, over a thousand possible HFF constituents exist, most of which are not tested for, and if they were, their effects on human health are so far unknown or inconclusive. Given the high levels of arsenic found in many drinking water sources adjacent to oil and gas operations, it has been included in the chemical analysis submodel. For this submodel, data are acquired from the Virden and Brandon treatment plant annual water test reports performed at ALS Labs in Winnipeg, Manitoba.

Industrial Infrastructure includes 10 variables that consist of waste disposal and sewage sites, water source sites, water treatment plants, petroleum storage sites, livestock waste storage sites, water wells, agricultural and municipality lagoons, septic systems, and oil and gas wells and drill sites.

Urban Infrastructure variables include hospitals, schools, nurseries/child care facilities, settlements, urban areas, public parks/camp sites, public swimming sites, hotels/motels, public use facilities (malls, stores, halls), and transportation routes.

Socioeconomic Factors include age, gender, marital status, income, place of work, shelter costs, number of children, education, employment status, mobility, and vocation.

The *Environmental Factors* submodel employs the DRASTIC method of classifying and weighting aquifer vulnerability. The acronym stands for depth of groundwater, recharge (based on precipitation averages), aquifer type, soil type, vadose zones (groundwater level), and hydraulic conductivity zones.

Level 4: This involves the reclassification of all variables into the appropriate numbering systems of ratio, interval, ordinal, and nominal. Given that no relationship exists between the four BTEX + arsenic chemicals, the numbering system used is nominal. The industrial and urban variables require an ordinal scale to rank variables from the most influential in the decision-making process to the least. This changes according to valuation by scale as well as other factors such as stakeholder interests, cultural values/norms, and political agendas. Socioeconomic factors are also classified using the ordinal system for similar reasons. Since the DRASTIC method is used for assessing the environmental factors, a preset classification system is employed with the method using a combination of interval and ordinal systems. The groundwater depth is classified using an interval system of seven classes, the recharge an interval system of three classes, the aquifer type an ordinal system that denotes substrata porosity in three classes, topography (elevation) an interval system based on four classes, vadose zones an ordinal scale of three classes based on soil porosity, and hydraulic conductivity an interval system of three classes. The DRASTIC method employs an incorporated weighting system.

Level 5: This involves weighting the variables accordingly, using the appropriate method. The BPMSG AHP system is used to weight the qualitative variables. For example, variables classified ordinally are weighted using the AHP method, and chemical submodel variables are classified nominally using the interval system and are weighted using the EPA-released OncoLogic 8.0 software. OncoLogic 8.0 is a chemical weighting software based on oncological data collected between 1968 and 1995 designed to produce reports on the carcinogenicity potential of chemicals, metals, polymers, and fibers. For the purposes of this study, the top four variables from each submodel are used in the final GIS analysis, with the exception of the chemical factors submodel, which includes all five variables.

Level 6: Once the top four variables are identified from each submodel and layers created, each of the layers is combined. All five submodels are then weighted within the full model using the AHP method.

Levels 7 and 8: During the analysis level, features and layers are overlain to determine the areas of highest vulnerability through using various geoprocessing methods and tools. One drinking water vulnerability map product each of Virden and Brandon is produced.

Level 9: Involves a comparison of the two communities and three adjacent municipalities utilized in the study is made in the discussion section, allowing for recommendations for future studies and policy suggestions.

For the purposes of this study, the entire model will be addressed, although the degree of evaluation of some components is constrained by lack of data in some locations and scales. The data sources used for the environmental factors submodel are Natural Resources Canada (NRCAN), Manitoba Land Initiative (MLI), Ecostrat (National Ecological Framework for Canada shapefiles), the Groundwater Information Network (GIN), the Government of Canada Water Office, and Manitoba Water Stewardship.

A minimalist terrain base map from ArcGIS online was used for the environmental factors submodel portion of this study because of the large scale of the geomatrix and to lessen the amount of background noise and possible misalignment problems that might occur. This would only confuse the visual and representational value of the processed data because of coordinate system transformations required from differing data sources. A topographic street base map is utilized for the other submodels of the study. The projected coordinate system utilized is North American Datum 1983 Universal Transverse Mercator Zone 14 North. A digital elevation model was not employed because the difference in elevation between Virden and Brandon is 40 meters (m) over a distance of approximately 80 km. This would be a valuable parameter over a shorter distance with more relief to the terrain.

Environmental Factors Submodel

The first submodel to be actualized is the Environmental Factors model because it deals with data at a much smaller scale than the other models and it defines the geographic and geologic conditions of the geomatrix. Using the DRASTIC method (Appendixes P and Q), the available variables are identified by classes and are weighted accordingly.

Depth of Groundwater: Manitoba Water Stewardship and Manitoba Groundwater Branch track but do not share their data results publicly, and therefore, this study does not integrate data regarding groundwater levels. Using the DRASTIC method, the classes would be apportioned 7 values ranging from 0 to > 31 m. From 1 to 5 (1 being the highest weight), the depth of the groundwater table is classified as 5 (low classification) within the environmental factors submodel. Shallow water tables are considered to be more vulnerable to contamination by pollutants than deeper tables.

Recharge: Recharge is calculated in many ways. The sources of this study use the soil water balance method employing the following calculation (Kommadath, n.d.):

$$Ri = P - E + \Delta W - Rn, \qquad \text{[Eq. 1]}$$

where Ri denotes recharge, P precipitation, E actual evapotranspiration, ΔW change in soil water storage, and Rn runoff. The Government of Canada Water Office real-time and historical discharge and water levels are used to determine the recharge (or lack thereof) rate. There are three classes ranging from 0 cm to 180 cm and three weights of 1, 3, and 6. The higher the recharge weight in this instance, the higher the net recharge and less optimal for drinking water resources in the presence of groundwater toxins. Vulnerability increases with recharge rate because of the migration of toxins within the groundwater. The recharge parameter is weighted at 4 within the environmental model.

Aquifer Type: No data were available through Natural Resources Canada, Manitoba Land Initiative, GeoGratis, or Canada's premier GIN at the 1:50,000 scale or greater that would be of use for the scale of this study. However, the class of aquifer type can be deduced through the geologic substrate by this simple method of weighting for the purposes of this study. Three classes of aquifer type range from clay to medium sand and sandstone with weights of 3, 4, and 6 from least permeable to most permeable, respectively. The higher class the aquifer media is, the higher the probability of transportation of pollutants, and therefore the higher the vulnerability. The aquifer parameter is weighted 3 within the environment factors submodel.

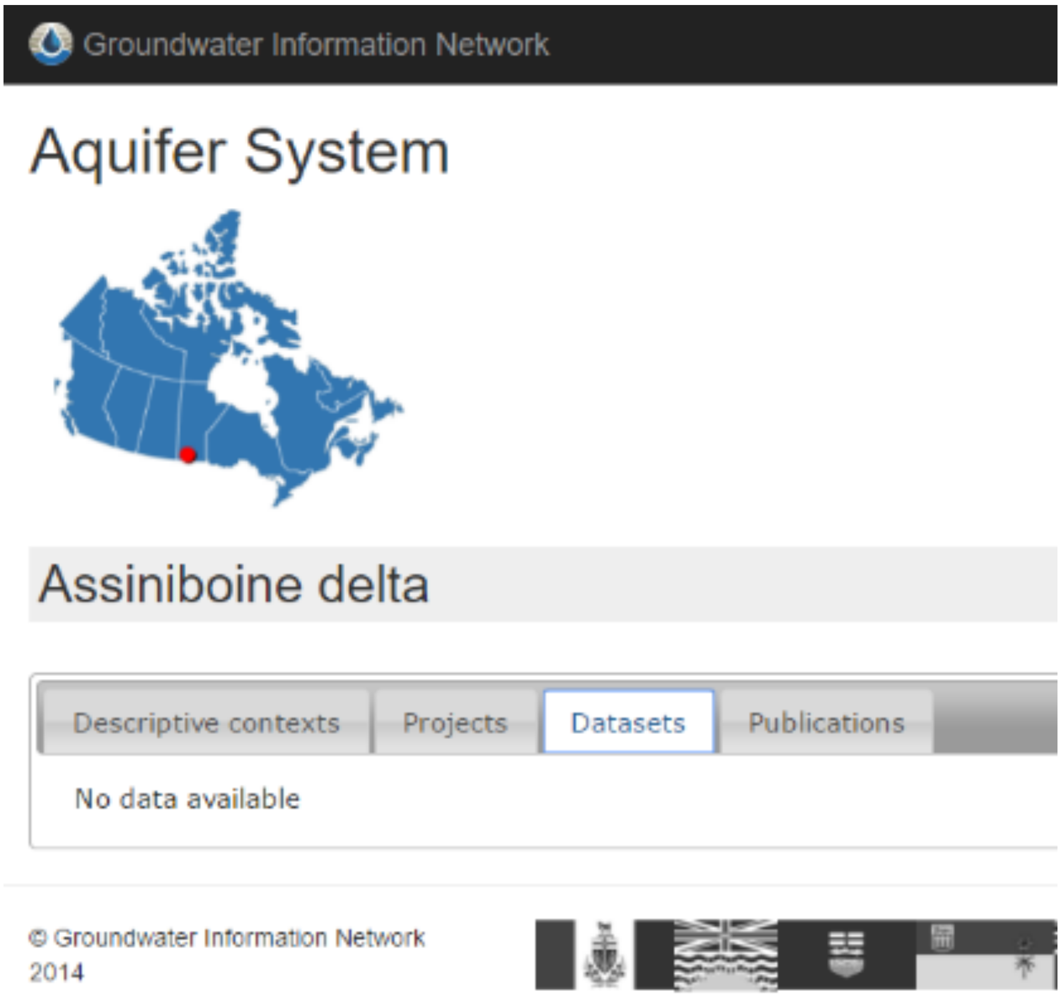

Figure 3.4. Screenshot of the Groundwater Information Network displaying the lack of aquifer information in the Assiniboine Valley. Source: Groundwater Information Network.

Soil Types: Soil types and substrate material derived from NRCAN and MLI are added in shapefile format to delineate the contrasting types between the two communities. The weights of 3, 4, and 6 are portioned to silty clay, sandy clay, and sandy and sandy loam materials, respectively. This parameter is particularly sensitive to flow back from HFFs during the drilling process. The vulnerability rating increases from classes 3 to 6. The soil type parameter is weighted 2 with the submodel.

Topography (elevation): No DEM will be utilized due to the lack of terrain relief in this geomatrix at this scale of study. This variable would otherwise be classified using four classes weighted 3, 5, 9, and 10 from lowest to highest relief, respectively. Given the low relief of the land of the entire region, it is classified as 3, which indicates meager runoff, and an indicator of high vulnerability to groundwater contamination. The topography variable is weighted as 1 (highest) within the submodel.

Vadose Zone: The Vadose Zone is sometimes referred to as the unsaturated zone and consists of the region of subsurface that lies above the water table (United States Geological Survey, 2013). No Vadose Zone data are available through the Provincial Groundwater Branch. However, the classes are based on soil types and can be deduced with rates 3, 4, and 6 ranging from clay to medium sandstone, respectively. Vadose Zones are classified 5 within the environmental factors submodel.

Hydraulic Conductivity Zones: No studies or data are known of the hydraulic conductivity of this area. Hydraulic conductivity is classified 3 within the submodel. Given that only topography, soil, aquifer, and recharge information are available, they are employed and weighted respectively in that order, 1 to 4.

Chemical Factors Submodel

For the purposes of this thesis, the VOCs found in Appendix G tested for both Brandon and Virden will be the primary variables considered for the vulnerability model along with arsenic. The most significant of these are benzene, toluene, ethylbenzene, and xylene (BTEX). Both the city of Brandon and the town of Virden did not begin testing and recording the full BTEX spectrum until 2016, which coincides as the first year Brandon has made its test results publicly accessible on its city website (Appendixes E, F, and G). The Brandon 2016 water treatment report is made available for this study. However, the historical reports are not. Historical reports dating back to 2007 for the town of Virden were acquired but only for arsenic levels. A brief temporal analysis is made for Virden. The Virden treatment plant was upgraded in 2010. Given the possible carcinogenic health effects of all five of the chemicals, all are to be considered and weighted (Appendix T) in the use of this model. Pretreatment data (when available) are used for the analysis to equally weight the vulnerability of surrounding rural areas without access to treated water sources. Given the reporting method of BTEX in the Brandon analysis, only a post-treatment "met standard" result is provided, allowing no comparative analysis to be made against the more explicit Virden report. Efforts were exerted to request explicit and historical data; however, none are available. ALS Labs performed the analysis for both the Brandon and Virden water treatment plants. OncoLogic 8.0 software is utilized to weight the chemical carcinogenicity of each chemical compound with classification system parameters ranging from marginal to very high.

Industrial Infrastructure Submodel

MLI and CanVec data are utilized for this model and include waste disposal sites, industrial waste/sewage sites, water source, water treatments facilities, petroleum storage sites, livestock waste storage sites, oil and gas wells, agriculture and municipal lagoons, septic systems, and industrial transportation routes. How variables are spatially categorized is as important as how they are weighted and processed. With regard to oil and gas fracturing sites, industrial infrastructure variables can be categorized as either point sources or nonpoint sources due to the nature of lateral drilling. Given that substrata fissures cannot be accurately modeled, for the purposes of this study, the oil and gas well locations are categorized as point sources as is the case for all industrial infrastructures.

The variables are weighted using the AHP methodology with the result of urban waste disposal sites (landfill), industrial waste sites, petroleum well sites, and water treatment facility locations being the top four from 1 to 4 respectively (Appendix X). All petroleum wells and industrial waste storage tanks are delineated on the map layout and should be 45 m from roads and 100 m from water-covered areas and urban subdivisions in accordance with the Manitoba Petroleum Branch Table of Minimum Distance Requirements (Appendix S). For the purposes of this thesis, a 100 m buffer zone is created for all of the stated variable layers to establish a high-vulnerability zone. The decision is also made to create a multiple ring buffer zone in sequential distances of 500 m for each of the landfill and industrial waste sites as well as petroleum wells to establish zones of vulnerability levels based on proximity. According to the CCME, no national standards exist for the spacing of waste disposal sites and proximity to urban areas. "Jurisdictions of authority may have specific numerical criteria regarding buffer areas and should be consulted regarding their specific requirements" (CCME, B-4). A proximity measurement is made from the city/town limits to the waste sites and a comparison made. Considering that Brandon has three such sites, the median measurement is used for purposes of comparison. The water treatment and wastewater treatment plants are delineated on the map layout and are there to simply illustratively confirm that there is one in service in the community.

Urban Infrastructure Submodel

Stats Canada Census Microsoft Excel tabular data from 2006 and CanVec data are utilized as the source data for this submodel. The variables considered in this submodel are hospitals, schools, nurseries/child care facilities, settlements, urban areas, public parks/camping sites, public camping and swimming areas (culled from leisure sites in the CanVec data base), hotels/motels/hostels, public use facilities (malls, stores, halls), and public transportation routes. AHP weighting resulted in the top four variables as hospitals/care homes, nurseries/child care facilities, schools, and camping/swimming sites weighted from 1 to 4 respectively (Appendix X). The approach used is based on the perceived vulnerability of the young and elderly and then those potentially risking direct exposure to groundwater. The proximity within the multiple ring buffer zones will determine the level of vulnerability for each site within the urban infrastructure submodel.

Socioeconomic Factors Submodel

Stats Canada Census data from 2006 are utilized for this submodel, as it is the last mandatory census available at the time of the research stage of this study. The 2016 census data have some missing gaps for the purposes of this study, so the 2006 shelter costs may be outdated, but the comparative narrative is not lost. The variables sought after are age, gender, marital status, income/earnings, place of work, shelter costs, number and ages of children, education, employment status, mobility, and vocation. Based on the literature reviewed that indicated income, education, and mobility as having the most influence on social vulnerability, these Census Canada parameters were selected. AHP weighting results in income/earnings, age, children in the home, and shelter costs weighted 1 to 4 respectively (Appendix X). Given that the smallest available census boundary files available for the two communities cover the entire urban area, the decision is made to include the adjacent rural communities into the analyses. Socioeconomic trends are difficult to spatially represent within a single census boundary.

In level 6 of the modeling stage, the submodels are combined and weighted according to Table 4.7.

CHAPTER FOUR

RESULTS AND ANALYSIS

Environmental Factors Submodel

This submodel will reference the DRASTIC weighting model found in Appendix P. As mentioned, groundwater depth data could not be acquired for this study. Most regions in southern Manitoba have a medium to low recharge rate of between 5 and 50 mm per year depending on the soil type, giving them a recharge weight of 1. Figure 4.1 shows Virden has a soft grey clay siltstone-based soil and Brandon has a black carbonaceous shale-based soil that is more permeable to groundwater migration. Virden falls under the recharge class of 0–50 and Brandon under the 50–100 class. Therefore, Virden has a recharge classification of 1 and Brandon a weight of 3 (Betcher et al., 1995). The Virden area soil is not as conducive to recharge, whereas the Brandon area soil is much more conducive to recharge and drainage due to the differing soil types (Michalyna, Podolsky, & Gardiner, 1976). Given the number of oil wells and production in the Virden region, the low recharge rates are conducive to the high amount of arsenic found in the groundwater. However, the higher recharge rate in Brandon results in a higher vulnerability factor due to the direction of discharge from the Virden oil fields in a northeasterly direction toward Brandon and the higher substrata component classification of 3.

The Assiniboine Delta Aquifer is primarily unconfined sand and gravel deposit covering 3,900 km^2, the thickness of which is varied from approximately 5 feet along the extremities to greater than 100 feet in the center (Manitoba Water Stewardship, 2015). This is the extent of the knowledge obtained about the regional aquifer. Deducing again from the substrate information from MLI, Virden has an aquifer weight of 3 and Brandon of 6. For groundwater quality standards, the former is less vulnerable to substrata toxins. However, if the groundwater is toxic, then a higher rate of recharge and discharge would be optimal if the recharge source were from a pure source such as would be the case in areas of high relief similar to the western cordillera in

British Columbia. In this particular case, the recharge source is from the direction of large oil and gas field operation zones to the southwest.

The practice of horizontal fracking adds a new dimension into the model, the effects of which cannot be foreseen on the substrate and are not incorporated into the DRASTIC method. Seismic detection of substrata fractures is both resource intensive and expensive. Often employing the use of controlled explosives, and given the average depth of 1,000 m to 1,600 m for drill wells adds to the sheer number of over 4,700 drill sites now active in the province, the task of detecting and mapping fractures would prove far beyond the means of provincial government groundwater monitoring expenditure budgets.

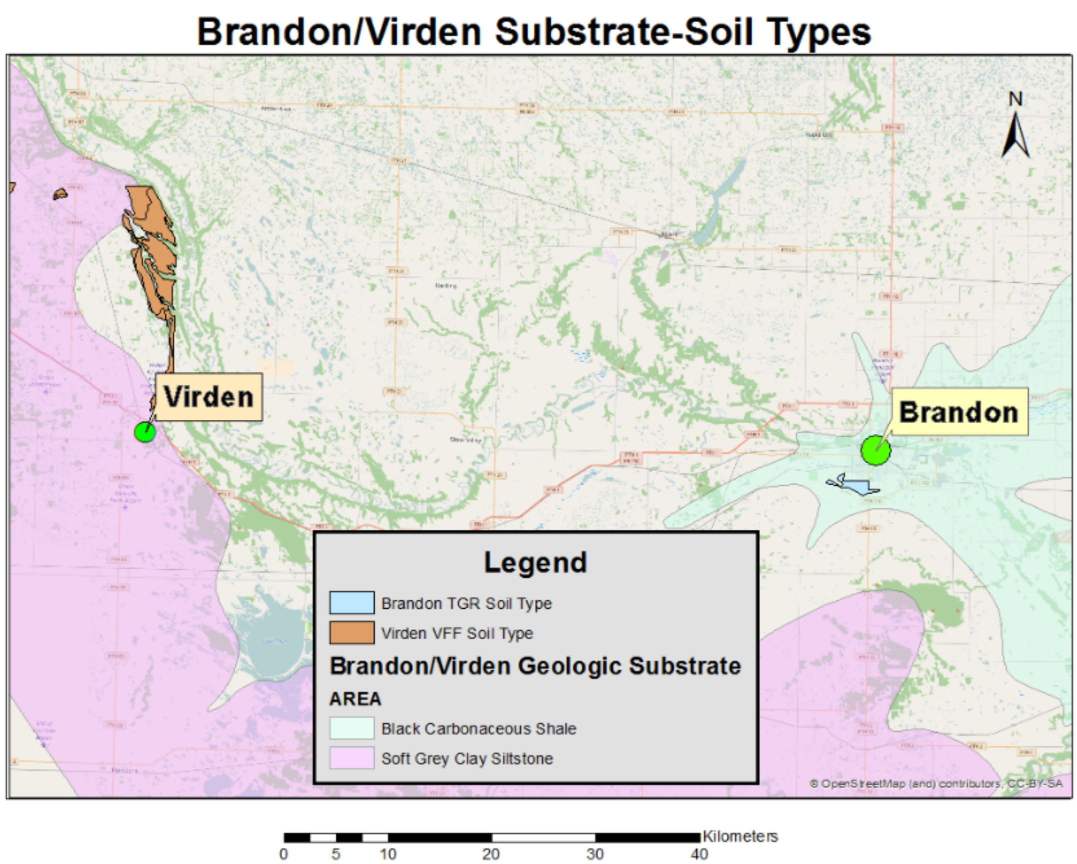

Figure 4.1. Brandon and Virden environmental submodel substrate-soil types. Source: G. R. McDonald, 2017.

The Virden area substrate consists of soft grey clayey siltstone with a surface soil type of code VFF, which is a classification of rego humic gleysol. The characteristics can be found in Appendix D. Discharge is very slow, giving the soil media a classification of 3. The Brandon area substrate consists of black carbonaceous shale and a soil type code of TGR, which denotes gleyed rego black chernozem (see Appendix C). This soil type discharges slowly but more rapidly in comparison with the Virden area. Discharge rates increase with increased recharge once the water table is maximized. This gives the Brandon soil type a classification of 4, and therefore a higher vulnerability to groundwater toxins than Virden over geologic time.

As mentioned, the topography of the area decreases slightly from Virden to Brandon from 440 m ASL (above sea level) to 400 m ASL in Brandon. The lack of topographic relief in this region results in very little contrast in this factor, essentially eliminating its influence in the current modelling exercise. Both communities are classified as 3 within the DRASTIC method. The slightly higher elevation of Virden is offset by the lack of drainage and discharge within the region.

The respective Vadose Zone weights, also based on soil and substrate, place Virden with a classification of 3 and Brandon a higher vulnerability classification of 4. Measuring hydraulic conductivity requires several on-site tests that require equipment and resources beyond the scope of this study. The spatial hydraulic conductivity measurements of the geomatrix are unknown.

The equal weighting of topography and the higher rating of vulnerability of Brandon over Virden in the classifications of recharge, aquifer, and soil media, this places Brandon at a higher vulnerability within the environmental factors submodel. This is delineated spatially on the final map product.

Industrial Infrastructure Submodel

Ten variables were weighted using AHP (Appendix M) based on literature with the top four variables represented in this submodel by level of highest to lowest weight being waste disposal sites, industrial sewage sites (delineated as industrial waste sites), oil and gas well sites, and water treatment facilities factored binarily (present or not present). The wastes and petroleum well sites shown in Figure 4.2 are culled from the CanVec data repository available online through Natural Resources Canada (NRCAN). Industrial waste sites in the region are all liquid waste holdings of unspecified constituents. Oil and gas (delineated as petroleum sites) are displayed in the map layout. Both the water treatment and wastewater treatment facilities are digitized as given by the city and township websites and geocoded accordingly. Virden has one land waste site lying one kilometer southeast of the town. Brandon has three landfill waste sites lying directly east of the city, the largest being adjacent to the city generating station 2 km to the east of the city.

According to the CCME (2014), the National Guidelines for Hazardous Waste Landfills specifies no numerical buffer between residential and landfill zones. The decision of site location is based on hydrogeologic studies and surveys with final recommendations made by local authorities.

The Virden water treatment facility lies within the town limits on the corner of Frame Street East and First Avenue, across the street from the Virden Hospital and Clinic. The water treatment facility in Brandon is located on the north side of the city on the south bank of the Assiniboine River. The Brandon wastewater treatment facility is located east of the city proper on Victoria Avenue east, west of Highway 110, and adjacent to the south from the city generating center.

Four industrial waste sites within the Brandon city limits are located at the juncture of the Trans-Canada Highway and 18th Street north, with approximately 20 more lying east by northeast of the city at a distance of approximately 160 km. None are found in Virden, within the township vicinity or the adjacent Rural Municipality of Wallace.

Figure 1.2 shows that the town of Virden is surrounded by a field of petroleum wells in contrast to Brandon by an approximate ratio of 20:1 based on calculations of active well numbers within a ten kilometre radius derived from the MLI data set. Four production wells exist within the town limits of Virden and three saltwater disposal wells within the city limits of Brandon. These sites are included in the 100 m buffer zone layer denoting high vulnerability (see Diagram B of Appendix S). This high-vulnerability buffer zone distance was selected based on the Province of Manitoba drilling restrictions and minimum distance requirements (Appendix S). Two subsequent 500 and 1000 m buffer zones are created to denote the medium- to low-vulnerability zones respectively using the ArcToolbox Buffer tool. The parameters of these zones may seem arbitrary. However, given the size of the communities in the study, smaller more frequent classes and parameters cannot not be justified as both the communities have central water treatment plants, and larger parameters would simply blanket the region. This does not serve any weighted analysis of either the urban or rural areas. All other areas are considered marginal within the industrial infrastructure submodel, given their remote vicinity to the area of interest. These classes and parameters are of course subject to change based on the scale of the study geomatrix. The spatial product below comparatively illustrates the substantially higher industrial infrastructure vulnerability of the Virden region within the geomatrix because of the ratio of petroleum operations' active well sites.

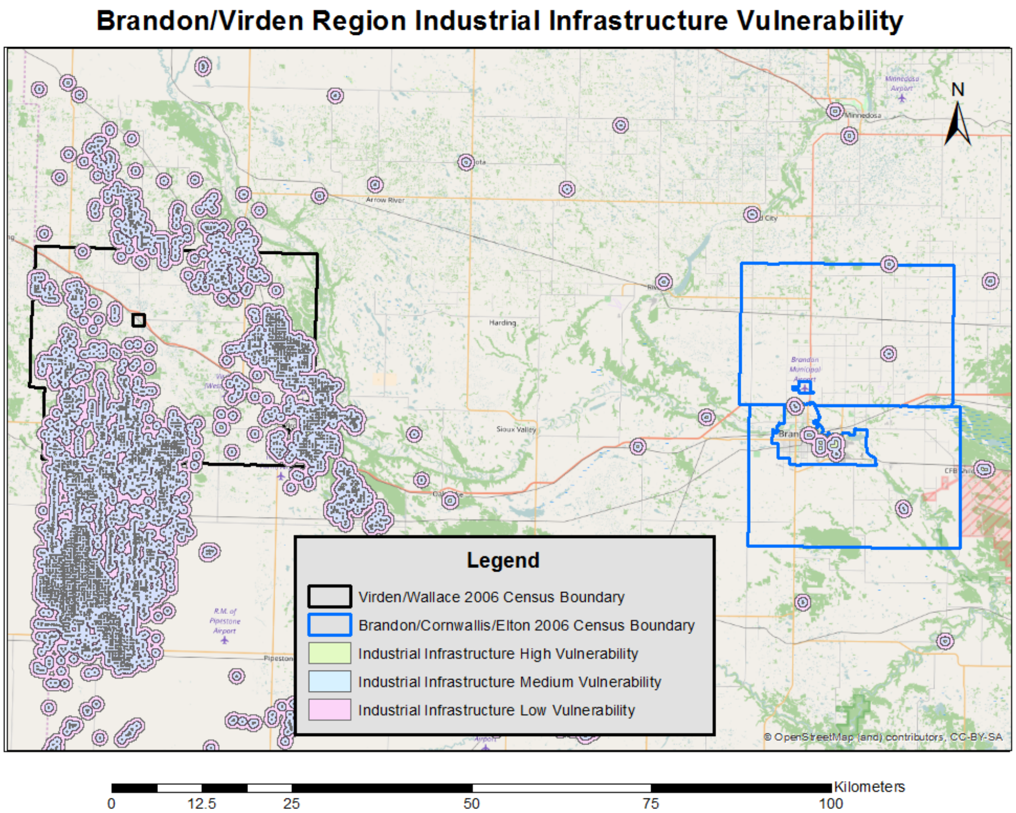

Figure 4.2. Brandon and Virden industrial vulnerability submodel illustrating the census boundaries employed along with the low-, medium-, and high-vulnerability zones. Source: G. R. McDonald, 2017.

Urban Infrastructure Submodel

Figure 4.3 indicates that the Virden Health Centre located at 480 King Street and the adjacent health unit facility are 33.5 metres west of the medium-vulnerability zone and are well within the low-vulnerability zone. This places the hospital/care center at the low to medium level of the urban infrastructure vulnerability submodel. The Virden nursery center lies well within the marginal zone at 244 m from any buffer zone, placing it within the marginal vulnerability classification according to the urban infrastructure submodel.

The school in Virden lies 23 m from a low-vulnerability zone, placing it at the marginal to low level of vulnerability. Two schools are located 15 and 30 km distance due west of Virden within the municipality of Wallace, lying within high-vulnerability zones, and one 10.5 km northwest of the town that lies in the marginal zone 500 m distance from any vulnerability zone. No delineated camping/swimming sites are detected within the Virden area of interest.

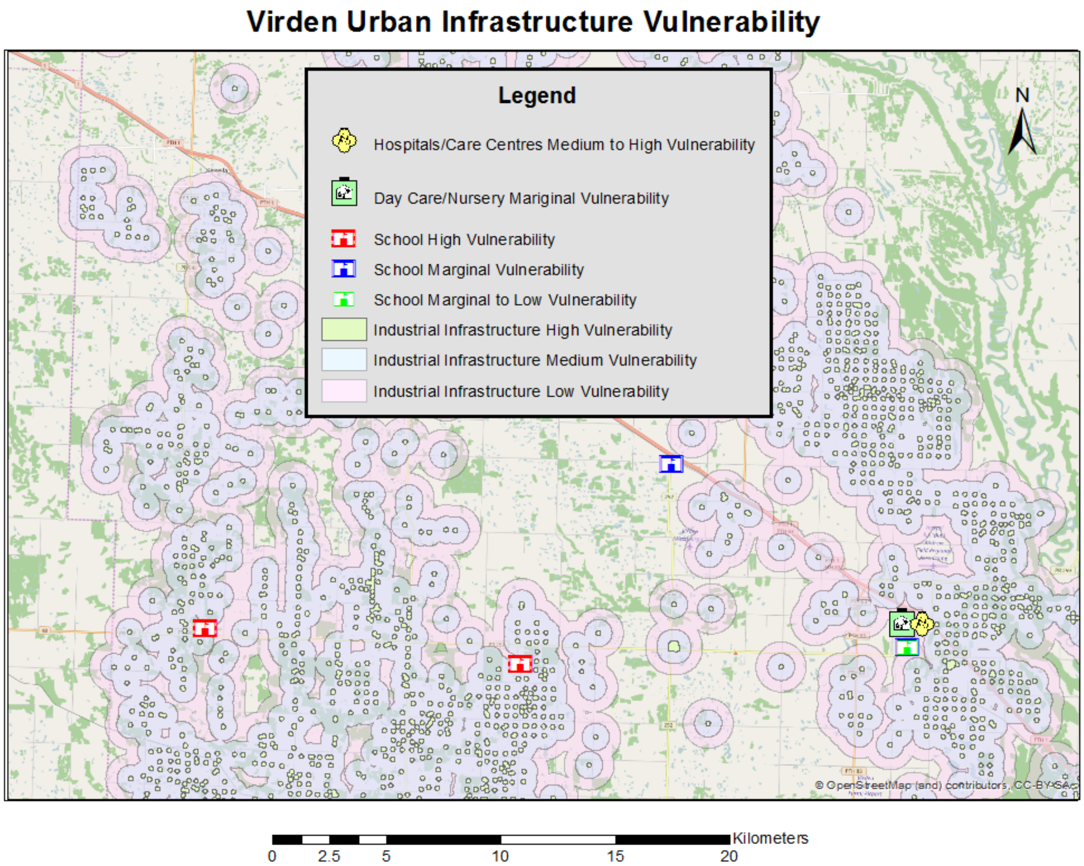

Figure 4.3. Virden urban infrastructure vulnerability submodel illustration depicting the top four weighted variables and their location in relation to the vulnerability level buffer zones. Source: G. R. McDonald, 2017.

Figure 4.4 indicates that no urban infrastructure facilities are within the high-vulnerability zones in the Brandon area. Two hospital/care facilities occur within a medium-vulnerability zone and 11 within a low-vulnerability zone. Two children's nurseries are found within a medium-vulnerability zone and three occur in a low-vulnerability zone. One school lies within a medium-vulnerability zone and another within a low-vulnerability zone.

Brandon has two hospitals/care facilities within a medium-vulnerability zone and 11 within a low-vulnerability zone. Two day cares/nurseries lie within a medium-vulnerability zone and three within a low-vulnerability zone (see Figure 4.3).

One school in each of the Cornwallis and Elton municipalities lies within a medium-vulnerability zone because of their proximity to industrial waste sites. One school in Brandon proper lies within a medium-vulnerability zone and three within a low-vulnerability zone. No campsites lie within a vulnerability zone. However, the slow drainage of the region and the medium aquifer and soil type media vulnerability classification could be considered a low to medium risk of vulnerability for any camping/swimming spots within the region.

This urban infrastructure submodel suggests that population size does not denote vulnerability level. Infrastructure density and proximity to highly weighted potential threats to safe drinking water appear to have a higher correlation to vulnerability.

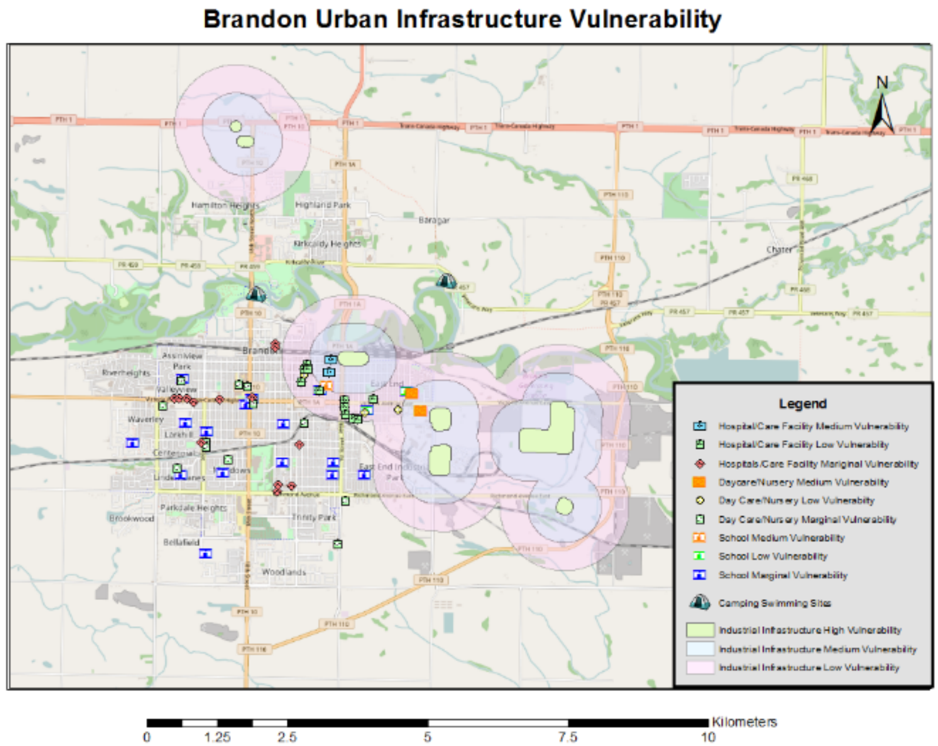

Figure 4.4. Brandon urban infrastructure vulnerability submodel product illustrating the top four weighted variables with the inclusion of campsites and their location in relation to the vulnerability buffer zones. Source: G. R. McDonald, 2017.

Socioeconomic Submodel

The percentages of the population within each Census Division boundary living on a low income are displayed in Table 4.1.

Table 4.1: Percentage of Low Income within Geomatrix by Population, for the areas sampled. Percentage how calculated

Description	Virden	Wallace	Brandon	Cornwallis	Elton
Total Population	3,010	1,500	41,510	4,055	1,285
% in Low Income After Tax - All Persons	3.8	5.1	12.6	4.9	2.4

Note: Source is Canada Census 2006.

The vulnerability classes with regard to income from 1 to 5 (1 = most vulnerable) are Brandon, Wallace, Cornwallis, Virden, and Elton, respectively. The vulnerable age parameters consider children of school age and seniors aged 65 and older. The percentages of the population of each census boundary at vulnerable age parameters are as follows:

Table 4.2 Percentage of Population within Vulnerable Age Parameters

Age Characteristics	Virden	Wallace	Brandon	Cornwallis	Elton
Total Population	3,010	1,500	41,510	4,055	1,285
0 to 4 years (%)	4.7	5.3	5.8	8.1	3.1
5 to 9 years (%)	5.1	8	5.3	7	5.4
10 to 14 years (%)	6.5	8.3	5.8	7	10.1
15 to 19 years (%)	6.6	10	7.2	7	8.6
65 to 69 years (%)	4	4.3	3.6	3.6	2.7
70 to 74 years (%)	4.7	3	3.3	2.3	2.7
75 to 79 years (%)	6.3	2.3	3.3	1.2	2.3
80 to 84 years (%)	5.6	1.3	2.7	0.5	1.6
85 years and over (%)	5.8	0.7	2.7	0.2	0.8
Total Percentage Vulnerable Population 0 to 20 and 65 and over	49.3	43.2	39.7	36.9	37.3

Note: Source is Canada Census 2006.

Families with children are represented in the 2006 Canada Census by married parents, common-law parents, and single parents, with female-led single-parent families earning a median income 68% of those led by male single parents. The decision is made to employ the female-led single-parent family statistics to represent the most vulnerable demographic of households with children. As such, the percentages of female-lone parent families are as follows:

Table 4.3 Percentage of Female Lone-Parent Families

Description	Virden	Wallace	Brandon	Cornwallis	Elton
Total Population	3,010	1,500	41,510	4,055	1,285
Number of Female Lone-Parent Families	70	15	1,480	90	20
Percentage of Female Lone-Parent Families (%)	2.3	1	3.5	2.2	1.5

Note: Source is Canada Census 2006.

Shelter costs for rented dwellings and owned dwellings for each census boundary are as follows:

Table 4.4 Median Shelter Costs for Rented and Owned Dwellings

Description	Virden	Wallace	Brandon	Cornwallis	Elton
Total Population	3,010	1,500	41,510	4,055	1,285
Median Monthly Payments for Rented Dwellings ($)	442	0	581	600	701
Median Monthly Payments for Owner-Occupied Dwellings ($)	437	355	676	560	776

Note: Source is Canada Census 2006.

According to the owned dwellings shelter costs, the vulnerability class parameters for the variable from 1 to 5 (1 being most vulnerable) are Elton, Brandon, Cornwallis, Virden, and Wallace, respectively (Census Canada, 2006).

Considering income, age, female-lone parent families, and median shelter costs, the following matrix is evaluated and the weighted classes are delineated as such.

Table 4.5 Weighted Socioeconomic Variables by Parameter

Census Boundary	Low Income	Vulnerable Age	Lone Female Families	Shelter Costs (Rented)	Vulnerability Classification	Overall Vulnerability Weighting
Brandon	1	3	1	3	8	1
Virden	4	1	2	4	11	2
Cornwallis	3	5	3	2	13	3
Wallace	2	2	5	5	13	4
Elton	5	4	4	1	14	5

Note: Lowest classification number = highest vulnerability. Source is Canada Census 2006.

The sum of the weighted variables is ordered from 1 to 5, representing highest to lowest vulnerability. The vulnerability classifications of Cornwallis and Wallace are equal at 13. However, Cornwallis has a higher classification weighting of both lone-female families and shelter costs, placing it higher at a vulnerability weight.

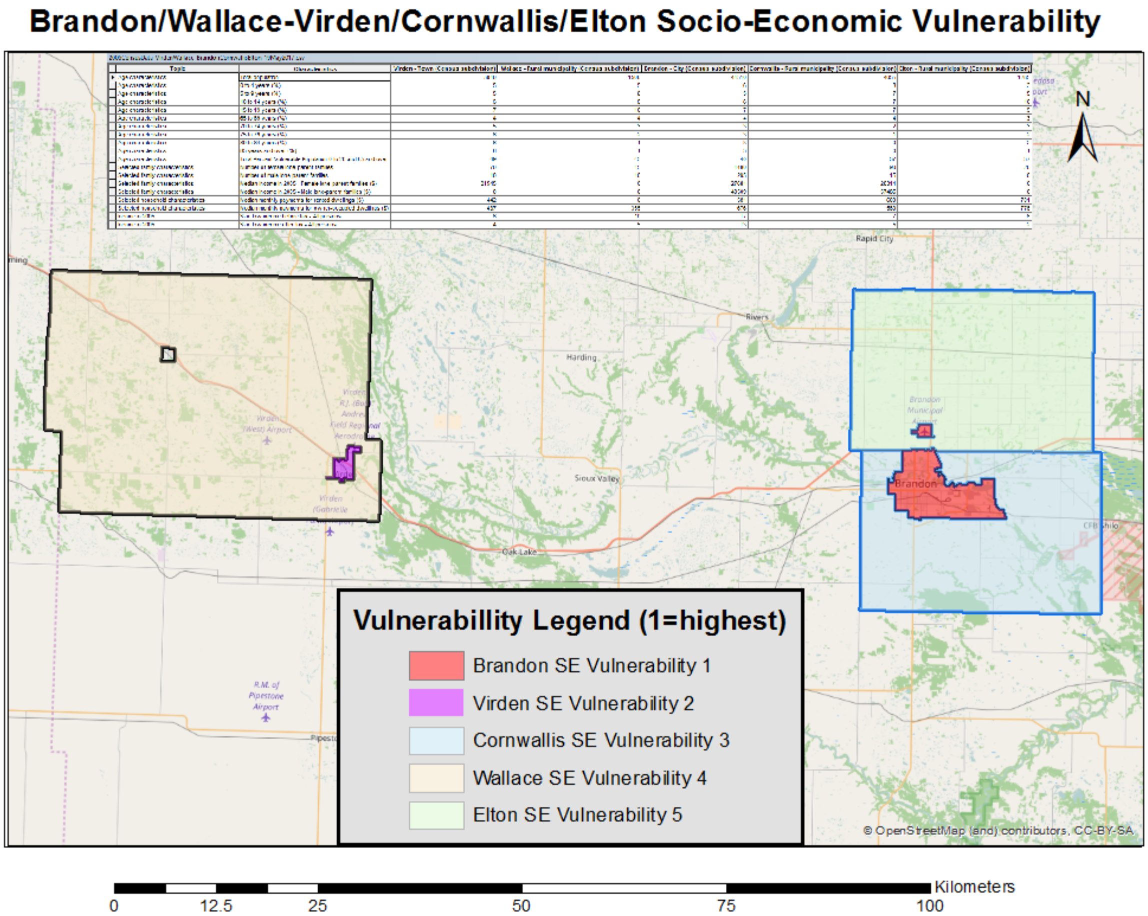

Figure 4.5. Socioeconomic vulnerability submodel product for the entire geomatrix. Source: G. R. McDonald, 2017.

<u>**Chemical Analysis Submodel**</u>

The annual Brandon environmental drinking water source analysis report (Appendix E) simply states whether or not a chemical compound met the pre- and post-treatment threshold parameters of metals, chemicals, and VOCs (BTEX) under the results column. No exact readings are released in the Brandon report for VOCs (BTEX). However, arsenic levels are stated as 0.00084 mg/L, well within the Manitoba Water Quality Standards, Objectives, and Guidelines threshold of 0.01 mg/L. All BTEX compounds met TLVs for Brandon. Upon request, no historical data are available from the Brandon water treatment plant.

The annual 2016 Virden environmental drinking water source analysis report lists the pretreatment (RAW) results of the VOCs. Benzene, toluene, ethylbenzene, and total xylene (the sum of o-xylene and m&p-xylene). All results are well above the stated TLVs. The TLV for benzene, toluene, and ethylbenzene chemical compounds is < 0.00050 mg/L (Manitoba Water Stewardship, 2011). The TLV for total xylene is 0.0015 mg/L. Benzene is reported at 0.005 mg/L (10 × the stated TLV), toluene at 0.06 mg/L (120 × TLV), ethylbenzene at 0.14 mg/L (280 × the TLV), and total xylene at 0.09 mg/L (60 × TLV).

The pretreatment arsenic levels indicated in the 2016 Virden chemical analysis (measured as total arsenic) were 0.0422 mg/L (RAW), which is 4.22 × the TLV of 0.005 mg/L. Arsenic levels fail the in-house tests in 2008 and 2009. In 2010, the post-treatment arsenic levels begin to meet the standards except for August and September. They then continuously fail from 2011 throughout 2016 despite the newly upgraded facilities. The available historic median annual levels of arsenic from the Virden water treatment plant from 2007 to 2015 (Appendix V) are as follows (RAW = Pretreatment, PT = Post-Treatment):

Table 4.6 Available Raw and Treated Water Sample from Virden Annual Water Test Results

Sample	2008	2009	2010	2011	2012	2013	2014	2015
Raw	0.0415	0.0435	-	-	-	-	-	0.0473
Treated	-	-	-	0.0135	0.0150	0.0180	0.0.153	-

Note: Source is ALS Environmental Laboratories. All samples in mg/L. Dashes signify that information is not available.

These results show that despite treatment, the arsenic levels in the Virden region water table are highly relative to the above-indicated safe drinking water levels and have remained so. Given that the adjacent rural municipalities of Wallace, Cornwallis, and Elton do not have access to the treated Virden drinking water source, the vulnerability classes of the five census boundaries within the chemical analysis submodel are as follows (from 1 = highest vulnerability to 5):

Wallace - 1 Virden - 2 Elton - 3 Cornwallis - 4 and Brandon - 5

The Wallace municipality rates as the most vulnerable because of its vicinity to, and surrounding, the town of Virden. The municipality is exposed to the same extremely high BTEX and arsenic levels without the benefit of access to the Virden plant-treated drinking water. Similarly, Virden rates the next highest on the vulnerability scale because of its access to a water treatment plant. The Elton municipality rates third because of its rural setting and that it is the most northeasterly municipality of the five communities as this is the direction of discharge within the province. The Cornwallis municipality rates fourth because of its lack of access to Brandon-treated drinking water, and finally, Brandon rates lowest in the chemical analysis submodel because of its low RAW and PT levels and its use of a functional water treatment plant.

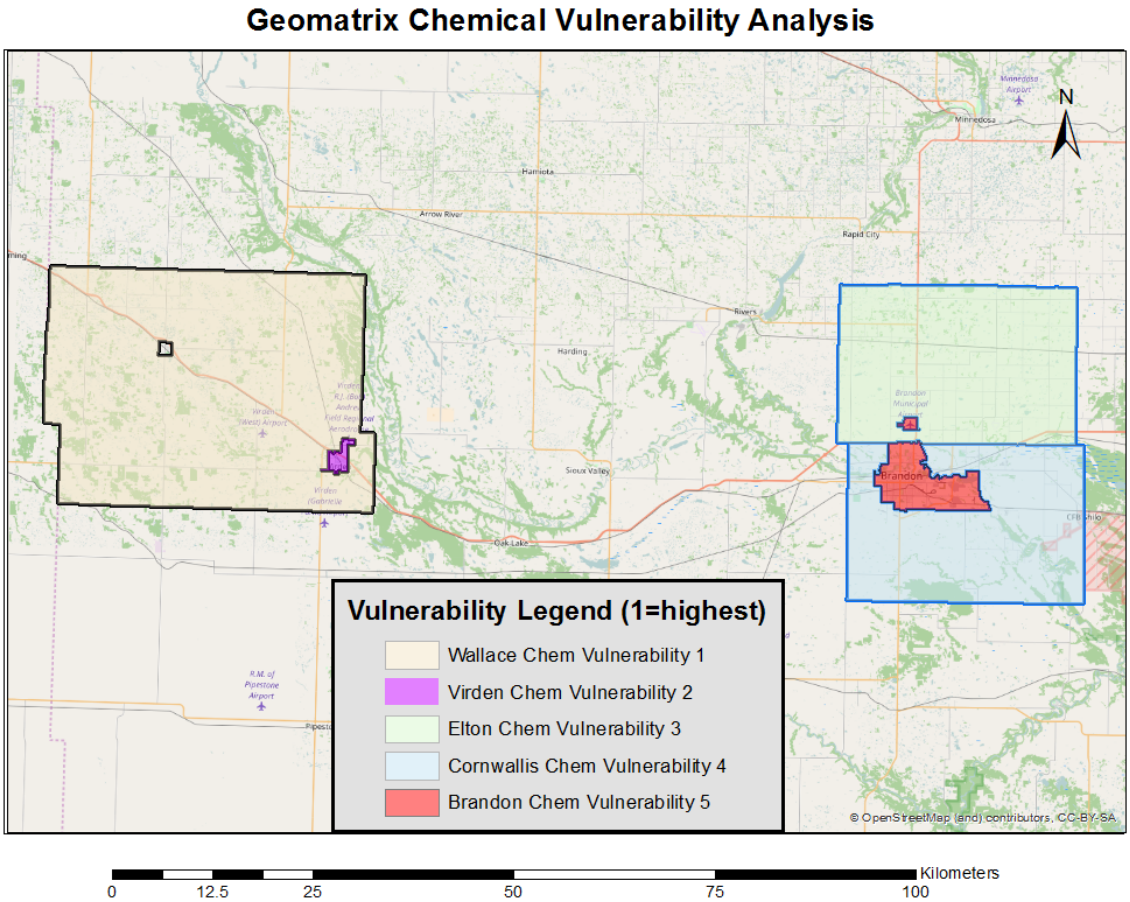

Figure 4.6. Geomatrix chemical analysis vulnerability submodel product illustrating the chemical vulnerability levels of each census boundary area of interest. Source: G. R. McDonald, 2017.

Final Geomatrix Drinking Water High-Vulnerability Spatial Analysis

The space of highest socioeconomic vulnerability by submodel weight is Brandon because it holds the highest percentage of female-led single-parent households with children. Brandon also lies within the most environmentally vulnerable region of the five communities studied because of the aquifer and soil medias. Wallace claims the highest chemical analysis submodel vulnerability because of the VOC and arsenic levels in the groundwater and its lack of access to treated drinking water. The Virden/Wallace region holds the highest industrial infrastructure vulnerability and also the higher urban infrastructure vulnerability between the two regions due to having two schools within a high-vulnerability zone as well as a hospital and senior care facility within 33.5 m of a medium-vulnerability zone. The township of Virden's has the highest chemical analysis vulnerability weighting, and all models considered, the highest overall urban vulnerability of the two communities, with Wallace claiming the highest overall vulnerability of all five of the communities, rural and urban (Appendix W). It is the recommendation of this study that the township of Virden conduct regular water quality analysis of its tap water at source.

Table 4.7 Final Unsafe Drinking Water Vulnerability AHP Weighting (Appendix R)

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Environmental Factors	25.6%	2
2	Socio-Economic Factors	40.8%	1
3	Urban Infrastructure	8.6%	5
4	Industrial Infrastructure	10.0%	4
5	Chemical Analysis	15.0%	3

Number of comparisons = 10
Consistency Ratio CR = 7.0%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4	5
1	1	1.00	4.00	2.00	1.00
2	1.00	1	7.00	6.00	2.00
3	0.25	0.14	1	1.00	1.00
4	0.50	0.17	1.00	1	1.00
5	1.00	0.50	1.00	1.00	1

Principal eigen value = 5.314
Eigenvector solution: 6 iterations, delta = 4.4E-9

AHP Submodel Priorities

Environmental Factors	Socio-Economic Factors	Urban Infrastructure	Industrial Infrastructure	Chemical Analysis
1	1	4	2	1
1	1	7	6	2
0.25	0.142857	1	1	1
0.5	0.166667	1	1	1
1	0.5	1	1	1
0.255752	0.408026	0.086277	0.100139	0.149806
5.313667	0.069732			

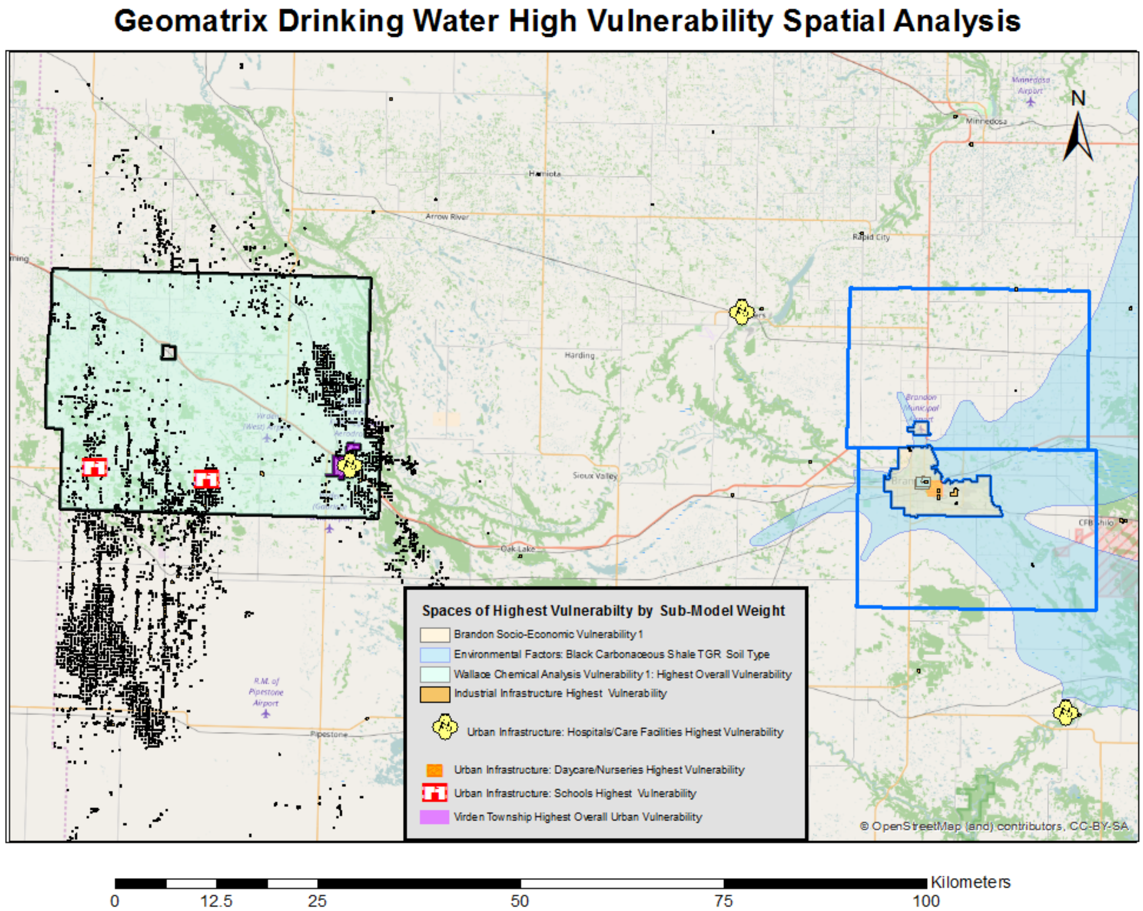

Figure 4.7. Complete geomatrix drinking water high-vulnerability spatial analysis by submodel illustrating the spatial areas of highest drinking water vulnerability. Source: G. R. McDonald, 2017.

CHAPTER FIVE

DISCUSSION, RECOMMENDATIONS AND CONCLUSIONS

The purpose of this study is to establish a working conceptual model that utilizes a multivariate approach to combine observable quantifiable science-based data, socioeconomic data, urban and industrial infrastructure locational data, along with environmental data within a geographic information systems (GIS) software environment in an attempt to determine the relationship between socioeconomic variables and sensitivity to specific spatial variables that contribute to drinking water vulnerability and unsafe drinking water geographies. As the literature has shown, vulnerability is a subjective and culturally sensitive concept. AHP allows for subjective weighting of socioeconomic parameters that reflect social norms.

Safe drinking water is an increasingly global scarcity. As Margaret Mead said, “Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it’s the only thing that ever has” (Peter Levine, 2011). Few studies so far have attempted to correlate demographic spatial distributions to the vulnerability of human populations residing adjacent to oil and gas fracking operations. Consider the following statement taken from the comprehensive study *Environmental Impacts of Shale Gas Extraction in Canada* conducted by the Council of Canadian Academies (2014): “There is only minimal reference literature and no peer-reviewed literature that assess the potential for the various chemicals in hydraulic fracturing fluids to persist, migrate, and impact the various types of subsurface systems or to discharge to surface waters.” If the discharge and migration of fluids are not being studied, certainly the effects on local populaces cannot be accurately analyzed.

The gradual and consistent toxification of the world’s freshwater resources is a complex problem requiring multifaceted solutions that employ multifaceted approaches to discern the many causes and possible solutions to the global issue. Groundwater does not follow borders or boundaries, so focusing on the issue at one particular scale serves only as a snapshot of the situation specific to a given space in time. A flexible and scalable model is required to provide insight into which spaces are vulnerable and require further investigation and to acquire a more comprehensive understanding of the covariable relationships between measurable causative variables and phenomena that affect and exacerbate vulnerable drinking water geographies.

The results of this study support the decision to employ the application of MCDA through GIS as a tool to determine areas of spatial vulnerability to unsafe drinking water. By creating layers of the highest vulnerable locations based on submodel criteria/parameters, spatial intersections of layers representing the zones of highest vulnerability to unsafe drinking water are revealed and illustrated. This allows for spatial patterns to emerge that would not be evident through the analysis of tables and numeric figures.

By using the general modeling approach of Cromley and McLafferty, the socioeconomic variables weighted by those of highest concerns are overlain onto the high-vulnerability risk zones derived from the industrial infrastructure submodel. The socioeconomic submodel is weighted as number one within the greater model for indicators of unsafe drinking water vulnerability. Variables indicating vulnerability are accentuated within the urban spatial contexts of Brandon and Virden because of the higher number of low-income and female-lone-parent-family households. As pointed out in Mosler et al. (2009), the roles and socioeconomic standing of women (particularly single mothers with children) play a large role in determining the percentage of the populace representing the high-vulnerably demographic by virtue of income as well as choices regarding access to alternative drinking water sources and location of dwelling. Brandon in particular had the comparatively highest percentage of economically and socially disadvantaged households within the geomatrix. Easier access to amenities and the availability of public transportation allow for low-income families to reside within these spaces. However, low-income households have fewer alternative choices to drinking city or well water from the tap. Access to newer accommodations with modern water pipe delivery systems are also variables of concern though not addressed in this study. Combined with higher shelter costs in urban spaces, the socioeconomic submodel is rated highest for weight within the context of the entire drinking water vulnerability model. For this reasoning, the lone-female-with-children-family data is used to represent the most vulnerable demographic and delineated by census municipality boundary files. This revealed a pattern of high vulnerability in urban areas, and had there been census tract data available, such as what is available for the metropolitan regions of Canada, the specific neighborhoods of highest vulnerability would have been identified at a more specific scale.

The environmental submodel, weighted as the second highest submodel within the vulnerability model, comparatively revealed which soils and substrate were at highest risk of toxification due to petroleum operations. Despite the fact that the chemical analysis revealed exponentially higher levels of groundwater toxins in the Virden region (as expected) than the DRASTIC method predicted, the extremely slow drainage rate characteristics of the Virden substrate and soil types do bear out that the groundwater toxicity is presently confined to the Virden area of interest because of the high clay/slow drainage soil content. As stated, shallow water tables are considered to be more vulnerable to contamination by pollutants than deeper tables. It is reasonable to extrapolate these findings into the future and predict that groundwater toxicity in the Brandon region will eventually rise considerably given the direction of discharge from southwest to northeast within the province and that once the contaminants do reach the region, they will migrate at an increased rate.

The chemical analyses of the Brandon and Virden water sources commissioned by the communities indicate a substantially higher drinking water source vulnerability rating for the Virden area. This may also be reasonably attributable to the high clay content of the soil in Virden which allows for meager drainage and migration of groundwater. The toxins are essentially trapped within the substrate aquifer. The cumulative effects of constant and intensive fracturing of the substrate in the region cannot be measured or underestimated. The extremely high levels of arsenic can be considered naturally occurring as the township website claims, but the extremely high levels of BTEX VOCs present in the RAW and PT tests results (Appendices F and G) are evident and may be attributed to the highly intensive petroleum industry operations in the region. This result illustrates the importance of scale when considering and employing methods and models to extrapolate results from a spatial environment. The DRASTIC model precludes the isolation of a geomatrix. However, these results reveal that surrounding regions and their substrate material must also be taken into consideration before drawing conclusions. A scale that allows for the comparison of surrounding environments provides for a more accurate analysis overall. This is the rationale for the smaller-scale representation of the environmental factors submodel. The environmental submodel results served the entire drinking water vulnerability model suitably as a spatial template to determine vulnerability zones.

Industrial infrastructure affects the health of the general population and the structural implications of the spatial socioeconomic and infrastructure of society as a whole. Industry directly affects our approach to how we structure our society physically and interactively with respect to mitigating drinking water hazards through water treatment methods and the placement of industrial regions such as treatment plants and social/residential infrastructure. The oil and gas industry requires direct access to large amounts of freshwater. Where we choose to plan and place our future social/residential neighborhoods plays a large role in vulnerability to industrial waste. The ratio of petroleum operations within the Virden region tilts the comparative industrial infrastructure vulnerability submodel drastically in the direction of Virden, a result that coincides with the expectations of this study and coincides with all the reviewed literature regarding petroleum hydraulic fracturing operations and groundwater effects. Despite the greater number of urban infrastructure variables within vulnerability risk zones in Brandon, these areas represent potential risk versus actual risk and did not appear to heavily influence the urban areas. However, when applied to the surrounding rural areas of Wallace, Cornwallis, and Elton, the weighting of the urban and industrial infrastructures becomes magnified because of the absence of access to centrally treated tap water. Substantiation of this would of course require tap sample testing data which is beyond the resources of this study. It bears mentioning that camping/swimming areas located outside the urban infrastructure are classified high-risk zones if RAW groundwater test results (BTEX and arsenic) are in high within the region.

The chemical analyses and environmental factors submodels both proved to be higher in the weighting of the results than anticipated. The weighting of the chemical analysis submodel is third within the vulnerability model because of high levels of seemingly nontreatable VOCs and arsenic in the groundwater. Arsenic levels, though stated to be naturally occurring, are extremely high within the Virden region, which may be interpreted as a result of vertical and horizontal hydraulic fracturing methods having been employed since the 1960s. This is pure conjecture and has not yet been verified by any present technology in use. Since no accurate testing data of groundwater or drinking water (RAW or PT) exists from that era, no comparative temporal studies can be carried out. With availability of VOC-BTEX data being restricted to 2016, the lack of data severely limited the comparative analysis between the two regions of Brandon and Virden. Having only “met/not met standard” results, the delineation is reduced to a simple binary outcome. However, the rising levels of arsenic and VOC-BTEX results indicate the effect the petroleum industry operations are having on the toxicity of the groundwater and drinking water sources in particular.

Fontenot et al. (2013) mention that the depth of the aquifer plays a more important role in water quality than distance to oil operations. Applied to the Virden model, which has a very shallow and poorly drained aquifer of unknown depth, this may account for the high levels of arsenic and BTEX. However, the lack of provincial vadose zone data due impedes further investigation into the results. The proximity to petroleum production zones is relied upon within the proposed model as a result, perhaps too heavily. Curiously, there are hundreds of hydrometric water testing sites found in the national CanVec data set, yet Provincial Water Stewardship authorities cannot publicly disclose the exact locations or results. One could postulate that this may be a result of lack of communication between levels of government represented by NRCAN and Manitoba Water Stewardship. The Virden treatment plants' inability to mitigate these levels to within national and provincial TLVs should be of great concern to local residents and the province. These results alone are a major red flag to local and provincial authorities that a ban on drinking tap water should be emplaced for the region. Again, a communication and awareness issue? Perhaps. It is certainly a political and resource expenditure issue to be sure.

Weighted fourth within the model is the industrial infrastructure because of its demonstrated inability to mitigate the effects of its HFFs in Virden as well as the industrial proximity to the community. The petroleum sites also weigh heavily within the submodel for their proximity to the drinking water source, the exact locations of which are not releasable to the public for safety reasons. This variable could certainly be delineated as a submodel of its own and subclassed as production, abandoned, brine storage, new drill injection, and extraction well sites. For the purposes of this study, the decision is made to simply delineate the production wells. An argument can certainly be made for inclusion of all injection, production, and abandoned well sites in the delineation because of the use of fracturing methods and their lasting effect on the postproduction substrata.

The final and fifth weighted submodel is the urban infrastructure submodel, most of which is mitigated by the presence of a successfully operated water treatment plant. In rural areas, proper testing and in-home water treatment systems can serve the same purpose. However, the camping/swimming sites are spatial areas of concern. They are included in the urban infrastructure submodel, as they are often located adjacent but outside the urban setting and may or may not have access to treated water. The dermal exposure to toxins due to swimming in polluted streams poses a high risk particularly in the Virden region. The only camping/swimming sites within the geomatrix are located in the Brandon region, which is certified as having met standards for post-treatment; however, RAW data is not given, so the responsibility lies with public health authorities to test swimming areas for chemicals, VOCs, and other potential health hazards.

Further substrata and hydrogeologic studies would be required to determine the causal effect of hydraulic fracturing on the naturally occurring levels of arsenic in the groundwater supply in the Virden area. A tap water comparative test study of the greater Brandon/Virden geomatrix is recommended for further study to determine the efficacy of the regional water treatment plants' methods and protocols including a systems analysis and equipment serviceability inspection. This is substantiated by the number of "offline" and negative "met/did not meet standard" results obtained from the Virden treatment plant within the oil field operational area. A comparative study based in a completely different geographical area would be a recommended test for this model. This would allow for further testing which was lacking in this thesis partly due to the lack of available transparent data.

The employment of principal component analysis for weighting nominal data is a viable and a certainly promising option for further study given availability of tap water test results. The failure to secure complete chemical analysis data from both water treatment facilities does preclude the use of this method for this study. This is a recommended method for any future study of addressing tap water sampling. Tap water analysis would also allow for the introduction of a greater number of drinking water vulnerability risk classifications and buffer zones to be employed rather than the existing three buffer zones extrapolated from the industrial infrastructure submodel. This would also allow for far greater accuracy through the use of raster data to delineate continuous data such as high-risk zones at a larger geographic scale.

Many studies have been conducted at the geographically large-scale perspective, concentrating on one-to-one or one-to-many modeling templates which do not take a multidisciplinary approach to the complex phenomena of causality. To study a given environmental geomatrix that combines man-made technologies and systems within the natural environment and attempt to model causation in simplistic ways that do not incorporate the effects on human health and the environment is to miss the entire point of the exercise. To conclude, as many studies do, that indeed there are volatile BTEX compounds present in the groundwater and that they are a result of lack of oversight regarding petroleum drilling practices offers little new information to further knowledge and discussion into the field of mitigation and policy formation as it concerns unsafe drinking water vulnerability. Industrial and urban infrastructure, socioeconomic, and natural environment and water testing results need to be combined into one MCDA model in a positivist approach, as employed by Demesouka et al. (2013) to locate optimal landfill sites in Thrace Greece. Results are verifiable by field checks and bear out in the chemical analysis of the regions of concern. The proposed model in this study has the added features of analyzing the socioeconomic and environmental facets to combine the five mentioned submodels in a novel approach to vulnerability studies.

The environmental modeling of fracking effects tends to be reductionist by nature and, even with the application of multicriteria analysis, uses few variables, commonly attempting to explain away spatial problems and phenomena by boiling the issue down to causation of a few or a single variable. Such studies emphasize either the specific hazards, exposure limits, or the environmental results of the analysis of specific observational locations (Cromley & McLafferty, 2012). They lose sight of the holistic nature of the environment as it relates to human health and often fall into a fallacious spatial notion of the real world by way of what may be termed the "delusion of scale," or simply the scale problem. This is the fallacy of asking the wrong questions at the wrong scale or the proper questions at the improper scale. A simple example is attempting to discern the direction of aquifer discharge within the province of Manitoba from a 1:50,000-scale hydrogeologic map of Brandon. This notion is closely related to modifiable area unit problems that occur when arbitrary spatial aggregation of point-based data can create statistical bias and boundary problems where boundaries created for administrative purposes (such as census) create clustering or dispersal problems and statistical bias.

Not all outcomes can be accurately predicted by deterministic approaches. There are certain questions that can be asked, and potentially answered, at one scale and not of another. Induction is as important a part of the deterministic process as deduction when it comes to the rationale employed. For instance, the choice of using census tracts can be a very precarious route to choose in some situations. The issue arising from employing the use of census tracts is that they are political and arbitrary as far as spatial and environmental sciences are concerned. They do not take natural environmental factors such as geomorphology, water sheds, substrata, rock and soil permeability, vadose zones, aquifers, and many other geological variables into consideration, and indeed they were not designed to. That being said, Census Canada is the most easily accessible and a reliable source of socioeconomic and physical infrastructure data. The cautionary principle to be employed in the instance of environmental health modeling is that analysis and conclusions are confined to the geomatrix and the scale they were collected at and that results may bleed through to other similar census tracts but may have absolutely no application to others within the same geomatrix of a similar scale. Each tract is unique, and caution should be used when drawing conclusions regarding epidemiological considerations. Nor can all census tracts be employed for consideration of causality at the identical scales of reference.

If urban census tracts are used, they will be disposed to many common variables; as a result, one or a small group of common variables may be isolated and accentuated or ignored completely when considering causation from a multivariate overlay analysis approach. A kind of perceptual myopia results. As an example, two neighborhoods within the same census tract may have been built several decades apart; one may have copper water pipes, the other plastic pipes. This important temporally sensitive variable will not be discerned or delineated at the census tract scale. When attempting to deduce the same problem of causation from a rural census tract, we must consider that we are observing phenomena at a much different scale, and many more potential variables and extremes of variance exist between observation points. Urban areas share a drinking water source that is treated centrally so the more sensible variables to consider would be sociologic and infrastructural such as income, dwelling costs, age of neighborhood, age of dwelling, water pipe materials, and others. The variables in a rural area would likely be more geomorphologic and environmental, such as slope, substrata material, location of aquifers, rainfall, vadose zones, soil type, well location, and other geologic, geographic, and spatial variables. Vicinity to industrial operations, transportation routes, and other infrastructure affect rural water quality more directly. As a result, the proposed overall model and submodels in this paper may be applied anywhere to any situation, but the choice of data processing methods, variables, and weighting needs to be readdressed for each scenario. The strength of the proposed model is that it combines observable quantifiable science-based data with urban an industrial infrastructure locational data along with environmental data and the use of geographic information technology in an attempt to determine which socioeconomic variables are sensitive to those which contribute to drinking water vulnerability.

Recommendations

No papers have come to light that combine scientific drinking water test analyses, social and industrial infrastructure, and socioeconomic factors along with natural environmental factors to develop a comprehensive approach to healthy drinking water vulnerability. Many studies concentrate on laboratory analysis at the expense of locational and spatial aspects of the environment. An environmental and health issue cannot be adequately studied if the spatial distribution of the problem is not addressed. It should be recognized that externalities such as government regulations and economic considerations play a role in the vulnerability model; however, all action and reaction to an environmental stressor occurs from the grassroots level in the home and community. This is what makes a vulnerability assessment simply an indicator and not a deterministic model. The strongest predictive indicators of adaptability are still education and income (Crabbé & Robin, 2006). If there is to be a balanced discussion as to the future of hydraulic fracturing and the environmental issue of safe drinking water, a more multidisciplinary approach is required. GIS can illustrate the spatial geographies requiring immediate concentration of future studies and resources. The current dichotomy of polarized posturing between industry, government, and public interest seems to have accomplishing little in the way of furthering the discussion addressing geographies of vulnerability to unsafe drinking water. A more inclusive multivariate model serves as a broad scope tool that allows all the tangible and intangible variables to be considered and weighed. Based on the review of the present literature, this contribution will demonstrate the utility of GIS in assisting policy makers in developing spatially optimized mitigation strategies for fracking guidelines and assist in identifying spatial locations that require additional resources and studies regarding water treatment methods.

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List of Terms

ADA: Assiniboine Delta Aquifer.
AHP: Analytical Hierarchy Processes.
AOI: Area of Interest.
ASL: Above Sea Level.
AVRA: Assiniboine River Aquifer.
BCA: Brandon Channel Aquifer.
BTEX: Refers to benzene, toluene, ethylbenzene, and xylene.
CanVec: Canadian Vector data for use in GIS software.
CCME: Canadian Council of Ministers of the Environment.
CCMEO: Mapping the North process conducted by the Canada Center for Mapping and Earth Observation.
CDEM: Canadian Digital Elevation Model.
DS: Delusion of Scale.
DTED: Digital Terrain Elevation Data.
EPHT: Environmental Public Health Tracking.
Fracking: Refers to the oil industry's gas extraction technique of hydraulic fracturing where a concoction of synthetic chemicals mixed with sand are injected into the sub-strata of the earth at a depth of approximately 1 kilometre in depth in order to cause fissures in the strata (usually in shale regions) in order to extract natural gas.
GIS: Geographic Information Systems.
HFF: Hydraulic Fracturing Fluid.
MCDA: Multi Criteria Decision Analysis. Employs a one to many or many to many approach to variable analysis.
MCL: Maximum Contamination Levels for drinking water (U.S.).
MLI: Manitoba Land Initiative.
NRCAN: Natural Resources Canada.
NTDB: National Topographic Data Base.
OncoLogic 8.0: Oncological software that weights chemicals by name or CAS number according to their studied carcinogenicity (cancer causing risk). Classified from marginal to very high.
PCA: Principle Component Analysis.
Raster Data: Consists of matrices of pixels (or cells) that represent tangible values such as an aerial photo or intangible phenomena such as temperature hazards and are organized into rows and columns (or a grid) where each cell contains a value representing information.
RZLI: Root Zone Leaching Index.
SoVI: Social Vulnerability Index.
SRTM: Shuttle Radar Topographic Mission.
TDS: Total Dissolved Solids.
TLV: Threshold Limit Values.
VOC: Volatile Organic Compounds. BTEX constituents fall under this category.

APPENDICES

APPENDIX A

BTEX CONCENTRATIONS WELD COUNTY

Table 3. BTEX concentrations (ppb) from groundwater samples taken before or early during the remediation process of Weld County surface spills involving groundwater contamination. Samples (*n* – 218) were pooled from spills that occurred between July 1, 2010, to July 1, 2011

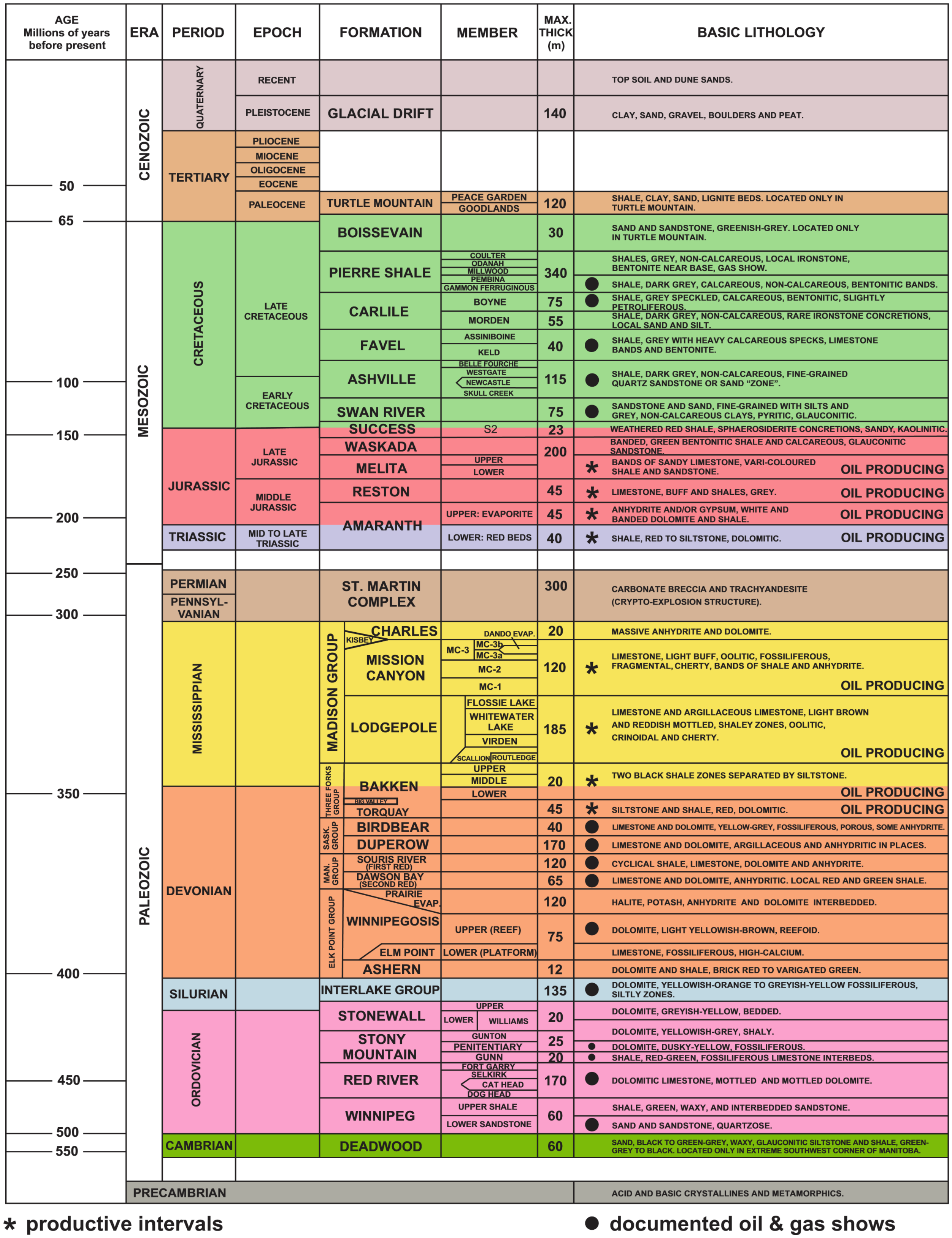
	Count	Percent below RL[a]	50th percentile	95th percentile	KM mean[f]	97.5% UCL	Percent above MCL
Benzene							
Spill #2608769	78	88%	<1.0[b]	14.6	6.6[d]	24[d]	8%
Other spills	140	27%	22	5900	920	2100	66%
-Inside excavated area	102	16%	38	6100	1100	2600	77%
-1st sampling date	60	8%	100	6100	1400	3400	90%
-2nd sampling date	25	20%	13	8900	970	5000	60%
-3rd or later sampling date	17	35%	5.5	140	34	160	59%
-Outside excavated area	38	58%	<1.0[b]	3300	510	1900	37%
All data	218	49%	1.5	4800	590	1400	45%
Toluene							
Spill #2608769	78	100%	<1.0[b]	<1.0[c]	na[e]	na[e]	0%
Other spills	140	42%	2.4	8800	1200	3000	17%
-Inside excavated area	102	31%	10	10,000	1400	3800	19%
-1st sampling date	60	25%	64	10,000	2200	5800	30%
-2nd sampling date	25	36%	7.0	630	680	4700	4%
-3rd or later sampling date	17	47%	1.3	120	34[d]	240[d]	0%
-Outside excavated area	38	71%	<1.0[b]	3200	430	1700	13%
All data	218	63%	<1.0[b]	4100	750	1900	11%
Ethylbenzene							
Spill #2608769	78	91%	<1.0[b]	49	8.2[d]	36[d]	0%
Other spills	140	41%	3.0	720	100	230	6%
-Inside excavated area	102	32%	4.3	780	120	290	7%
-1st sampling date	60	18%	47	900	190	460	12%
-2nd sampling date	25	32%	2.3	150	20	88	0%
-3rd or later sampling date	17	82%	<1.0[b]	26	5.3[d]	28[d]	0%
-Outside excavated area	38	66%	<1.0[b]	420	65	220	3%
All data	218	59%	<1.0[b]	420	67	150	4%
Xylene							
Spill #2608769	78	86%	3.0	1700	230	810	0%
Other spills	140	25%	66	8400	1500	3900	4%
-Inside excavated area	102	15%	130	12,000	1800	5000	6%
-1st sampling date	60	7%	320	12,000	2600	7600	8%
-2nd sampling date	25	20%	41	6900	1100	6000	4%
-3rd or later sampling date	17	35%	7.6	390	62	310	0%
-Outside excavated area	38	53%	<1.0[b]	2200	520	2000	0%
All data	218	47%	4.4	5600	1000	2600	3%

"The reporting limit was 1 pbb for all benzene, toluene, and ethylbenzene samples that were below the reporting limit. The average reporting limit and standard deviation for the xylene samples that were below the reporting limit was 2.3 ± 0.9 ppb. "More than 50% of the data were below the reporting limit (RL), and therefore the reported 50th percentiles are based on nondetect values. "More than 95% of the data were below the reporting limit (RL), and therefore the reported 95Th percentile is based on nondetect values. "These values were calculated based on fewer than 10 values above reporting limit (9 for benzene and toluene, 7 for ethylbenzene spill #2608769, and 3 for ethylbenzene day 3 or later), and thus may not be as reliable as the other reported values. "It was not possible to calculate a value because there were no measurements above the reporting limit. "The

Gehan test was used to test the significant differences between the following measurements: 1^{st} sampling date vs. 2^{nd} sampling date, 1^{st} sampling date vs. 3^{rd} or later sampling date, 2^{nd} sampling date vs. 3^{rd} or later sampling date, and inside vs. outside the excavation area. All pairwise comparisons were found to be significant ($p < 0.05$) except for benzene 2^{nd} sampling vs 3^{rd} or later sampling date.

APPENDIX B

OIL PRODUCING STRATOCOLUMN SOUTHWESTERN MANITOBA



Manitoba geologic column, showing productive intervals and documented oil and gas shows.

APPENDIX C

DESCRIPTION OF BRANDON REGION SOIL TYPE

Description of soil MBTGR~~1~~A (Taggart)

General Characteristics

Classification	**GLR.BLC** Gleyed Rego Black Chernozem
Profile	**Agricultural soil profile** The soil has been disturbed by agriculture.
Kind of material	**Mineral** The soil material is primarily composed of mineral particles.
Water table	**Unspecified period** The water table is present in the soil during an unspecified period.
Root restrictions	**No root restricting layer** The growth of plant roots is not restricted by any soil layer.
Type of root restricting layer	**n/a** Not Applicable
Drainage	**Imperfectly drained** Water is removed from the soil sufficiently slowly in relation to supply, to keep the soil wet for a significant part of the growing season. Excess water moves slowly downward if precipitation is the major supply. If subsurface water or groundwater, or both, is the main source, the flow rate may vary but the soil remains wet for a significant part of the growing season. Precipitation is the main source if available water storage capacity is high; contribution by subsurface flow or groundwater flow, or both, increases as available water storage capacity decreases. Soils have a wide range in available water supply, texture, and depth, and are gleyed phases of well drained subgroups.

APPENDIX D

DESCRIPTION OF VIRDEN AREA SOIL TYPE

Description of soil MBVFF~~~~~A (Vodroff)

General Characteristics

Classification	**R.HG** Rego Humic Gleysol
Profile	**Agricultural soil profile** The soil has been disturbed by agriculture.
Kind of material	**Mineral** The soil material is primarily composed of mineral particles.
Water table	**Always** The water table is always present in the soil.
Root restrictions	**No root restricting layer** The growth of plant roots is not restricted by any soil layer.
Type of root restricting layer	**n/a** Not Applicable
Drainage	**Poorly drained** Water is removed so slowly in relation to supply that the soil remains wet for a comparatively large part of the time the soil is not frozen. Excess water is evident in the soil for a large part of the time. Subsurface flow or groundwater flow, or both, in addition to precipitation are the main water sources; there may also be a perched water table, with precipitation exceeding evapotranspiration. Soils have a wide range in available water storage capacity, texture, and depth, and are gleyed subgroups, Gleysols, and Organic soils.

APPENDIX E

BRANDON WATER ANALYSIS REPORT

City of Brandon - Water Treatment Plant

108 - 26th Street North
Brandon MB R7B 1J6

Date Received: 15-OCT-16
Report Date: 31-OCT-16 19:24 (MT)
Version: FINAL

Certificate of Analysis

Lab Work Order #:
Project P.O. #:
Job Reference:
C of C Numbers:
Legal Site Desc:

ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters	Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1843955-1 LAB TAP							
Sampled By: CLIENT on 14-OCT-16							
Matrix: Water							
MB Chemistry for PWS							
Alkalinity, Bicarbonate							
Bicarbonate (HCO3)	104		1.2	mg/L		21-OCT-16	
Alkalinity, Carbonate							
Carbonate (CO3)	<0.60		0.60	mg/L		21-OCT-16	
Alkalinity, Hydroxide							
Hydroxide (OH)	<0.34		0.34	mg/L		21-OCT-16	
Alkalinity, Total (as CaCO3)							
Alkalinity, Total (as CaCO3)	85.1		1.0	mg/L		20-OCT-16	R3576387
Ammonia by colour							
Ammonia, Total (as N)	0.019		0.010	mg/L		24-OCT-16	R3579014
Bromide in Water by IC (Low Level)							
Bromide (Br)	0.028		0.010	mg/L		17-OCT-16	R3573718
Chloride in Water by IC (Low Level)							
Chloride (Cl)	28.9		0.10	mg/L		17-OCT-16	R3573718
Colour, True							
Colour, True	<5.0		5.0	CU		17-OCT-16	R3577440
Conductivity							
Conductivity	729		1.0	umhos/cm		20-OCT-16	R3576387
Dissolved Organic Carbon by Combustion							
Dissolved Organic Carbon	6.06		0.50	mg/L		20-OCT-16	R3576334
Fluoride in Water by IC							
Fluoride (F)	0.717		0.020	mg/L		17-OCT-16	R3573718
Hardness Calculated							
Hardness (as CaCO3)	169	HTC	0.25	mg/L		28-OCT-16	
Langelier Index 4C							
Langelier Index (4 C)	-0.25					28-OCT-16	
Langelier Index 60C							
Langelier Index (60 C)	0.51					28-OCT-16	
Nitrate in Water by IC (Low Level)							
Nitrate (as N)	0.199		0.0050	mg/L		17-OCT-16	R3573718
Nitrite in Water by IC (Low Level)							
Nitrite (as N)	<0.0010		0.0010	mg/L		17-OCT-16	R3573718
Sulfate in Water by IC							
Sulfate (SO4)	238		0.30	mg/L		17-OCT-16	R3573718
Total Dissolved Solids (TDS)							
Total Dissolved Solids	490		20	mg/L		21-OCT-16	R3579091
Total Metals by ICP-MS							
Aluminum (Al)-Total	0.0881		0.0050	mg/L	27-OCT-16	27-OCT-16	R3581787
Antimony (Sb)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Arsenic (As)-Total	0.00226		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Barium (Ba)-Total	0.00819		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Beryllium (Be)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Bismuth (Bi)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Boron (B)-Total	0.100		0.010	mg/L	27-OCT-16	27-OCT-16	R3581787
Cadmium (Cd)-Total	<0.000010		0.000010	mg/L	27-OCT-16	27-OCT-16	R3581787
Calcium (Ca)-Total	45.2		0.10	mg/L	27-OCT-16	27-OCT-16	R3581787
Cesium (Cs)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Chromium (Cr)-Total	<0.0010		0.0010	mg/L	27-OCT-16	27-OCT-16	R3581787
Cobalt (Co)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Copper (Cu)-Total	0.00089		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Iron (Fe)-Total	0.011		0.010	mg/L	27-OCT-16	27-OCT-16	R3581787
Lead (Pb)-Total	<0.000090		0.000090	mg/L	27-OCT-16	27-OCT-16	R3581787

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

16465,292F9

ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters	Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1843955-1 LAB TAP							
Sampled By: CLIENT on 14-OCT-16							
Matrix: Water							
Total Metals by ICP-MS							
Lithium (Li)-Total	0.0683		0.0020	mg/L	27-OCT-16	27-OCT-16	R3581787
Magnesium (Mg)-Total	13.7		0.010	mg/L	27-OCT-16	27-OCT-16	R3581787
Manganese (Mn)-Total	0.00062		0.00030	mg/L	27-OCT-16	27-OCT-16	R3581787
Molybdenum (Mo)-Total	0.00297		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Nickel (Ni)-Total	<0.0020		0.0020	mg/L	27-OCT-16	27-OCT-16	R3581787
Phosphorus (P)-Total	<0.10		0.10	mg/L	27-OCT-16	27-OCT-16	R3581787
Potassium (K)-Total	11.6		0.020	mg/L	27-OCT-16	27-OCT-16	R3581787
Rubidium (Rb)-Total	0.00237		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Selenium (Se)-Total	<0.0010		0.0010	mg/L	27-OCT-16	27-OCT-16	R3581787
Silicon (Si)-Total	5.78		0.10	mg/L	27-OCT-16	27-OCT-16	R3581787
Silver (Ag)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Sodium (Na)-Total	97.9		0.030	mg/L	27-OCT-16	27-OCT-16	R3581787
Strontium (Sr)-Total	0.131		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Tellurium (Te)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Thallium (Tl)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Thorium (Th)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Tin (Sn)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Titanium (Ti)-Total	<0.00050		0.00050	mg/L	27-OCT-16	27-OCT-16	R3581787
Tungsten (W)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Uranium (U)-Total	0.00025		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Vanadium (V)-Total	0.00261		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Zinc (Zn)-Total	<0.0020		0.0020	mg/L	27-OCT-16	27-OCT-16	R3581787
Zirconium (Zr)-Total	<0.00040		0.00040	mg/L	27-OCT-16	27-OCT-16	R3581787
Total Organic Carbon by Combustion							
Total Organic Carbon	5.79		0.50	mg/L		20-OCT-16	R3576337
Turbidity							
Turbidity	<0.10		0.10	NTU		20-OCT-16	R3576677
UV Transmittance (Calculated)							
Transmittance, UV (254 nm)	82.6		1.0	%T/cm		20-OCT-16	R3578369
pH							
pH	7.88		0.10	pH units		20-OCT-16	R3576387
MB VOC PWS							
Sum of Xylene Isomer Concentrations							
Xylenes (Total)	<0.0015		0.0015	mg/L		28-OCT-16	
VOC plus F1 by GCMS							
Benzene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
1,1-dichloroethene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Dichloromethane	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Ethylbenzene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
MTBE	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Tetrachloroethene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Toluene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Trichloroethene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
M+P-Xylenes	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
o-Xylene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Surrogate: 4-Bromofluorobenzene (SS)	90.2		70-130	%		24-OCT-16	R3581422
Surrogate: 1,4-Difluorobenzene (SS)	99.8		70-130	%		24-OCT-16	R3581422
Total Coliform and E.coli							
Total Coliforms	0		0	MPN/100mL		15-OCT-16	R3572813
Escherichia Coli	0		0	MPN/100mL		15-OCT-16	R3572813

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters	Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1843955-2 CIVIC WORKS							
Sampled By: CLIENT on 14-OCT-16							
Matrix: Water							
MB Chemistry for PWS							
Alkalinity, Bicarbonate							
Bicarbonate (HCO3)	82.8		1.2	mg/L		21-OCT-16	
Alkalinity, Carbonate							
Carbonate (CO3)	<0.60		0.60	mg/L		21-OCT-16	
Alkalinity, Hydroxide							
Hydroxide (OH)	<0.34		0.34	mg/L		21-OCT-16	
Alkalinity, Total (as CaCO3)							
Alkalinity, Total (as CaCO3)	67.9		1.0	mg/L		20-OCT-16	R3576387
Ammonia by colour							
Ammonia, Total (as N)	0.016		0.010	mg/L		24-OCT-16	R3579014
Bromide in Water by IC (Low Level)							
Bromide (Br)	0.033		0.010	mg/L		17-OCT-16	R3573718
Chloride in Water by IC (Low Level)							
Chloride (Cl)	25.9		0.10	mg/L		17-OCT-16	R3573718
Colour, True							
Colour, True	<5.0		5.0	CU		17-OCT-16	R3577440
Conductivity							
Conductivity	750		1.0	umhos/cm		20-OCT-16	R3576387
Dissolved Organic Carbon by Combustion							
Dissolved Organic Carbon	5.91		0.50	mg/L		20-OCT-16	R3576334
Fluoride in Water by IC							
Fluoride (F)	0.756		0.020	mg/L		17-OCT-16	R3573718
Hardness Calculated							
Hardness (as CaCO3)	176	HTC	0.25	mg/L		28-OCT-16	
Langelier Index 4C							
Langelier Index (4 C)	-0.59					28-OCT-16	
Langelier Index 60C							
Langelier Index (60 C)	0.17					28-OCT-16	
Nitrate in Water by IC (Low Level)							
Nitrate (as N)	0.210		0.0050	mg/L		17-OCT-16	R3573718
Nitrite in Water by IC (Low Level)							
Nitrite (as N)	<0.0010		0.0010	mg/L		17-OCT-16	R3573718
Sulfate in Water by IC							
Sulfate (SO4)	254		0.30	mg/L		17-OCT-16	R3573718
Total Dissolved Solids (TDS)							
Total Dissolved Solids	486		20	mg/L		21-OCT-16	R3579091
Total Metals by ICP-MS							
Aluminum (Al)-Total	0.0551		0.0050	mg/L	27-OCT-16	27-OCT-16	R3581787
Antimony (Sb)-Total	0.00022		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Arsenic (As)-Total	0.00084		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Barium (Ba)-Total	0.0108		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Beryllium (Be)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Bismuth (Bi)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Boron (B)-Total	0.090		0.010	mg/L	27-OCT-16	27-OCT-16	R3581787
Cadmium (Cd)-Total	<0.000010		0.000010	mg/L	27-OCT-16	27-OCT-16	R3581787
Calcium (Ca)-Total	49.2		0.10	mg/L	27-OCT-16	27-OCT-16	R3581787
Cesium (Cs)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Chromium (Cr)-Total	<0.0010		0.0010	mg/L	27-OCT-16	27-OCT-16	R3581787
Cobalt (Co)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Copper (Cu)-Total	0.0300		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Iron (Fe)-Total	0.030		0.010	mg/L	27-OCT-16	27-OCT-16	R3581787
Lead (Pb)-Total	0.000171		0.000090	mg/L	27-OCT-16	27-OCT-16	R3581787

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters	Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1843955-2 CIVIC WORKS							
Sampled By: CLIENT on 14-OCT-16							
Matrix: Water							
Total Metals by ICP-MS							
Lithium (Li)-Total	0.0675		0.0020	mg/L	27-OCT-16	27-OCT-16	R3581787
Magnesium (Mg)-Total	13.0		0.010	mg/L	27-OCT-16	27-OCT-16	R3581787
Manganese (Mn)-Total	0.00089		0.00030	mg/L	27-OCT-16	27-OCT-16	R3581787
Molybdenum (Mo)-Total	0.00267		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Nickel (Ni)-Total	<0.0020		0.0020	mg/L	27-OCT-16	27-OCT-16	R3581787
Phosphorus (P)-Total	<0.10		0.10	mg/L	27-OCT-16	27-OCT-16	R3581787
Potassium (K)-Total	13.2		0.020	mg/L	27-OCT-16	27-OCT-16	R3581787
Rubidium (Rb)-Total	0.00240		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Selenium (Se)-Total	<0.0010		0.0010	mg/L	27-OCT-16	27-OCT-16	R3581787
Silicon (Si)-Total	4.91		0.10	mg/L	27-OCT-16	27-OCT-16	R3581787
Silver (Ag)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Sodium (Na)-Total	94.3		0.030	mg/L	27-OCT-16	27-OCT-16	R3581787
Strontium (Sr)-Total	0.140		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Tellurium (Te)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Thallium (Tl)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Thorium (Th)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Tin (Sn)-Total	<0.00020		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Titanium (Ti)-Total	<0.00050		0.00050	mg/L	27-OCT-16	27-OCT-16	R3581787
Tungsten (W)-Total	<0.00010		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Uranium (U)-Total	0.00017		0.00010	mg/L	27-OCT-16	27-OCT-16	R3581787
Vanadium (V)-Total	0.00225		0.00020	mg/L	27-OCT-16	27-OCT-16	R3581787
Zinc (Zn)-Total	0.0033		0.0020	mg/L	27-OCT-16	27-OCT-16	R3581787
Zirconium (Zr)-Total	<0.00040		0.00040	mg/L	27-OCT-16	27-OCT-16	R3581787
Total Organic Carbon by Combustion							
Total Organic Carbon	5.68		0.50	mg/L		20-OCT-16	R3576337
Turbidity							
Turbidity	0.14		0.10	NTU		20-OCT-16	R3576677
UV Transmittance (Calculated)							
Transmittance, UV (254 nm)	84.1		1.0	%T/cm		20-OCT-16	R3578369
pH							
pH	7.60		0.10	pH units		20-OCT-16	R3576387
MB VOC PWS							
Sum of Xylene Isomer Concentrations							
Xylenes (Total)	<0.0015		0.0015	mg/L		28-OCT-16	
VOC plus F1 by GCMS							
Benzene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
1,1-dichloroethene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Dichloromethane	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Ethylbenzene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
MTBE	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Tetrachloroethene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Toluene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Trichloroethene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
M+P-Xylenes	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
o-Xylene	<0.00050		0.00050	mg/L		24-OCT-16	R3581422
Surrogate: 4-Bromofluorobenzene (SS)	82.8		70-130	%		24-OCT-16	R3581422
Surrogate: 1,4-Difluorobenzene (SS)	99.5		70-130	%		24-OCT-16	R3581422
Total Coliform and E.coli							
Total Coliforms	0		0	MPN/100mL		15-OCT-16	R3572813
Escherichia Coli	0		0	MPN/100mL		15-OCT-16	R3572813

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

Reference Information

Sample Parameter Qualifier Key:

Qualifier	Description
HTC	Hardness was calculated from Total Ca and/or Mg concentrations and may be biased high (dissolved Ca/Mg results unavailable).
MS-B	Matrix Spike recovery could not be accurately calculated due to high analyte background in sample.

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
ALK-CO3CO3-CALC-WP	Water	Alkalinity, Carbonate	CALCULATION

The Alkalinity of water is a measure of its acid neutralizing capacity.Alkalinity is imparted by bicarbonate, carbonate and hydroxide components of water. The fraction of alkalinity contributed by carbonate is calculated and reported as mg CO3 2-/L.

ALS Test Code	Matrix	Test Description	Method Reference**
ALK-HCO3HCO3-CALC-WP	Water	Alkalinity, Bicarbonate	CALCULATION

The Alkalinity of water is a measure of its acid neutralizing capacity.Alkalinity is imparted by bicarbonate, carbonate and hydroxide components of water. The fraction of alkalinity contributed by bicarbonate is calculated and reported as mg HCO3-/L

ALS Test Code	Matrix	Test Description	Method Reference**
ALK-OHOH-CALC-WP	Water	Alkalinity, Hydroxide	CALCULATION

The Alkalinity of water is a measure of its acid neutralizing capacity.Alkalinity is imparted by bicarbonate, carbonate and hydroxide components of water. The fraction of alkalinity contributed by hydroxide is calculated and reported as mg OH-/L.

ALS Test Code	Matrix	Test Description	Method Reference**
ALK-TITR-WP	Water	Alkalinity, Total (as CaCO3)	APHA 2320B

The Alkalinity of water is a measure of its acid neutralizing capacity. Alkalinity is imparted by bicarbonate, carbonate and hydroxide components of water. Total alkalinity is determined by titration with a strong standard mineral acid to the successive HCO3- and H2CO3 endpoints indicated electrometrically.

ALS Test Code	Matrix	Test Description	Method Reference**
BR-L-IC-N-WP	Water	Bromide in Water by IC (Low Level)	EPA 300.1 (mod)-LR

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

ALS Test Code	Matrix	Test Description	Method Reference**
C-DOC-HTC-WP	Water	Dissolved Organic Carbon by Combustion	APHA 5310 B-WP

Filtered (0.45 um) sample is acidified and purged to remove inorganic carbon, then injected into a heated reaction chamber where organic carbon is oxidized to CO2 which is then transported in the carrier gas stream and measured via a non-dispersive infrared analyzer.

ALS Test Code	Matrix	Test Description	Method Reference**
C-TOC-HTC-WP	Water	Total Organic Carbon by Combustion	APHA 5310 B-WP

Sample is acidified and purged to remove inorganic carbon, then injected into a heated reaction chamber where organic carbon is oxidized to CO2 which is then transported in the carrier gas stream and measured via a non-dispersive infrared analyzer.

ALS Test Code	Matrix	Test Description	Method Reference**
CL-L-IC-N-WP	Water	Chloride in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

ALS Test Code	Matrix	Test Description	Method Reference**
COLOUR-TRUE-WP	Water	Colour, True	APHA 2120C

True Colour is measured spectrophotometrically by comparison to platinum-cobalt standards using the single wavelength method (450 - 465 nm) after filtration of sample through a 0.45 um filter. Colour measurements can be highly pH dependent, and apply to the pH of the sample as received (at time of testing), without pH adjustment. Concurrent measurement of sample pH is recommended.

ALS Test Code	Matrix	Test Description	Method Reference**
EC-WP	Water	Conductivity	APHA 2510B

Conductivity of an aqueous solution refers to its ability to carry an electric current. Conductance of a solution is measured between two spatially fixed and chemically inert electrodes.

ALS Test Code	Matrix	Test Description	Method Reference**
ETL-LANGELIER-4-WP	Water	Langelier Index 4C	Calculated
ETL-LANGELIER-60-WP	Water	Langelier Index 60C	Calculated
F-IC-N-WP	Water	Fluoride in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

ALS Test Code	Matrix	Test Description	Method Reference**
HARDNESS-CALC-WP	Water	Hardness Calculated	APHA 2340B

Hardness (also known as Total Hardness) is calculated from the sum of Calcium and Magnesium concentrations, expressed in CaCO3 equivalents. Dissolved Calcium and Magnesium concentrations are preferentially used for the hardness calculation.

ALS Test Code	Matrix	Test Description	Method Reference**
IONBALANCE-CALC-WP	Water	Ion Balance Calculation	APHA 1030E

Cation Sum, Anion Sum, and Ion Balance (as % difference) are calculated based on guidance from APHA Standard Methods (1030E Checking Correctness of Analysis). Because all aqueous solutions are electrically neutral, the calculated ion balance (% difference of cations minus anions)

Reference Information

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**

should be near-zero.

Cation and Anion Sums are the total meq/L concentration of major cations and anions. Dissolved species are used where available. Minor ions are included where data is present. Ion Balance (as % difference) cannot be calculated accurately for waters with very low electrical conductivity (EC), and is reported as "Low EC" where EC < 100 uS/cm (umhos/cm). Ion Balance is calculated as:

Ion Balance (%) = [Cation Sum-Anion Sum] / [Cation Sum+Anion Sum]

ALS Test Code	Matrix	Test Description	Method Reference**
MET-T-L-MS-WP	Water	Total Metals by ICP-MS	APHA 3030E/EPA 6020A-TL

This analysis involves preliminary sample treatment by hotblock acid digestion (APHA 3030E). Instrumental analysis is by inductively coupled plasma - mass spectrometry (EPA Method 6020A).

ALS Test Code	Matrix	Test Description	Method Reference**
NH3-COL-WP	Water	Ammonia by colour	APHA 4500 NH3 F

Ammonia in water samples forms indophenol when reacted with hypochlorite and phenol. The intensity is amplified by the addition of sodium nitroprusside and measured colourmetrically.

ALS Test Code	Matrix	Test Description	Method Reference**
NO2-L-IC-N-WP	Water	Nitrite in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

ALS Test Code	Matrix	Test Description	Method Reference**
NO3-L-IC-N-WP	Water	Nitrate in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

ALS Test Code	Matrix	Test Description	Method Reference**
PH-WP	Water	pH	APHA 4500H

The pH of a sample is the determination of the activity of the hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode.

ALS Test Code	Matrix	Test Description	Method Reference**
SO4-IC-N-WP	Water	Sulfate in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

ALS Test Code	Matrix	Test Description	Method Reference**
TC,EC-QT51-WP	Water	Total Coliform and E.coli	APHA 9223B QT51

This analysis is carried out using procedures adapted from APHA Method 9223B "Enzyme Substrate Coliform Test". E. coli and Total Coliform are determined simultaneously. The sample is mixed with a mixture of hydrolyzable substrates and then sealed in a 51-well packet. The packet is incubated at 35.0 – 0.5□C for 18 or 24 hours and then the number of wells exhibiting positive responses are counted. The final results are obtained by comparing the number of positive responses to a probability table.

ALS Test Code	Matrix	Test Description	Method Reference**
TDS-WP	Water	Total Dissolved Solids (TDS)	APHA 2540 SOLIDS C,E

A well-mixed sample is filtered through a glass fiber filter paper. The filtrate is then evaportaed to dryness in a pre-weighed vial and dried at 180 – 2C. The increase in vial weight represents the total dissolved solids.

ALS Test Code	Matrix	Test Description	Method Reference**
TURBIDITY-WP	Water	Turbidity	APHA 2130B (modified)

Turbidity in aqueous matrices is determined by the nephelometric method.

ALS Test Code	Matrix	Test Description	Method Reference**
UV-%TRANS-WP	Water	UV Transmittance (Calculated)	APHA 5910B

Test method is adapted from APHA Method 5910B. A sample is filtered through a 0.45 um polyethersulfone (PES) filter and its UV Absorbance is measured in a quartz cell at 254 nm. UV Transmittance is calculated from the UV Absorbance result and reported as UV Transmittance per cm. The analysis is carried out without pH adjustment.

ALS Test Code	Matrix	Test Description	Method Reference**
VOC+F1-HSMS-WP	Water	VOC plus F1 by GCMS	EPA 8260C / EPA 5021A

In this method samples are analyzed using a headspace autosampler interfaced to a dual column gas chromatograph with MS and Flame Ionization detectors.

ALS Test Code	Matrix	Test Description	Method Reference**
XYLENES-SUM-CALC-WP	Water	Sum of Xylene Isomer Concentrations	CALCULATED RESULT

Total xylenes represents the sum of o-xylene and m&p-xylene.

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
WP	ALS ENVIRONMENTAL - WINNIPEG, MANITOBA, CANADA

Reference Information

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**

Chain of Custody Numbers:

GLOSSARY OF REPORT TERMS

Surrogates are compounds that are similar in behaviour to target analyte(s), but that do not normally occur in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery. In reports that display the D.L. column, laboratory objectives for surrogates are listed there.
mg/kg - milligrams per kilogram based on dry weight of sample
mg/kg wwt - milligrams per kilogram based on wet weight of sample
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight
mg/L - unit of concentration based on volume, parts per million.
< - Less than.
D.L. - The reporting limit.
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
ALK-TITR-WP	Water							
Batch R3576387								
WG2415727-10 DUP		**L1843955-2**						
Alkalinity, Total (as CaCO3)		67.9	69.0		mg/L	1.6	20	20-OCT-16
WG2415727-5 DUP		**L1840362-8**						
Alkalinity, Total (as CaCO3)		44.8	45.3		mg/L	1.1	20	20-OCT-16
WG2415727-4 LCS								
Alkalinity, Total (as CaCO3)			104.4		%		85-115	20-OCT-16
WG2415727-9 LCS								
Alkalinity, Total (as CaCO3)			101.6		%		85-115	20-OCT-16
WG2415727-1 MB								
Alkalinity, Total (as CaCO3)			<1.0		mg/L		1	20-OCT-16
WG2415727-6 MB								
Alkalinity, Total (as CaCO3)			<1.0		mg/L		1	20-OCT-16
BR-L-IC-N-WP	Water							
Batch R3573718								
WG2412088-2 LCS								
Bromide (Br)			101.1		%		85-115	17-OCT-16
WG2412088-1 MB								
Bromide (Br)			<0.010		mg/L		0.01	17-OCT-16
C-DOC-HTC-WP	Water							
Batch R3576334								
WG2415528-3 DUP		**L1840362-6**						
Dissolved Organic Carbon		3.87	3.79		mg/L	2.1	20	20-OCT-16
WG2415528-2 LCS								
Dissolved Organic Carbon			100.6		%		80-120	20-OCT-16
WG2415528-1 MB								
Dissolved Organic Carbon			<0.50		mg/L		0.5	20-OCT-16
WG2415528-4 MS		**L1840362-6**						
Dissolved Organic Carbon			97.5		%		70-130	20-OCT-16
C-TOC-HTC-WP	Water							
Batch R3576337								
WG2415588-3 DUP		**L1842042-1**						
Total Organic Carbon		1.18	1.13		mg/L	4.3	20	20-OCT-16
WG2415588-2 LCS								
Total Organic Carbon			99.4		%		80-120	20-OCT-16
WG2415588-1 MB								
Total Organic Carbon			<0.50		mg/L		0.5	20-OCT-16
WG2415588-4 MS		**L1842042-2**						

ALS Environmental

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
C-TOC-HTC-WP	Water							
Batch R3576337								
WG2415588-4 MS		L1842042-2						
Total Organic Carbon			97.3		%		70-130	20-OCT-16
CL-L-IC-N-WP	Water							
Batch R3573718								
WG2412088-2 LCS								
Chloride (Cl)			100.5		%		90-110	17-OCT-16
WG2412088-1 MB								
Chloride (Cl)			<0.10		mg/L		0.1	17-OCT-16
COLOUR-TRUE-WP	Water							
Batch R3577440								
WG2412093-3 DUP		L1843533-1						
Colour, True		7.5	7.7		CU	3.2	20	17-OCT-16
WG2412093-2 LCS								
Colour, True			102.7		%		85-115	17-OCT-16
WG2412093-1 MB								
Colour, True			<5.0		CU		5	17-OCT-16
EC-WP	Water							
Batch R3576387								
WG2415727-10 DUP		L1843955-2						
Conductivity		750	735		umhos/cm	2.0	10	20-OCT-16
WG2415727-5 DUP		L1840362-8						
Conductivity		963	964		umhos/cm	0.1	10	20-OCT-16
WG2415727-3 LCS								
Conductivity			101.3		%		90-110	20-OCT-16
WG2415727-8 LCS								
Conductivity			99.9		%		90-110	20-OCT-16
WG2415727-1 MB								
Conductivity			<1.0		umhos/cm		1	20-OCT-16
WG2415727-6 MB								
Conductivity			<1.0		umhos/cm		1	20-OCT-16
F-IC-N-WP	Water							
Batch R3573718								
WG2412088-2 LCS								
Fluoride (F)			99.3		%		90-110	17-OCT-16
WG2412088-1 MB								
Fluoride (F)			<0.020		mg/L		0.02	17-OCT-16

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch R3581787								
WG2420093-4 DUP		**WG2420093-3**						
Aluminum (Al)-Total		0.0487	0.0477		mg/L	2.2	20	27-OCT-16
Antimony (Sb)-Total		0.00086	0.00086		mg/L	0.3	20	27-OCT-16
Arsenic (As)-Total		0.00119	0.00117		mg/L	1.6	20	27-OCT-16
Barium (Ba)-Total		0.0114	0.0113		mg/L	0.9	20	27-OCT-16
Beryllium (Be)-Total		<0.00020	<0.00020	RPD-NA	mg/L	N/A	20	27-OCT-16
Bismuth (Bi)-Total		<0.00020	<0.00020	RPD-NA	mg/L	N/A	20	27-OCT-16
Boron (B)-Total		0.280	0.274		mg/L	2.2	20	27-OCT-16
Cadmium (Cd)-Total		0.000025	0.000024		mg/L	7.8	20	27-OCT-16
Calcium (Ca)-Total		95.9	92.5		mg/L	3.6	20	27-OCT-16
Cesium (Cs)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	27-OCT-16
Chromium (Cr)-Total		<0.0010	<0.0010	RPD-NA	mg/L	N/A	20	27-OCT-16
Cobalt (Co)-Total		0.00040	0.00039		mg/L	3.0	20	27-OCT-16
Copper (Cu)-Total		0.00205	0.00205		mg/L	0.0	20	27-OCT-16
Iron (Fe)-Total		0.024	0.027		mg/L	12	20	27-OCT-16
Lead (Pb)-Total		0.000317	0.000285		mg/L	10	20	27-OCT-16
Lithium (Li)-Total		0.0853	0.0821		mg/L	3.8	20	27-OCT-16
Magnesium (Mg)-Total		44.7	44.0		mg/L	1.5	20	27-OCT-16
Manganese (Mn)-Total		0.0278	0.0260		mg/L	6.4	20	27-OCT-16
Molybdenum (Mo)-Total		0.00414	0.00394		mg/L	5.0	20	27-OCT-16
Nickel (Ni)-Total		0.0032	0.0032		mg/L	1.3	20	27-OCT-16
Phosphorus (P)-Total		0.42	0.44		mg/L	3.5	20	27-OCT-16
Potassium (K)-Total		35.6	34.6		mg/L	3.0	20	27-OCT-16
Rubidium (Rb)-Total		0.0215	0.0214		mg/L	0.5	20	27-OCT-16
Selenium (Se)-Total		<0.0010	<0.0010	RPD-NA	mg/L	N/A	20	27-OCT-16
Silicon (Si)-Total		9.39	9.06		mg/L	3.7	20	27-OCT-16
Silver (Ag)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	27-OCT-16
Sodium (Na)-Total		175	168		mg/L	4.0	20	27-OCT-16
Strontium (Sr)-Total		0.257	0.247		mg/L	3.7	20	27-OCT-16
Tellurium (Te)-Total		<0.00020	<0.00020	RPD-NA	mg/L	N/A	20	27-OCT-16
Thallium (Tl)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	27-OCT-16
Thorium (Th)-Total		0.00011	0.00010		mg/L	8.4	20	27-OCT-16
Tin (Sn)-Total		<0.00020	<0.00020	RPD-NA	mg/L	N/A	20	27-OCT-16
Titanium (Ti)-Total		<0.00050	<0.00050		mg/L			27-OCT-16

ALS Environmental

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch R3581787								
WG2420093-4 DUP		**WG2420093-3**						
Titanium (Ti)-Total		<0.00050	<0.00050	RPD-NA	mg/L	N/A	20	27-OCT-16
Tungsten (W)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	27-OCT-16
Uranium (U)-Total		0.00385	0.00366		mg/L	5.0	20	27-OCT-16
Vanadium (V)-Total		0.00082	0.00083		mg/L	1.6	20	27-OCT-16
Zinc (Zn)-Total		0.0246	0.0240		mg/L	2.3	20	27-OCT-16
Zirconium (Zr)-Total		<0.00040	<0.00040	RPD-NA	mg/L	N/A	20	27-OCT-16
WG2420093-2 LCS								
Aluminum (Al)-Total			107.3		%		80-120	27-OCT-16
Antimony (Sb)-Total			98.5		%		80-120	27-OCT-16
Arsenic (As)-Total			98.5		%		80-120	27-OCT-16
Barium (Ba)-Total			104.5		%		80-120	27-OCT-16
Beryllium (Be)-Total			99.8		%		80-120	27-OCT-16
Bismuth (Bi)-Total			98.8		%		80-120	27-OCT-16
Boron (B)-Total			101.2		%		80-120	27-OCT-16
Cadmium (Cd)-Total			96.3		%		80-120	27-OCT-16
Calcium (Ca)-Total			107.0		%		80-120	27-OCT-16
Cesium (Cs)-Total			99.9		%		80-120	27-OCT-16
Chromium (Cr)-Total			103.8		%		80-120	27-OCT-16
Cobalt (Co)-Total			99.6		%		80-120	27-OCT-16
Copper (Cu)-Total			93.6		%		80-120	27-OCT-16
Iron (Fe)-Total			102.3		%		80-120	27-OCT-16
Lead (Pb)-Total			94.4		%		80-120	27-OCT-16
Lithium (Li)-Total			104.6		%		80-120	27-OCT-16
Magnesium (Mg)-Total			106.0		%		80-120	27-OCT-16
Manganese (Mn)-Total			107.9		%		80-120	27-OCT-16
Molybdenum (Mo)-Total			105.3		%		80-120	27-OCT-16
Nickel (Ni)-Total			98.1		%		80-120	27-OCT-16
Phosphorus (P)-Total			101.9		%		80-120	27-OCT-16
Potassium (K)-Total			108.8		%		80-120	27-OCT-16
Rubidium (Rb)-Total			103.7		%		80-120	27-OCT-16
Selenium (Se)-Total			97.8		%		80-120	27-OCT-16
Silicon (Si)-Total			106.0		%		80-120	27-OCT-16
Silver (Ag)-Total			95.7		%		80-120	27-OCT-16

ALS Environmental

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch **R3581787**								
WG2420093-2 **LCS**								
Sodium (Na)-Total			107.9		%		80-120	27-OCT-16
Strontium (Sr)-Total			108.4		%		80-120	27-OCT-16
Tellurium (Te)-Total			97.9		%		80-120	27-OCT-16
Thallium (Tl)-Total			93.3		%		80-120	27-OCT-16
Thorium (Th)-Total			98.9		%		80-120	27-OCT-16
Tin (Sn)-Total			99.2		%		80-120	27-OCT-16
Titanium (Ti)-Total			105.9		%		80-120	27-OCT-16
Tungsten (W)-Total			103.9		%		80-120	27-OCT-16
Uranium (U)-Total			101.5		%		80-120	27-OCT-16
Vanadium (V)-Total			103.1		%		80-120	27-OCT-16
Zinc (Zn)-Total			98.8		%		80-120	27-OCT-16
Zirconium (Zr)-Total			101.8		%		80-120	27-OCT-16
WG2420093-1 **MB**								
Aluminum (Al)-Total			<0.0050		mg/L		0.005	27-OCT-16
Antimony (Sb)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Arsenic (As)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Barium (Ba)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Beryllium (Be)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Bismuth (Bi)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Boron (B)-Total			<0.010		mg/L		0.01	27-OCT-16
Cadmium (Cd)-Total			<0.000010		mg/L		0.00001	27-OCT-16
Calcium (Ca)-Total			<0.10		mg/L		0.1	27-OCT-16
Cesium (Cs)-Total			<0.00010		mg/L		0.0001	27-OCT-16
Chromium (Cr)-Total			<0.0010		mg/L		0.001	27-OCT-16
Cobalt (Co)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Copper (Cu)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Iron (Fe)-Total			<0.010		mg/L		0.01	27-OCT-16
Lead (Pb)-Total			<0.000090		mg/L		0.00009	27-OCT-16
Lithium (Li)-Total			<0.0020		mg/L		0.002	27-OCT-16
Magnesium (Mg)-Total			<0.010		mg/L		0.01	27-OCT-16
Manganese (Mn)-Total			<0.00030		mg/L		0.0003	27-OCT-16
Molybdenum (Mo)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Nickel (Ni)-Total			<0.0020		mg/L		0.002	27-OCT-16
Phosphorus (P)-Total			<0.10		mg/L		0.1	27-OCT-16

ALS Environmental

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch **R3581787**								
WG2420093-1 **MB**								
Potassium (K)-Total			<0.020		mg/L		0.02	27-OCT-16
Rubidium (Rb)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Selenium (Se)-Total			<0.0010		mg/L		0.001	27-OCT-16
Silicon (Si)-Total			<0.10		mg/L		0.1	27-OCT-16
Silver (Ag)-Total			<0.00010		mg/L		0.0001	27-OCT-16
Sodium (Na)-Total			<0.030		mg/L		0.03	27-OCT-16
Strontium (Sr)-Total			<0.00010		mg/L		0.0001	27-OCT-16
Tellurium (Te)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Thallium (Tl)-Total			<0.00010		mg/L		0.0001	27-OCT-16
Thorium (Th)-Total			<0.00010		mg/L		0.0001	27-OCT-16
Tin (Sn)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Titanium (Ti)-Total			<0.00050		mg/L		0.0005	27-OCT-16
Tungsten (W)-Total			<0.00010		mg/L		0.0001	27-OCT-16
Uranium (U)-Total			<0.00010		mg/L		0.0001	27-OCT-16
Vanadium (V)-Total			<0.00020		mg/L		0.0002	27-OCT-16
Zinc (Zn)-Total			<0.0020		mg/L		0.002	27-OCT-16
Zirconium (Zr)-Total			<0.00040		mg/L		0.0004	27-OCT-16
WG2420093-5 **MS**		**WG2420093-3**						
Aluminum (Al)-Total			104.6		%		70-130	27-OCT-16
Antimony (Sb)-Total			95.3		%		70-130	27-OCT-16
Arsenic (As)-Total			94.8		%		70-130	27-OCT-16
Barium (Ba)-Total			98.7		%		70-130	27-OCT-16
Beryllium (Be)-Total			105.5		%		70-130	27-OCT-16
Bismuth (Bi)-Total			87.0		%		70-130	27-OCT-16
Boron (B)-Total			N/A	MS-B	%		-	27-OCT-16
Cadmium (Cd)-Total			89.3		%		70-130	27-OCT-16
Calcium (Ca)-Total			N/A	MS-B	%		-	27-OCT-16
Cesium (Cs)-Total			97.6		%		70-130	27-OCT-16
Chromium (Cr)-Total			100.8		%		70-130	27-OCT-16
Cobalt (Co)-Total			97.1		%		70-130	27-OCT-16
Copper (Cu)-Total			90.1		%		70-130	27-OCT-16
Iron (Fe)-Total			101.4		%		70-130	27-OCT-16
Lead (Pb)-Total			91.9		%		70-130	27-OCT-16
Lithium (Li)-Total			109.4		%		70-130	27-OCT-16

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch R3581787								
WG2420093-5 MS		**WG2420093-3**						
Magnesium (Mg)-Total			N/A	MS-B	%		-	27-OCT-16
Manganese (Mn)-Total			N/A	MS-B	%		-	27-OCT-16
Molybdenum (Mo)-Total			101.2		%		70-130	27-OCT-16
Nickel (Ni)-Total			91.6		%		70-130	27-OCT-16
Phosphorus (P)-Total			105.6		%		70-130	27-OCT-16
Potassium (K)-Total			N/A	MS-B	%		-	27-OCT-16
Rubidium (Rb)-Total			N/A	MS-B	%		-	27-OCT-16
Selenium (Se)-Total			89.0		%		70-130	27-OCT-16
Silicon (Si)-Total			104.4		%		70-130	27-OCT-16
Silver (Ag)-Total			96.2		%		70-130	27-OCT-16
Sodium (Na)-Total			N/A	MS-B	%		-	27-OCT-16
Strontium (Sr)-Total			N/A	MS-B	%		-	27-OCT-16
Tellurium (Te)-Total			85.7		%		70-130	27-OCT-16
Thallium (Tl)-Total			91.8		%		70-130	27-OCT-16
Tin (Sn)-Total			98.8		%		70-130	27-OCT-16
Titanium (Ti)-Total			104.5		%		70-130	27-OCT-16
Tungsten (W)-Total			102.1		%		70-130	27-OCT-16
Uranium (U)-Total			95.4		%		70-130	27-OCT-16
Vanadium (V)-Total			105.4		%		70-130	27-OCT-16
Zinc (Zn)-Total			80.9		%		70-130	27-OCT-16
Zirconium (Zr)-Total			104.2		%		70-130	27-OCT-16
NH3-COL-WP	Water							
Batch R3579014								
WG2417588-7 DUP		**L1843960-3**						
Ammonia, Total (as N)		0.043	0.043		mg/L	2.0	20	24-OCT-16
WG2417588-6 LCS								
Ammonia, Total (as N)			100.7		%		85-115	24-OCT-16
WG2417588-5 MB								
Ammonia, Total (as N)			<0.010		mg/L		0.01	24-OCT-16
WG2417588-8 MS		**L1843960-3**						
Ammonia, Total (as N)			106.8		%		75-125	24-OCT-16
NO2-L-IC-N-WP	Water							

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
NO2-L-IC-N-WP	Water							
Batch R3573718								
WG2412088-2 LCS								
Nitrite (as N)			100.8		%		90-110	17-OCT-16
WG2412088-1 MB								
Nitrite (as N)			<0.0010		mg/L		0.001	17-OCT-16
NO3-L-IC-N-WP	Water							
Batch R3573718								
WG2412088-2 LCS								
Nitrate (as N)			100.2		%		90-110	17-OCT-16
WG2412088-1 MB								
Nitrate (as N)			<0.0050		mg/L		0.005	17-OCT-16
PH-WP	Water							
Batch R3576387								
WG2415727-10 DUP		**L1843955-2**						
pH		7.60	7.51	J	pH units	0.09	0.2	20-OCT-16
WG2415727-5 DUP		**L1840362-8**						
pH		7.52	7.49	J	pH units	0.03	0.2	20-OCT-16
WG2415727-2 LCS								
pH			7.41		pH units		7.3-7.5	20-OCT-16
WG2415727-7 LCS								
pH			7.40		pH units		7.3-7.5	20-OCT-16
SO4-IC-N-WP	Water							
Batch R3573718								
WG2412088-2 LCS								
Sulfate (SO4)			99.9		%		90-110	17-OCT-16
WG2412088-1 MB								
Sulfate (SO4)			<0.30		mg/L		0.3	17-OCT-16
TC,EC-QT51-WP	Water							
Batch R3572813								
WG2412027-1 MB								
Total Coliforms			0		MPN/100mL		1	15-OCT-16
Escherichia Coli			0		MPN/100mL		1	15-OCT-16
TDS-WP	Water							
Batch R3579091								
WG2415638-3 DUP		**L1843955-1**						
Total Dissolved Solids		490	485		mg/L	1.0	20	21-OCT-16
WG2415638-2 LCS								
Total Dissolved Solids			97.8		%		85-115	21-OCT-16

ALS Environmental

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
TDS-WP	Water							
Batch R3579091								
WG2415638-1 MB								
Total Dissolved Solids			<10		mg/L		10	21-OCT-16
TURBIDITY-WP	Water							
Batch R3576677								
WG2416018-2 DUP		**L1843274-1**						
Turbidity		451	449		NTU	0.4	15	20-OCT-16
WG2416018-3 LCS								
Turbidity			101.0		%		85-115	20-OCT-16
WG2416018-1 MB								
Turbidity			<0.10		NTU		0.1	20-OCT-16
UV-%TRANS-WP	Water							
Batch R3578369								
WG2415207-3 DUP		**L1843530-1**						
Transmittance, UV (254 nm)		96.8	96.6		%T/cm	0.2	20	20-OCT-16
WG2415207-6 IRM		**BLANK**						
Transmittance, UV (254 nm)			100.0		%		99.5-100.5	20-OCT-16
WG2415207-2 LCS								
Transmittance, UV (254 nm)			105.4		%		85-115	20-OCT-16
VOC+F1-HSMS-WP	Water							
Batch R3581422								
WG2420272-3 DUP		**L1846670-1**						
Benzene		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
1,1-dichloroethene		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
Dichloromethane		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
Ethylbenzene		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
MTBE		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
Tetrachloroethene		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
Toluene		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
Trichloroethene		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
M+P-Xylenes		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
o-Xylene		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	24-OCT-16
WG2420272-2 LCS								
Benzene			113.3		%		70-130	24-OCT-16
1,1-dichloroethene			109.6		%		70-130	24-OCT-16
Dichloromethane			114.0		%		70-130	24-OCT-16

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC+F1-HSMS-WP	Water							
Batch R3581422								
WG2420272-2 LCS								
Ethylbenzene			119.1		%		70-130	24-OCT-16
MTBE			120.2		%		70-130	24-OCT-16
Tetrachloroethene			109.3		%		70-130	24-OCT-16
Toluene			114.3		%		70-130	24-OCT-16
Trichloroethene			114.2		%		70-130	24-OCT-16
M+P-Xylenes			123.5		%		70-130	24-OCT-16
o-Xylene			117.2		%		70-130	24-OCT-16
WG2420272-1 MB								
Benzene			<0.00050		mg/L		0.0005	24-OCT-16
1,1-dichloroethene			<0.00050		mg/L		0.0005	24-OCT-16
Dichloromethane			<0.00050		mg/L		0.0005	24-OCT-16
Ethylbenzene			<0.00050		mg/L		0.0005	24-OCT-16
MTBE			<0.00050		mg/L		0.0005	24-OCT-16
Tetrachloroethene			<0.00050		mg/L		0.0005	24-OCT-16
Toluene			<0.00050		mg/L		0.0005	24-OCT-16
Trichloroethene			<0.00050		mg/L		0.0005	24-OCT-16
M+P-Xylenes			<0.00050		mg/L		0.0005	24-OCT-16
o-Xylene			<0.00050		mg/L		0.0005	24-OCT-16
Surrogate: 4-Bromofluorobenzene (SS)			95.5		%		70-130	24-OCT-16
Surrogate: 1,4-Difluorobenzene (SS)			100.5		%		70-130	24-OCT-16

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Legend:

Limit ALS Control Limit (Data Quality Objectives)
DUP Duplicate
RPD Relative Percent Difference
N/A Not Available
LCS Laboratory Control Sample
SRM Standard Reference Material
MS Matrix Spike
MSD Matrix Spike Duplicate
ADE Average Desorption Efficiency
MB Method Blank
IRM Internal Reference Material
CRM Certified Reference Material
CCV Continuing Calibration Verification
CVS Calibration Verification Standard
LCSD Laboratory Control Sample Duplicate

Sample Parameter Qualifier Definitions:

Qualifier	Description
J	Duplicate results and limits are expressed in terms of absolute difference.
MS-B	Matrix Spike recovery could not be accurately calculated due to high analyte background in sample.
RPD-NA	Relative Percent Difference Not Available due to result(s) being less than detection limit.

Quality Control Report

Workorder: L1843955 Report Date: 31-OCT-16

Client: City of Brandon - Water Treatment Plant
108 - 26th Street North
Brandon MB R7B 1J6

Contact:

Hold Time Exceedances:

ALS Product Description	Sample ID	Sampling Date	Date Processed	Rec. HT	Actual HT	Units	Qualifier
Physical Tests							
Turbidity							
	1	14-OCT-16	20-OCT-16 15:00	48	147	hours	EHT
	2	14-OCT-16	20-OCT-16 15:00	48	147	hours	EHT
UV Transmittance (Calculated)							
	1	14-OCT-16	20-OCT-16 08:00	3	6	days	EHT
	2	14-OCT-16	20-OCT-16 08:00	3	6	days	EHT
pH							
	1	14-OCT-16	20-OCT-16 13:54	0.25	146	hours	EHTR-FM
	2	14-OCT-16	20-OCT-16 13:54	0.25	146	hours	EHTR-FM
Anions and Nutrients							
Colour, True							
	1	14-OCT-16	17-OCT-16 13:23	48	73	hours	EHT
	2	14-OCT-16	17-OCT-16 13:23	48	73	hours	EHT
Nitrate in Water by IC (Low Level)							
	1	14-OCT-16	17-OCT-16 12:00	48	72	hours	EHT
	2	14-OCT-16	17-OCT-16 12:00	48	72	hours	EHT
Nitrite in Water by IC (Low Level)							
	1	14-OCT-16	17-OCT-16 12:00	48	72	hours	EHT
	2	14-OCT-16	17-OCT-16 12:00	48	72	hours	EHT

Legend & Qualifier Definitions:

EHTR-FM:	Exceeded ALS recommended hold time prior to sample receipt. Field Measurement recommended.
EHTR:	Exceeded ALS recommended hold time prior to sample receipt.
EHTL:	Exceeded ALS recommended hold time prior to analysis. Sample was received less than 24 hours prior to expiry.
EHT:	Exceeded ALS recommended hold time prior to analysis.
Rec. HT:	ALS recommended hold time (see units).

Notes*:
Where actual sampling date is not provided to ALS, the date (& time) of receipt is used for calculation purposes.
Where actual sampling time is not provided to ALS, the earlier of 12 noon on the sampling date or the time (& date) of receipt is used for calculation purposes. Samples for L1843955 were received on 15-OCT-16 11:45.

ALS recommended hold times may vary by province. They are assigned to meet known provincial and/or federal government requirements. In the absence of regulatory hold times, ALS establishes recommendations based on guidelines published by the US EPA, APHA Standard Methods, or Environment Canada (where available). For more information, please contact ALS.

The ALS Quality Control Report is provided to ALS clients upon request. ALS includes comprehensive QC checks with every analysis to ensure our high standards of quality are met. Each QC result has a known or expected target value, which is compared against pre-determined data quality objectives to provide confidence in the accuracy of associated test results.

Please note that this report may contain QC results from anonymous Sample Duplicates and Matrix Spikes that do not originate from this Work Order.

ALS Laboratory Group
ANALYTICAL CHEMISTRY & TESTING SERVICES

Environmental Division

Ship to: Unit 12- 1329 Nia

L1843955-COFC

CHAIN OF CUSTODY/ANALYTICAL REQUEST FORM

City of Brandon
108-26TH Street North, Brandon Manitoba, R7B 1J6

Service Requested: Regular _X_ Priority _____ Emergency _____

Customer Number: W460 ________________________

Sample ID	Watertrax Code	Date/Time Sampled	Sample Type	MB-CH-PWS-WP	MB-VOC-PWS-WP	Benzene	Trichloroethylene	Tetrachloroethylene	TC & EC
Lab Tap	16465,292F9	Oct 14, 2016	water						
Civic Works	16465,293D2	Oct 14, 2016	water						

CLIENT INFORMATION:

FOR LABORATORY USE ONLY:
SAMPLE CONDITION UPON RECEIPT: FROZEN _____ COLD _____ AMBIENT
ACCEPTABLE _____ NON ACCEPTABLE _____
OTHER (BREAKAGE, LEAKAGE, ETC.):

NOTES AND CONDITIONS: 1. Hazardous samples must be labelled to comply with WHMIS regulations.
2. ETL's liability limited to cost of analysis. 3. Failure to complete all portions of this form may delay analysis.

Relinquished By:	Date: Time:	Received By: ETL Lab:	Date: Time:
Relinquished By:	Date: Time:	Received By: ETL Lab:	Date: Time:

APPENDIX F

VIRDEN WATER ANALYSIS POST TREATMENT

Town of Virden - Water Plant

Virden - PWS
PO Box 310
Virden MB R0M 2C0

Date Received: 03-NOV-16
Report Date: 15-NOV-16 08:04 (MT)
Version: FINAL

Certificate of Analysis

Lab Work Order #: L1852803

Project P.O. #:

Job Reference:

C of C Numbers:

Legal Site Desc:

ALS Environmental

ANALYTICAL REPORT

Physical Tests (WATER)

			ALS ID	L1852803-1	L1852803-2
			Sampled Date	02-NOV-16	02-NOV-16
			Sampled Time	11:50	11:40
			Sample ID	**VIRDEN 1 - RAW**	**VIRDEN 2 - TREATED**
Analyte	Unit	Guide Limit #1	Guide Limit #2		
Colour, True	CU	15	-	36.5	<5.0
Conductivity	umhos/cm	-	-	1520	73.1
Hardness (as CaCO3)	mg/L	-	-	40.3 HTC	0.58 HTC
Langelier Index (4 C)	No Unit	-	-	0.42	-3.8
Langelier Index (60 C)	No Unit	-	-	1.2	-3.1
pH	pH units	6.5-8.5	-	8.45	7.18
Total Dissolved Solids	mg/L	500	-	960	46
Transmittance, UV (254 nm)	%T/cm	-	-	41.1	97.9
Turbidity	NTU	-	-	0.46	0.14

Federal Guidelines for Canadian Drinking Water Quality (MAR, 2015)
#1: GCDWQ - Aesthetic Objective
#2: GCDWQ - Maximum Acceptable Concentrations (MACs)

Anions and Nutrients (WATER)

			ALS ID	L1852803-1	L1852803-2
			Sampled Date	02-NOV-16	02-NOV-16
			Sampled Time	11:50	11:40
			Sample ID	**VIRDEN 1 - RAW**	**VIRDEN 2 - TREATED**
Analyte	Unit	Guide Limit #1	Guide Limit #2		
Alkalinity, Total (as CaCO3)	mg/L	-	-	522	16.1
Ammonia, Total (as N)	mg/L	-	-	1.57	0.011
Bicarbonate (HCO3)	mg/L	-	-	637	19.6
Bromide (Br)	mg/L	-	-	<0.50 DLM	<0.10
Carbonate (CO3)	mg/L	-	-	<0.60	<0.60
Chloride (Cl)	mg/L	250	-	179	10.0
Fluoride (F)	mg/L	-	1.5	0.54	<0.020
Hydroxide (OH)	mg/L	-	-	<0.34	<0.34
Nitrate (as N)	mg/L	-	10	<0.025 DLM	<0.0050
Nitrite (as N)	mg/L	-	1	0.0064 DLM	<0.0010
Sulfate (SO4)	mg/L	500	-	36.4	1.50

Federal Guidelines for Canadian Drinking Water Quality (MAR, 2015)
#1: GCDWQ - Aesthetic Objective
#2: GCDWQ - Maximum Acceptable Concentrations (MACs)

Organic / Inorganic Carbon (WATER)

			ALS ID	L1852803-1	L1852803-2
			Sampled Date	02-NOV-16	02-NOV-16
			Sampled Time	11:50	11:40
			Sample ID	**VIRDEN 1 - RAW**	**VIRDEN 2 - TREATED**
Analyte	Unit	Guide Limit #1	Guide Limit #2		
Dissolved Organic Carbon	mg/L	-	-	12.8	0.56
Total Organic Carbon	mg/L	-	-	10.9	0.57

Federal Guidelines for Canadian Drinking Water Quality (MAR, 2015)
#1: GCDWQ - Aesthetic Objective
#2: GCDWQ - Maximum Acceptable Concentrations (MACs)

(Yellow) Detection Limit for result exceeds Guide Limit. Assessment against Guide Limit cannot be made.
(Pink) Analytical result for this parameter exceeds Guide Limit listed on this report.
* Please refer to the Reference Information section for an explanation of any qualifiers noted.

ALS Environmental

ANALYTICAL REPORT

Total Metals (WATER)

Analyte	Unit	Guide Limit #1	Guide Limit #2	L1852803-1	L1852803-2
			Sampled Date	02-NOV-16	02-NOV-16
			Sampled Time	11:50	11:40
			Sample ID	VIRDEN 1 - RAW	VIRDEN 2 - TREATED
Aluminum (Al)-Total	mg/L	0.1	-	<0.0050	<0.0050
Antimony (Sb)-Total	mg/L	-	0.006	<0.00020	<0.00020
Arsenic (As)-Total	mg/L	-	0.01	0.0422	0.00475
Barium (Ba)-Total	mg/L	-	1	0.197	0.00050
Beryllium (Be)-Total	mg/L	-	-	<0.00020	<0.00020
Bismuth (Bi)-Total	mg/L	-	-	<0.00020	<0.00020
Boron (B)-Total	mg/L	-	5	0.773	0.675
Cadmium (Cd)-Total	mg/L	-	0.005	<0.000010	<0.000010
Calcium (Ca)-Total	mg/L	-	-	10.1	0.20
Cesium (Cs)-Total	mg/L	-	-	<0.00010	<0.00010
Chromium (Cr)-Total	mg/L	-	0.05	<0.0010	<0.0010
Cobalt (Co)-Total	mg/L	-	-	0.00022	<0.00020
Copper (Cu)-Total	mg/L	1	-	0.00413	0.00032
Iron (Fe)-Total	mg/L	0.3	-	0.396	0.079
Lead (Pb)-Total	mg/L	-	0.01	0.000418	<0.000090
Lithium (Li)-Total	mg/L	-	-	0.0519	<0.0020
Magnesium (Mg)-Total	mg/L	-	-	3.64	0.017
Manganese (Mn)-Total	mg/L	0.05	-	0.0266	0.00151
Molybdenum (Mo)-Total	mg/L	-	-	0.0111	<0.00020
Nickel (Ni)-Total	mg/L	-	-	<0.0020	<0.0020
Phosphorus (P)-Total	mg/L	-	-	1.48	0.80
Potassium (K)-Total	mg/L	-	-	4.13	0.104
Rubidium (Rb)-Total	mg/L	-	-	0.00123	<0.00020
Selenium (Se)-Total	mg/L	-	0.05	<0.0010	<0.0010
Silicon (Si)-Total	mg/L	-	-	13.0	0.78
Silver (Ag)-Total	mg/L	-	-	<0.00010	<0.00010
Sodium (Na)-Total	mg/L	200	-	366	14.4
Strontium (Sr)-Total	mg/L	-	-	0.150	0.00065
Tellurium (Te)-Total	mg/L	-	-	<0.00020	<0.00020
Thallium (Tl)-Total	mg/L	-	-	<0.00010	<0.00010
Thorium (Th)-Total	mg/L	-	-	<0.00010	<0.00010
Tin (Sn)-Total	mg/L	-	-	<0.00020	<0.00020
Titanium (Ti)-Total	mg/L	-	-	0.00064	<0.00050

Federal Guidelines for Canadian Drinking Water Quality (MAR, 2015)
#1: GCDWQ - Aesthetic Objective
#2: GCDWQ - Maximum Acceptable Concentrations (MACs)

Detection Limit for result exceeds Guide Limit. Assessment against Guide Limit cannot be made.
Analytical result for this parameter exceeds Guide Limit listed on this report.
* Please refer to the Reference Information section for an explanation of any qualifiers noted.

ALS Environmental

ANALYTICAL REPORT

Total Metals (WATER)

			ALS ID	L1852803-1	L1852803-2
			Sampled Date	02-NOV-16	02-NOV-16
			Sampled Time	11:50	11:40
			Sample ID	**VIRDEN 1 - RAW**	**VIRDEN 2 - TREATED**
Analyte	Unit	Guide Limit #1	Guide Limit #2		
Tungsten (W)-Total	mg/L	-	-	0.00021	<0.00010
Uranium (U)-Total	mg/L	-	0.02	<0.00010	<0.00010
Vanadium (V)-Total	mg/L	-	-	0.00028	<0.00020
Zinc (Zn)-Total	mg/L	5	-	0.0390	0.660
Zirconium (Zr)-Total	mg/L	-	-	<0.00040	<0.00040

Federal Guidelines for Canadian Drinking Water Quality (MAR, 2015)
#1: GCDWQ - Aesthetic Objective
#2: GCDWQ - Maximum Acceptable Concentrations (MACs)

Detection Limit for result exceeds Guide Limit. Assessment against Guide Limit cannot be made.
Analytical result for this parameter exceeds Guide Limit listed on this report.
* Please refer to the Reference Information section for an explanation of any qualifiers noted.

Reference Information

Qualifiers for Individual Parameters Listed:

Qualifier	Description
HTC	Hardness was calculated from Total Ca and/or Mg concentrations and may be biased high (dissolved Ca/Mg results unavailable).
DLM	Detection Limit Adjusted due to sample matrix effects (e.g. chemical interference, colour, turbidity).

Methods Listed (if applicable):

ALS Test Code	Matrix	Test Description	Method Reference**
ALK-CO3CO3-CALC-WP	Water	Alkalinity, Carbonate	CALCULATION

The Alkalinity of water is a measure of its acid neutralizing capacity.Alkalinity is imparted by bicarbonate, carbonate and hydroxide components of water. The fraction of alkalinity contributed by carbonate is calculated and reported as mg CO3 2-/L.

ALK-HCO3HCO3-CALC-WP	Water	Alkalinity, Bicarbonate	CALCULATION

The Alkalinity of water is a measure of its acid neutralizing capacity.Alkalinity is imparted by bicarbonate, carbonate and hydroxide components of water. The fraction of alkalinity contributed by bicarbonate is calculated and reported as mg HCO3-/L

ALK-OHOH-CALC-WP	Water	Alkalinity, Hydroxide	CALCULATION

The Alkalinity of water is a measure of its acid neutralizing capacity.Alkalinity is imparted by bicarbonate, carbonate and hydroxide components of water. The fraction of alkalinity contributed by hydroxide is calculated and reported as mg OH-/L.

ALK-TITR-WP	Water	Alkalinity, Total (as CaCO3)	APHA 2320B

The Alkalinity of water is a measure of its acid neutralizing capacity. Alkalinity is imparted by bicarbonate, carbonate and hydroxide components of water. Total alkalinity is determined by titration with a strong standard mineral acid to the successive HCO3- and H2CO3 endpoints indicated electrometrically.

BR-IC-N-WP	Water	Bromide in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

C-DOC-HTC-WP	Water	Dissolved Organic Carbon by Combustion	APHA 5310 B-WP

Filtered (0.45 um) sample is acidified and purged to remove inorganic carbon, then injected into a heated reaction chamber where organic carbon is oxidized to CO2 which is then transported in the carrier gas stream and measured via a non-dispersive infrared analyzer.

C-TOC-HTC-WP	Water	Total Organic Carbon by Combustion	APHA 5310 B-WP

Sample is acidified and purged to remove inorganic carbon, then injected into a heated reaction chamber where organic carbon is oxidized to CO2 which is then transported in the carrier gas stream and measured via a non-dispersive infrared analyzer.

CL-L-IC-N-WP	Water	Chloride in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

COLOUR-TRUE-WP	Water	Colour, True	APHA 2120C

True Colour is measured spectrophotometrically by comparison to platinum-cobalt standards using the single wavelength method (450 - 465 nm) after filtration of sample through a 0.45 um filter. Colour measurements can be highly pH dependent, and apply to the pH of the sample as received (at time of testing), without pH adjustment. Concurrent measurement of sample pH is recommended.

EC-WP	Water	Conductivity	APHA 2510B

Conductivity of an aqueous solution refers to its ability to carry an electric current. Conductance of a solution is measured between two spatially fixed and chemically inert electrodes.

ETL-LANGELIER-4-WP	Water	Langelier Index 4C	Calculated
ETL-LANGELIER-60-WP	Water	Langelier Index 60C	Calculated
F-IC-N-WP	Water	Fluoride in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

HARDNESS-CALC-WP	Water	Hardness Calculated	APHA 2340B

Hardness (also known as Total Hardness) is calculated from the sum of Calcium and Magnesium concentrations, expressed in CaCO3 equivalents. Dissolved Calcium and Magnesium concentrations are preferentially used for the hardness calculation.

IONBALANCE-CALC-WP	Water	Ion Balance Calculation	APHA 1030E

Cation Sum, Anion Sum, and Ion Balance (as % difference) are calculated based on guidance from APHA Standard Methods (1030E Checking

Reference Information

Methods Listed (if applicable):

ALS Test Code	Matrix	Test Description	Method Reference**

Correctness of Analysis). Because all aqueous solutions are electrically neutral, the calculated ion balance (% difference of cations minus anions) should be near-zero.

Cation and Anion Sums are the total meq/L concentration of major cations and anions. Dissolved species are used where available. Minor ions are included where data is present. Ion Balance (as % difference) cannot be calculated accurately for waters with very low electrical conductivity (EC), and is reported as "Low EC" where EC < 100 uS/cm (umhos/cm). Ion Balance is calculated as:

Ion Balance (%) = [Cation Sum-Anion Sum] / [Cation Sum+Anion Sum]

MET-T-L-MS-WP	Water	Total Metals by ICP-MS	APHA 3030E/EPA 6020A-TL

This analysis involves preliminary sample treatment by hotblock acid digestion (APHA 3030E). Instrumental analysis is by inductively coupled plasma - mass spectrometry (EPA Method 6020A).

NH3-COL-WP	Water	Ammonia by colour	APHA 4500 NH3 F

Ammonia in water samples forms indophenol when reacted with hypochlorite and phenol. The intensity is amplified by the addition of sodium nitroprusside and measured colourmetrically.

NO2-L-IC-N-WP	Water	Nitrite in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

NO3-L-IC-N-WP	Water	Nitrate in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

PH-WP	Water	pH	APHA 4500H

The pH of a sample is the determination of the activity of the hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode.

SO4-IC-N-WP	Water	Sulfate in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

TDS-WP	Water	Total Dissolved Solids (TDS)	APHA 2540 SOLIDS C,E

A well-mixed sample is filtered through a glass fiber filter paper. The filtrate is then evaportaed to dryness in a pre-weighed vial and dried at 180 – 2C. The increase in vial weight represents the total dissolved solids.

TURBIDITY-WP	Water	Turbidity	APHA 2130B (modified)

Turbidity in aqueous matrices is determined by the nephelometric method.

UV-%TRANS-WP	Water	UV Transmittance (Calculated)	APHA 5910B

Test method is adapted from APHA Method 5910B. A sample is filtered through a 0.45 um polyethersulfone (PES) filter and its UV Absorbance is measured in a quartz cell at 254 nm. UV Transmittance is calculated from the UV Absorbance result and reported as UV Transmittance per cm. The analysis is carried out without pH adjustment.

**ALS test methods may incorporate modifications from specified reference methods to improve performance.

Chain of Custody Numbers:

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
WP	ALS ENVIRONMENTAL - WINNIPEG, MANITOBA, CANADA

Reference Information

GLOSSARY OF REPORT TERMS

Surrogates are compounds that are similar in behaviour to target analyte(s), but that do not normally occur in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery. In reports that display the D.L. column, laboratory objectives for surrogates are listed there.
mg/kg - milligrams per kilogram based on dry weight of sample
mg/kg wwt - milligrams per kilogram based on wet weight of sample
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight
mg/L - unit of concentration based on volume, parts per million.
< - Less than.
D.L. - The reporting limit.
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

Application of guidelines is provided "as is" without warranty of any kind, either expressed or implied, including, but not limited to fitness for a particular purpose, or non-infringement. ALS assumes no responsibility for errors or omissions in the information.

ALS Environmental

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
ALK-TITR-WP	Water							
Batch R3589373								
WG2427503-5 DUP		**L1852796-1**						
Alkalinity, Total (as CaCO3)		23.1	22.4		mg/L	3.1	20	04-NOV-16
WG2427503-4 LCS								
Alkalinity, Total (as CaCO3)			96.7		%		85-115	04-NOV-16
WG2427503-1 MB								
Alkalinity, Total (as CaCO3)			<1.0		mg/L		1	04-NOV-16
BR-IC-N-WP	Water							
Batch R3590363								
WG2426713-2 LCS								
Bromide (Br)			106.5		%		85-115	04-NOV-16
WG2426713-1 MB								
Bromide (Br)			<0.10		mg/L		0.1	04-NOV-16
C-DOC-HTC-WP	Water							
Batch R3594394								
WG2431769-3 DUP		**L1852055-1**						
Dissolved Organic Carbon		2.41	2.38		mg/L	1.3	20	13-NOV-16
WG2431769-2 LCS								
Dissolved Organic Carbon			100.8		%		80-120	13-NOV-16
WG2431769-1 MB								
Dissolved Organic Carbon			<0.50		mg/L		0.5	13-NOV-16
WG2431769-4 MS		**L1852055-2**						
Dissolved Organic Carbon			111.7		%		70-130	13-NOV-16
Batch R3595019								
WG2432587-3 DUP		**L1852803-2**						
Dissolved Organic Carbon		0.56	<0.50	RPD-NA	mg/L	N/A	20	14-NOV-16
WG2432587-2 LCS								
Dissolved Organic Carbon			103.3		%		80-120	14-NOV-16
WG2432587-1 MB								
Dissolved Organic Carbon			<0.50		mg/L		0.5	14-NOV-16
WG2432587-4 MS		**L1852853-3**						
Dissolved Organic Carbon			107.0		%		70-130	14-NOV-16
C-TOC-HTC-WP	Water							
Batch R3594390								
WG2431776-3 DUP		**L1852055-1**						
Total Organic Carbon		2.39	2.26		mg/L	5.6	20	13-NOV-16
WG2431776-2 LCS								
Total Organic Carbon			100.8		%		80-120	13-NOV-16

ALS Environmental

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
C-TOC-HTC-WP	Water							
Batch R3594390								
WG2431776-1 MB								
Total Organic Carbon			<0.50		mg/L		0.5	13-NOV-16
WG2431776-4 MS		**L1852055-2**						
Total Organic Carbon			110.5		%		70-130	13-NOV-16
Batch R3595013								
WG2432602-3 DUP		**L1852803-2**						
Total Organic Carbon		0.57	<0.50	RPD-NA	mg/L	N/A	20	14-NOV-16
WG2432602-2 LCS								
Total Organic Carbon			102.3		%		80-120	14-NOV-16
WG2432602-1 MB								
Total Organic Carbon			<0.50		mg/L		0.5	14-NOV-16
WG2432602-4 MS		**L1852853-3**						
Total Organic Carbon			107.0		%		70-130	14-NOV-16
CL-L-IC-N-WP	Water							
Batch R3590363								
WG2426713-2 LCS								
Chloride (Cl)			100.5		%		90-110	04-NOV-16
WG2426713-1 MB								
Chloride (Cl)			<0.10		mg/L		0.1	04-NOV-16
COLOUR-TRUE-WP	Water							
Batch R3587943								
WG2426456-3 DUP		**L1851493-1**						
Colour, True		32.3	31.9		CU	1.2	20	03-NOV-16
WG2426456-2 LCS								
Colour, True			99.8		%		85-115	03-NOV-16
WG2426456-1 MB								
Colour, True			<5.0		CU		5	03-NOV-16
EC-WP	Water							
Batch R3589373								
WG2427503-5 DUP		**L1852796-1**						
Conductivity		58.0	57.2		umhos/cm	1.4	10	04-NOV-16
WG2427503-3 LCS								
Conductivity			102.1		%		90-110	04-NOV-16
WG2427503-1 MB								
Conductivity			<1.0		umhos/cm		1	04-NOV-16
F-IC-N-WP	Water							

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
F-IC-N-WP	Water							
Batch R3590363								
WG2426713-3 DUP		**L1851665-1**						
Fluoride (F)		0.681	0.679		mg/L	0.3	20	04-NOV-16
WG2426713-2 LCS								
Fluoride (F)			99.6		%		90-110	04-NOV-16
WG2426713-1 MB								
Fluoride (F)			<0.020		mg/L		0.02	04-NOV-16
WG2426713-4 MS		**L1851665-1**						
Fluoride (F)			113.7		%		75-125	04-NOV-16
MET-T-L-MS-WP	Water							
Batch R3590217								
WG2427744-4 DUP		**WG2427744-3**						
Aluminum (Al)-Total		0.213	0.174		mg/L	20	20	07-NOV-16
Arsenic (As)-Total		0.00299	0.00301		mg/L	0.6	20	07-NOV-16
Barium (Ba)-Total		0.0542	0.0529		mg/L	2.3	20	07-NOV-16
Beryllium (Be)-Total		<0.00020	<0.00020	RPD-NA	mg/L	N/A	20	07-NOV-16
Bismuth (Bi)-Total		<0.00020	<0.00020	RPD-NA	mg/L	N/A	20	07-NOV-16
Boron (B)-Total		0.058	0.057		mg/L	1.4	20	07-NOV-16
Cadmium (Cd)-Total		0.000050	0.000046		mg/L	10	20	07-NOV-16
Calcium (Ca)-Total		77.5	77.8		mg/L	0.3	20	07-NOV-16
Cesium (Cs)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	07-NOV-16
Chromium (Cr)-Total		<0.0010	<0.0010	RPD-NA	mg/L	N/A	20	07-NOV-16
Cobalt (Co)-Total		0.00033	0.00033		mg/L	1.2	20	07-NOV-16
Copper (Cu)-Total		0.00446	0.00441		mg/L	1.1	20	07-NOV-16
Iron (Fe)-Total		0.341	0.321		mg/L	6.1	20	07-NOV-16
Lead (Pb)-Total		0.000189	0.000186		mg/L	1.6	20	07-NOV-16
Lithium (Li)-Total		0.0413	0.0398		mg/L	3.6	20	07-NOV-16
Magnesium (Mg)-Total		43.5	43.5		mg/L	0.0	20	07-NOV-16
Manganese (Mn)-Total		0.0886	0.0882		mg/L	0.4	20	07-NOV-16
Molybdenum (Mo)-Total		0.00234	0.00234		mg/L	0.2	20	07-NOV-16
Nickel (Ni)-Total		0.0024	0.0024		mg/L	1.2	20	07-NOV-16
Phosphorus (P)-Total		0.11	0.13		mg/L	16	20	07-NOV-16
Potassium (K)-Total		11.3	11.3		mg/L	0.1	20	07-NOV-16
Rubidium (Rb)-Total		0.00216	0.00214		mg/L	0.7	20	07-NOV-16
Selenium (Se)-Total		<0.0010	<0.0010	RPD-NA	mg/L	N/A	20	07-NOV-16
Silicon (Si)-Total		5.18	5.04		mg/L	2.8	20	07-NOV-16

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch **R3590217**								
WG2427744-4 DUP		**WG2427744-3**						
Silver (Ag)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	07-NOV-16
Sodium (Na)-Total		22.7	22.4		mg/L	1.3	20	07-NOV-16
Strontium (Sr)-Total		0.262	0.259		mg/L	1.2	20	07-NOV-16
Tellurium (Te)-Total		<0.00020	<0.00020	RPD-NA	mg/L	N/A	20	07-NOV-16
Thallium (Tl)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	07-NOV-16
Thorium (Th)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	07-NOV-16
Tin (Sn)-Total		<0.00020	<0.00020	RPD-NA	mg/L	N/A	20	07-NOV-16
Titanium (Ti)-Total		0.00717	0.00579	DUP-H	mg/L	21	20	07-NOV-16
Tungsten (W)-Total		<0.00010	<0.00010	RPD-NA	mg/L	N/A	20	07-NOV-16
Uranium (U)-Total		0.00626	0.00642		mg/L	2.5	20	07-NOV-16
Vanadium (V)-Total		0.00209	0.00193		mg/L	7.9	20	07-NOV-16
Zinc (Zn)-Total		0.0026	0.0031		mg/L	17	20	07-NOV-16
Zirconium (Zr)-Total		0.00049	0.00046		mg/L	6.3	20	07-NOV-16
WG2427744-2 LCS								
Aluminum (Al)-Total			102.5		%		80-120	07-NOV-16
Antimony (Sb)-Total			96.6		%		80-120	07-NOV-16
Arsenic (As)-Total			98.8		%		80-120	07-NOV-16
Barium (Ba)-Total			105.0		%		80-120	07-NOV-16
Beryllium (Be)-Total			104.2		%		80-120	07-NOV-16
Bismuth (Bi)-Total			99.5		%		80-120	07-NOV-16
Boron (B)-Total			102.1		%		80-120	07-NOV-16
Cadmium (Cd)-Total			97.2		%		80-120	07-NOV-16
Calcium (Ca)-Total			102.3		%		80-120	07-NOV-16
Cesium (Cs)-Total			100.0		%		80-120	07-NOV-16
Chromium (Cr)-Total			96.6		%		80-120	07-NOV-16
Cobalt (Co)-Total			96.5		%		80-120	07-NOV-16
Copper (Cu)-Total			94.2		%		80-120	07-NOV-16
Iron (Fe)-Total			94.0		%		80-120	07-NOV-16
Lead (Pb)-Total			101.1		%		80-120	07-NOV-16
Lithium (Li)-Total			104.0		%		80-120	07-NOV-16
Magnesium (Mg)-Total			99.0		%		80-120	07-NOV-16
Manganese (Mn)-Total			99.3		%		80-120	07-NOV-16
Molybdenum (Mo)-Total			102.3		%		80-120	07-NOV-16

ALS Environmental

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch R3590217								
WG2427744-2 LCS								
Nickel (Ni)-Total			95.8		%		80-120	07-NOV-16
Phosphorus (P)-Total			97.6		%		80-120	07-NOV-16
Potassium (K)-Total			101.3		%		80-120	07-NOV-16
Rubidium (Rb)-Total			100.9		%		80-120	07-NOV-16
Selenium (Se)-Total			91.6		%		80-120	07-NOV-16
Silicon (Si)-Total			108.3		%		80-120	07-NOV-16
Silver (Ag)-Total			102.3		%		80-120	07-NOV-16
Sodium (Na)-Total			97.6		%		80-120	07-NOV-16
Strontium (Sr)-Total			113.1		%		80-120	07-NOV-16
Tellurium (Te)-Total			96.1		%		80-120	07-NOV-16
Thallium (Tl)-Total			100.3		%		80-120	07-NOV-16
Thorium (Th)-Total			100.8		%		80-120	07-NOV-16
Tin (Sn)-Total			98.6		%		80-120	07-NOV-16
Titanium (Ti)-Total			97.8		%		80-120	07-NOV-16
Tungsten (W)-Total			103.6		%		80-120	07-NOV-16
Uranium (U)-Total			102.6		%		80-120	07-NOV-16
Vanadium (V)-Total			99.1		%		80-120	07-NOV-16
Zinc (Zn)-Total			91.8		%		80-120	07-NOV-16
Zirconium (Zr)-Total			102.1		%		80-120	07-NOV-16
WG2427744-1 MB								
Aluminum (Al)-Total			<0.0050		mg/L		0.005	07-NOV-16
Antimony (Sb)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Arsenic (As)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Barium (Ba)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Beryllium (Be)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Bismuth (Bi)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Boron (B)-Total			<0.010		mg/L		0.01	07-NOV-16
Cadmium (Cd)-Total			<0.000010		mg/L		0.00001	07-NOV-16
Calcium (Ca)-Total			<0.10		mg/L		0.1	07-NOV-16
Cesium (Cs)-Total			<0.00010		mg/L		0.0001	07-NOV-16
Chromium (Cr)-Total			<0.0010		mg/L		0.001	07-NOV-16
Cobalt (Co)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Copper (Cu)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Iron (Fe)-Total			<0.010		mg/L		0.01	07-NOV-16

ALS Environmental

Quality Control Report

Workorder: L1852803   Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch R3590217								
WG2427744-1 MB								
Lead (Pb)-Total			<0.000090		mg/L		0.00009	07-NOV-16
Lithium (Li)-Total			<0.0020		mg/L		0.002	07-NOV-16
Magnesium (Mg)-Total			<0.010		mg/L		0.01	07-NOV-16
Manganese (Mn)-Total			<0.00030		mg/L		0.0003	07-NOV-16
Molybdenum (Mo)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Nickel (Ni)-Total			<0.0020		mg/L		0.002	07-NOV-16
Phosphorus (P)-Total			<0.10		mg/L		0.1	07-NOV-16
Potassium (K)-Total			<0.020		mg/L		0.02	07-NOV-16
Rubidium (Rb)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Selenium (Se)-Total			<0.0010		mg/L		0.001	07-NOV-16
Silicon (Si)-Total			<0.10		mg/L		0.1	07-NOV-16
Silver (Ag)-Total			<0.00010		mg/L		0.0001	07-NOV-16
Sodium (Na)-Total			<0.030		mg/L		0.03	07-NOV-16
Strontium (Sr)-Total			<0.00010		mg/L		0.0001	07-NOV-16
Tellurium (Te)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Thallium (Tl)-Total			<0.00010		mg/L		0.0001	07-NOV-16
Thorium (Th)-Total			<0.00010		mg/L		0.0001	07-NOV-16
Tin (Sn)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Titanium (Ti)-Total			<0.00050		mg/L		0.0005	07-NOV-16
Tungsten (W)-Total			<0.00010		mg/L		0.0001	07-NOV-16
Uranium (U)-Total			<0.00010		mg/L		0.0001	07-NOV-16
Vanadium (V)-Total			<0.00020		mg/L		0.0002	07-NOV-16
Zinc (Zn)-Total			<0.0020		mg/L		0.002	07-NOV-16
Zirconium (Zr)-Total			<0.00040		mg/L		0.0004	07-NOV-16
WG2427744-5 MS		WG2427744-3						
Aluminum (Al)-Total			N/A	MS-B	%		-	07-NOV-16
Antimony (Sb)-Total			100.6		%		70-130	07-NOV-16
Arsenic (As)-Total			91.1		%		70-130	07-NOV-16
Barium (Ba)-Total			N/A	MS-B	%		-	07-NOV-16
Beryllium (Be)-Total			94.0		%		70-130	07-NOV-16
Bismuth (Bi)-Total			93.2		%		70-130	07-NOV-16
Boron (B)-Total			90.5		%		70-130	07-NOV-16
Cadmium (Cd)-Total			89.7		%		70-130	07-NOV-16
Calcium (Ca)-Total			N/A	MS-B	%		-	07-NOV-16

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
MET-T-L-MS-WP	Water							
Batch R3590217								
WG2427744-5 MS		**WG2427744-3**						
Cesium (Cs)-Total			101.7		%		70-130	07-NOV-16
Chromium (Cr)-Total			95.2		%		70-130	07-NOV-16
Cobalt (Co)-Total			90.7		%		70-130	07-NOV-16
Copper (Cu)-Total			85.8		%		70-130	07-NOV-16
Iron (Fe)-Total			92.9		%		70-130	07-NOV-16
Lead (Pb)-Total			94.2		%		70-130	07-NOV-16
Lithium (Li)-Total			93.2		%		70-130	07-NOV-16
Magnesium (Mg)-Total			N/A	MS-B	%		-	07-NOV-16
Manganese (Mn)-Total			N/A	MS-B	%		-	07-NOV-16
Molybdenum (Mo)-Total			101.6		%		70-130	07-NOV-16
Nickel (Ni)-Total			88.0		%		70-130	07-NOV-16
Phosphorus (P)-Total			94.8		%		70-130	07-NOV-16
Potassium (K)-Total			N/A	MS-B	%		-	07-NOV-16
Rubidium (Rb)-Total			101.6		%		70-130	07-NOV-16
Selenium (Se)-Total			88.1		%		70-130	07-NOV-16
Silicon (Si)-Total			95.9		%		70-130	07-NOV-16
Silver (Ag)-Total			96.0		%		70-130	07-NOV-16
Sodium (Na)-Total			N/A	MS-B	%		-	07-NOV-16
Strontium (Sr)-Total			N/A	MS-B	%		-	07-NOV-16
Tellurium (Te)-Total			87.3		%		70-130	07-NOV-16
Thallium (Tl)-Total			96.4		%		70-130	07-NOV-16
Tin (Sn)-Total			99.2		%		70-130	07-NOV-16
Titanium (Ti)-Total			96.8		%		70-130	07-NOV-16
Tungsten (W)-Total			102.7		%		70-130	07-NOV-16
Uranium (U)-Total			N/A	MS-B	%		-	07-NOV-16
Vanadium (V)-Total			98.9		%		70-130	07-NOV-16
Zinc (Zn)-Total			78.9		%		70-130	07-NOV-16
Zirconium (Zr)-Total			105.3		%		70-130	07-NOV-16
NH3-COL-WP	Water							
Batch R3591036								
WG2428800-7 DUP		**L1850912-1**						
Ammonia, Total (as N)		0.42	0.44		mg/L	2.9	20	08-NOV-16
WG2428800-6 LCS								
Ammonia, Total (as N)			100.1		%		85-115	08-NOV-16

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
NH3-COL-WP	Water							
Batch R3591036								
WG2428800-5 MB								
Ammonia, Total (as N)			<0.010		mg/L		0.01	08-NOV-16
WG2428800-8 MS		**L1850912-1**						
Ammonia, Total (as N)			N/A	MS-B	%		-	08-NOV-16
NO2-L-IC-N-WP	Water							
Batch R3590363								
WG2426713-2 LCS								
Nitrite (as N)			101.2		%		90-110	04-NOV-16
WG2426713-1 MB								
Nitrite (as N)			<0.0010		mg/L		0.001	04-NOV-16
NO3-L-IC-N-WP	Water							
Batch R3590363								
WG2426713-2 LCS								
Nitrate (as N)			100.7		%		90-110	04-NOV-16
WG2426713-1 MB								
Nitrate (as N)			<0.0050		mg/L		0.005	04-NOV-16
PH-WP	Water							
Batch R3589373								
WG2427503-5 DUP		**L1852796-1**						
pH		7.48	7.40	J	pH units	0.08	0.2	04-NOV-16
WG2427503-2 LCS								
pH			7.41		pH units		7.3-7.5	04-NOV-16
SO4-IC-N-WP	Water							
Batch R3590363								
WG2426713-2 LCS								
Sulfate (SO4)			101.0		%		90-110	04-NOV-16
WG2426713-1 MB								
Sulfate (SO4)			<0.30		mg/L		0.3	04-NOV-16
TDS-WP	Water							
Batch R3591259								
WG2427808-3 DUP		**L1852377-1**						
Total Dissolved Solids		649	647		mg/L	0.3	20	07-NOV-16
WG2427808-2 LCS								
Total Dissolved Solids			100.3		%		85-115	07-NOV-16
WG2427808-1 MB								
Total Dissolved Solids			<10		mg/L		10	07-NOV-16
TURBIDITY-WP	Water							

ALS Environmental

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
TURBIDITY-WP	Water							
Batch **R3589358**								
WG2427592-2 DUP		**L1852833-2**						
Turbidity		1.62	1.69		NTU	4.2	15	03-NOV-16
WG2427592-3 LCS								
Turbidity			98.5		%		85-115	03-NOV-16
WG2427592-1 MB								
Turbidity			<0.10		NTU		0.1	03-NOV-16
UV-%TRANS-WP	Water							
Batch **R3589729**								
WG2426564-3 DUP		**L1851736-1**						
Transmittance, UV (254 nm)		94.2	94.4		%T/cm	0.2	20	03-NOV-16
WG2426564-1 IRM		**BLANK**						
Transmittance, UV (254 nm)			100.0		%		99.5-100.5	03-NOV-16
WG2426564-2 LCS								
Transmittance, UV (254 nm)			106.6		%		85-115	03-NOV-16

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Legend:

Limit	ALS Control Limit (Data Quality Objectives)
DUP	Duplicate
RPD	Relative Percent Difference
N/A	Not Available
LCS	Laboratory Control Sample
SRM	Standard Reference Material
MS	Matrix Spike
MSD	Matrix Spike Duplicate
ADE	Average Desorption Efficiency
MB	Method Blank
IRM	Internal Reference Material
CRM	Certified Reference Material
CCV	Continuing Calibration Verification
CVS	Calibration Verification Standard
LCSD	Laboratory Control Sample Duplicate

Sample Parameter Qualifier Definitions:

Qualifier	Description
DUP-H	Duplicate results outside ALS DQO, due to sample heterogeneity.
J	Duplicate results and limits are expressed in terms of absolute difference.
MS-B	Matrix Spike recovery could not be accurately calculated due to high analyte background in sample.
RPD-NA	Relative Percent Difference Not Available due to result(s) being less than detection limit.

Quality Control Report

Workorder: L1852803 Report Date: 15-NOV-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Hold Time Exceedances:

ALS Product Description	Sample ID	Sampling Date	Date Processed	Rec. HT	Actual HT	Units	Qualifier
Physical Tests							
pH							
	1	02-NOV-16 11:50	04-NOV-16 11:11	0.25	47	hours	EHTR-FM
	2	02-NOV-16 11:40	04-NOV-16 11:11	0.25	48	hours	EHTR-FM

Legend & Qualifier Definitions:

EHTR-FM:	Exceeded ALS recommended hold time prior to sample receipt. Field Measurement recommended.
EHTR:	Exceeded ALS recommended hold time prior to sample receipt.
EHTL:	Exceeded ALS recommended hold time prior to analysis. Sample was received less than 24 hours prior to expiry.
EHT:	Exceeded ALS recommended hold time prior to analysis.
Rec. HT:	ALS recommended hold time (see units).

Notes*:
Where actual sampling date is not provided to ALS, the date (& time) of receipt is used for calculation purposes.
Where actual sampling time is not provided to ALS, the earlier of 12 noon on the sampling date or the time (& date) of receipt is used for calculation purposes. Samples for L1852803 were received on 03-NOV-16 08:00.

ALS recommended hold times may vary by province. They are assigned to meet known provincial and/or federal government requirements. In the absence of regulatory hold times, ALS establishes recommendations based on guidelines published by the US EPA, APHA Standard Methods, or Environment Canada (where available). For more information, please contact ALS.

The ALS Quality Control Report is provided to ALS clients upon request. ALS includes comprehensive QC checks with every analysis to ensure our high standards of quality are met. Each QC result has a known or expected target value, which is compared against pre-determined data quality objectives to provide confidence in the accuracy of associated test results.

Please note that this report may contain QC results from anonymous Sample Duplicates and Matrix Spikes that do not originate from this Work Order.

L1852803-COFC

Manitoba Conservation Water Stewardship
Office of Drinking Water
1007 Century Street, Winnipeg, Manitoba,
Canada R3H 0W4

Chain of Custody (COC)
Manitoba Drinking Water Systems
ONLY FOR: Regulatory General Chemistry & VOC Samples

Report to Operator (email pdf):				**Owner billing (Email):**				**Regular Service (default):**		**Regular Service** (is 5-7 Days):		
Contact:								**Unless otherwise requested:**		1 Day, rush / priority		
Address:										2 Day, rush / priority		
Phone:										3 Day, rush / priority		
Email:								**Email pdf copy to:**				
Operator cont								DWO:				
Contact:								DWO Address:				
Address:								DWO Phone:				
Phone:								DWO Email:				
Email:												
Account:		ODW Report type:	EMS (Lab-MWS)	**Client / Project Information:**						**Analysis Request**		
Agency Code:	382	Project:	DWQ-C	Operation Name:	VIRDEN - PWS					MB-CH-PWS-V2013	MB-VOC-PWS-V2013	Number of Containers
Lab:		Lab Work Order # / Job # (lab use only)		Operation Code (com code):	239.00							
				Operation Id:	16933							
				Sampled by:								
Lab Sample # (lab use only)	**Sample Number** (YYMMJJ9999)	**Station Number** (MH99XXD999) / (MB99XXY999)	**Sample Identification**		**Date** dd-mmm-yyyy	**Time** hh:mm	**Sample Matrix**	**Sample Type**				
	1610GR0118	MB05MGD081	Virden 1 - Raw		02/11/2016	11:00	6	1		X	X	4
	1610GR0119	MB05MGD082	Virden 2 - Treated		04/11/2016	11:40	10	1		X	X	4

Failure to complete all portions of this form may delay analysis.
Please fill in this form LEGIBLY.

Sample Matrix: 6-Raw Water, 10-Treated Water

Sample Type: 1-Grab Sample

By the use of this form the user acknowledges and agrees with the Terms and Conditions as specified by the Laboratory.
For ALL other testing, please use Laboratory specific forms.

DO NOT COPY or RE-USE this form. Sample Numbers are unique to the Office of Drinking Water and provided by DWO.

Relinquished By:		Date & Time:		Received By: (lab use only)		Date & Time: (lab use only)	NOV 3 8:00am
Relinquished By:		Date & Time:		Received By: (lab use only)		Date & Time: (lab use only)	

Sample Condition (lab use only): Temperature: 16°C; Samples Received in Good Condition? Y / N (if no provide details)

Operator mandatory | Operator optional | Operator to fill, if information above has changed | Opr to fill, Lab specific | pre-filled by DWO

Note: Cyanide and Mercury are not required and have been removed from the list.
Please use the Rev. July 29, 2013 Water System Chemistry List.

APPENDIX G

VIRDEN VOC ANALYSIS

Town of Virden - Water Plant

Virden - PWS
PO Box 310
Virden MB R0M 2C0

Date Received: 05-OCT-16
Report Date: 14-OCT-16 14:31 (MT)
Version: FINAL

Certificate of Analysis

Lab Work Order #: L1838898
Project P.O. #:
Job Reference:
C of C Numbers:
Legal Site Desc:

ANALYTICAL REPORT

Volatile Organic Compounds (WATER)

Analyte	Unit	Guide Limit #1	Guide Limit #2	ALS ID: L1838898-1 Sampled Date: 04-OCT-16 Sampled Time: 10:50 Sample ID: VIRDEN 1 - RAW
Benzene	mg/L	-	0.005	<0.00050
1,1-dichloroethene	mg/L	-	0.014	<0.00050
Dichloromethane	mg/L	-	0.05	<0.00050
Ethylbenzene	mg/L	0.0016	0.14	<0.00050
MTBE	mg/L	0.015	-	<0.00050
Tetrachloroethene	mg/L	-	0.01	<0.00050
Toluene	mg/L	0.024	0.06	<0.00050
Trichloroethene	mg/L	-	0.005	<0.00050
o-Xylene	mg/L	-	-	<0.00050
M+P-Xylenes	mg/L	-	-	<0.00050
Xylenes (Total)	mg/L	0.02	0.09	<0.0015
Surrogate: 4-Bromofluorobenzene (SS)	%	-	-	79.7
Surrogate: 1,4-Difluorobenzene (SS)	%	-	-	97.1

Federal Guidelines for Canadian Drinking Water Quality (MAR, 2015)
#1: GCDWQ - Aesthetic Objective
#2: GCDWQ - Maximum Acceptable Concentrations (MACs)

Detection Limit for result exceeds Guide Limit. Assessment against Guide Limit cannot be made.
Analytical result for this parameter exceeds Guide Limit listed on this report.

Reference Information

Methods Listed (if applicable):

ALS Test Code	Matrix	Test Description	Method Reference**
VOC+F1-HSMS-WP	Water	VOC plus F1 by GCMS	EPA 8260C / EPA 5021A

In this method samples are analyzed using a headspace autosampler interfaced to a dual column gas chromatograph with MS and Flame Ionization detectors.

XYLENES-SUM-CALC-WP	Water	Sum of Xylene Isomer Concentrations	CALCULATED RESULT

Total xylenes represents the sum of o-xylene and m&p-xylene.

**ALS test methods may incorporate modifications from specified reference methods to improve performance.

Chain of Custody Numbers:

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
WP	ALS ENVIRONMENTAL - WINNIPEG, MANITOBA, CANADA

GLOSSARY OF REPORT TERMS

Surrogates are compounds that are similar in behaviour to target analyte(s), but that do not normally occur in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery. In reports that display the D.L. column, laboratory objectives for surrogates are listed there.
mg/kg - milligrams per kilogram based on dry weight of sample
mg/kg wwt - milligrams per kilogram based on wet weight of sample
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight
mg/L - unit of concentration based on volume, parts per million.
< - Less than.
D.L. - The reporting limit.
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

Application of guidelines is provided "as is" without warranty of any kind, either expressed or implied, including, but not limited to fitness for a particular purpose, or non-infringement. ALS assumes no responsibility for errors or omissions in the information.

ALS Environmental

Quality Control Report

Workorder: L1838898 Report Date: 14-OCT-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC+F1-HSMS-WP	Water							
Batch **R3571076**								
WG2409842-3 DUP		**L1840396-2**						
Benzene		<0.00050	<0.00050	RPD-NA	mg/L	N/A	30	13-OCT-16
WG2409842-2 LCS								
Benzene			99.1		%		70-130	13-OCT-16
1,1-dichloroethene			96.5		%		70-130	13-OCT-16
Dichloromethane			104.8		%		70-130	13-OCT-16
Ethylbenzene			97.4		%		70-130	13-OCT-16
MTBE			93.2		%		70-130	13-OCT-16
Tetrachloroethene			94.3		%		70-130	13-OCT-16
Toluene			95.8		%		70-130	13-OCT-16
Trichloroethene			100.5		%		70-130	13-OCT-16
M+P-Xylenes			100.7		%		70-130	13-OCT-16
o-Xylene			98.5		%		70-130	13-OCT-16
WG2409842-1 MB								
Benzene			<0.00050		mg/L		0.0005	13-OCT-16
1,1-dichloroethene			<0.00050		mg/L		0.0005	13-OCT-16
Dichloromethane			<0.00050		mg/L		0.0005	13-OCT-16
Ethylbenzene			<0.00050		mg/L		0.0005	13-OCT-16
MTBE			<0.00050		mg/L		0.0005	13-OCT-16
Tetrachloroethene			<0.00050		mg/L		0.0005	13-OCT-16
Toluene			<0.00050		mg/L		0.0005	13-OCT-16
Trichloroethene			<0.00050		mg/L		0.0005	13-OCT-16
M+P-Xylenes			<0.00050		mg/L		0.0005	13-OCT-16
o-Xylene			<0.00050		mg/L		0.0005	13-OCT-16
Surrogate: 4-Bromofluorobenzene (SS)			79.9		%		70-130	13-OCT-16
Surrogate: 1,4-Difluorobenzene (SS)			97.5		%		70-130	13-OCT-16

Quality Control Report

Workorder: L1838898 Report Date: 14-OCT-16

Client: Town of Virden - Water Plant
Virden - PWS PO Box 310
Virden MB R0M 2C0

Contact:

Legend:

Limit	ALS Control Limit (Data Quality Objectives)
DUP	Duplicate
RPD	Relative Percent Difference
N/A	Not Available
LCS	Laboratory Control Sample
SRM	Standard Reference Material
MS	Matrix Spike
MSD	Matrix Spike Duplicate
ADE	Average Desorption Efficiency
MB	Method Blank
IRM	Internal Reference Material
CRM	Certified Reference Material
CCV	Continuing Calibration Verification
CVS	Calibration Verification Standard
LCSD	Laboratory Control Sample Duplicate

Sample Parameter Qualifier Definitions:

Qualifier	Description
RPD-NA	Relative Percent Difference Not Available due to result(s) being less than detection limit.

Hold Time Exceedances:

All test results reported with this submission were conducted within ALS recommended hold times.

ALS recommended hold times may vary by province. They are assigned to meet known provincial and/or federal government requirements. In the absence of regulatory hold times, ALS establishes recommendations based on guidelines published by the US EPA, APHA Standard Methods, or Environment Canada (where available). For more information, please contact ALS.

The ALS Quality Control Report is provided to ALS clients upon request. ALS includes comprehensive QC checks with every analysis to ensure our high standards of quality are met. Each QC result has a known or expected target value, which is compared against pre-determined data quality objectives to provide confidence in the accuracy of associated test results.

Please note that this report may contain QC results from anonymous Sample Duplicates and Matrix Spikes that do not originate from this Work Order.

L1838898-COFC

Manitoba Conservation Water Stewardship
Office of Drinking Water
1007 Century Street, Winnipeg, Manitoba,
Canada R3H 0W4

ONLY FOR: Regulatory General Chemistry & VOC Samples L1838898

Report to Operator (email pdf):		**Owner billing (Email):**		**Regular Service (default):**	**Regular Service** (is 5-7 Days):
Contact:				**Unless otherwise requested:**	1 Day, rush / priority
Address:					2 Day, rush / priority
Phone:					3 Day, rush / priority
Email:					
Operator contact update (if different then above):		**Owner contact update (if different then above):**		**Email pdf copy to:**	
Contact:		Contact:		DWO:	
Address:		Address:		DWO Address:	
Phone:		Phone:		DWO Phone:	
Email:		Email:		DWO Email:	

Account:		ODW Report type:	**EMS (Lab-MWS)**	**Client / Project Information:**	
Agency Code:	**382**	Project:	**DWQ-C**	Operation Name:	VIRDEN - PWS
Lab:		Lab Work Order # / Job # (lab use only)		Operation Code (com code):	239.00
				Operation Id:	16933
				Sampled by:	

Lab Sample # (lab use only)	Sample Number (YYMMII9999)	Station Number (MB99XXD999) / (MB99XXY999)	Sample Identification	Date dd-mmm-yyyy	Time hh:mm	Sample Matrix	Sample Type	MB-CH-PWS-V2013	MB-VOC-PWS-V2013	Number of Containers
	1602GR0012	MB05MGD081	Virden 1 - Raw	04-Oct-2016	10:50	6	1	X	X	2
	1602GR0013	MB05MGD082	Virden 2 - Treated	04-Oct-2016	11:00	10	1	X		1

Failure to complete all portions of this form may delay analysis.
Please fill in this form LEGIBLY.

Sample Matrix: 6-Raw Water, 10-Treated Water

Sample Type: 1-Grab Sample

By the use of this form the user acknowledges and agrees with the Terms and Conditions as specified by the Laboratory.

For ALL other testing, please use Laboratory specific forms.

DO NOT COPY or RE-USE this form. Sample Numbers are unique to the Office of Drinking Water and provided by DWO.

Relinquished By:		Date & Time:		Received By: (lab use only)		Date & Time: (lab use only)	Oct 5/16 8:00	Sample Condition (lab use only): Temperature; Samples Received in Good Condition? Y / N (if no provide details)
Relinquished By:		Date & Time:		Received By: (lab use only)		Date & Time: (lab use only)		19.

Operator mandatory | Operator optional | Operator to fill, if information above has changed | Opr to fill, Lab specific | pre-filled by DWO

Note: Cyanide and Mercury are not required and have been removed from the list.
Please use the Rev. July 29, 2013 Water System Chemistry List.

APPENDIX H

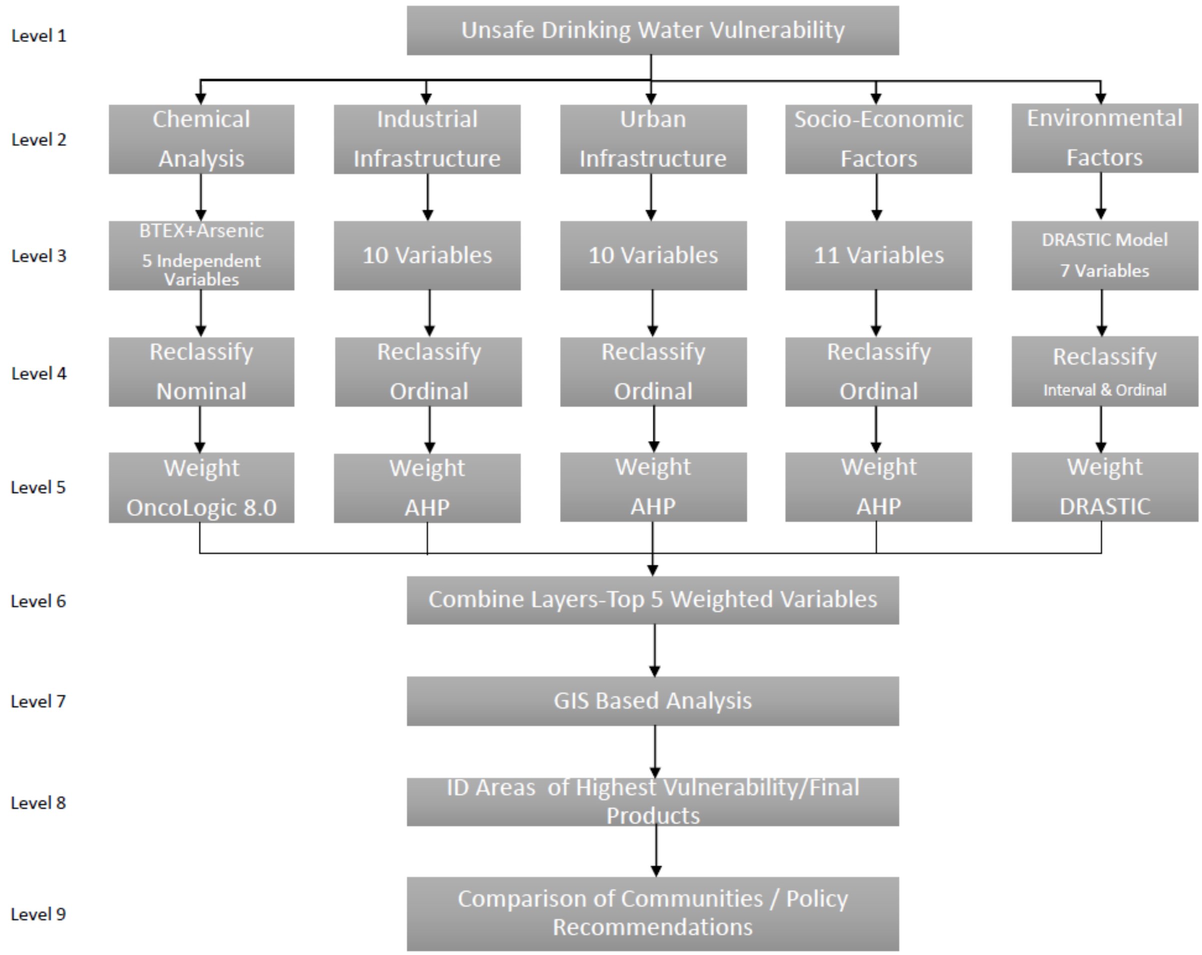
MAJOR CHEMICALS AND TRACE ELEMENTS POTENTIAL HEALTH HAZARDS

Major Chemistry, and Trace Metals in the ground water at the median distance of 4.6 km from the nearest oil and gas well in the upper Fort Union Formation of the Bakken (Adapted from McMahon et al. (2015), Tchobanoglous and Burton (1991)).

Potential Contaminant	Concentration in nearby ground water sources (Upper Fort Union Formation) (μg/l)	Potential Health hazard
TDS	$3590*10^3$	Hardness, Deposits, Colored water, Staining, Salty taste but no health hazard
Conductivity (mS/cm)		Especially for fish and other aquatic species
COD		Especially for fish and other aquatic species
pH		Especially for fish and other aquatic species
Na		Kidney damage, Increases in blood pressure, Skin, Eyes, Nose and Throat irritation
Ca		Kidney stones, Reproductive toxicity
K		Fluid in the lungs, Eyes irritation, Nose and Throat Irritation
Mg		Fever, Chills, Nausea, Vomiting & muscle pain, Irritation of upper respiratory tract irritation upon inhalation
Fe	4460	Conjunctivitis, Choroiditis, and Retinitis, Neurological disorder
P		Kidney damage, Osteoporosis,Nausea, Stomach cramps and Drowsiness
NO_3^--N	6.47	Harmful to infants, Shortness of breath and blue-baby syndrome
NO_2^--N		Harmful to infants, Shortness of breath and blue-baby syndrome
Si		Fibrosis in lung tissue, Skin and eyes irritation, Renal system diseases
Mn	1090	Hallucinations, Forgetfulness, Parkinson, lung embolism, Bronchitis, Nerve damage, Endocrine disruptor.
Al		Severe trembling, listlessness, Loss of memory, Damage to the central nervous system, Dementia
B		Infection in stomach, liver, kidneys and brain
Ba	223	Flammable at room temperature in powder form, Long term- Increased blood pressure and nerve block
Cd		Flammable in powder form, Toxic by inhalation of dust or fume, A carcinogen. Soluble compounds of Cd are highly toxic. Long term- concentrates in the liver, kidney, pancreas, and thyroid, Hypertension suspected effect
Cu		Gastrointestinal distress, liver or kidney damage, Neurological disorder
Cr		Hexavalent Cr compounds are carcinogens and corrosive on tissue. Long term- skin sensitization and kidney damage, Reproductive toxicity
Li		Corrosive to the eyes, skin and respiratory tract
Pb		Toxic by ingestion or inhalation of dust or fumes, Long term-brain and kidney damage, Birth defects, Reproductive toxicity, Neurological disorder,, Immunological disorder
Sr		Problems with bone growth, Anaemia and carcinogenic
Rb		Skin and eye burns, Failure to gain weight, Ataxia, Hyper irritation, Skin ulcers, and Extreme nervousness
V		Cardiac and vascular disease, Damage to the nervous system, Dizziness, Eye, nose and throat irritation
Tl		Hair loss, Changes in blood and Kidney, Intestine, or liver problems
Se	42.8	Long term- red staining of fingers, teeth and hair, General weakness, Depression, Irritation of nose and mouth
Ti		Pain in chest, Skin and eye irritation
Zn		Loss of appetite, Decreased sense of taste and smell, Slow wound healing and Skin sores, Endocrine disruptor, Neurological disorder
Hg		Kidney damage, Reproductive toxicity, Immunological disorder
Ag		Toxic metal, Long term-permanent gray discoloration of skin, eyes, and mucous membranes
Ni		Lung cancer, Nose cancer, Larynx cancer, Prostate cancer, Asthma and chronic bronchitis, Heart disorders and Allergic reactions such as skin rashes
Be		Kidney damage
Cl^-	$162*10^3$	Irritates skin and eyes, Chest pain, Water retention in the lungs
Br^-		Malfunctioning of the nervous system and disturbances in genetic materials
Mo	<0.2	Hyperbilirubinemia, Gout and Joint pains
F	4.22	Dermal, Musculoskeletal, Ocular (Eyes), Respiratory (From the Nose to the Lungs)
SO_4^{2-}	<59	Dehydration, Laxative effect, Decrease in gastrointestinal retention of food
CN^-		Nerve damage or thyroid problem
As	11.5	Carcinogen and mutagen, Long term- sometimes can cause fatigue and loss of energy, Dermatitis, Endocrine disruptor, Reproductive toxicity.
Ammonia		Skin, eyes, respiratory tract and lungs irritation
Sulfide		Dermatitis and burning eyes
Sulfate	$1830*10^3$	Salty taste but no health hazard
Sb		Increase in blood cholesterol, Decrease in blood sugar
Benzene	<0.026	Anemia; decrease in blood platelets, Increased risk of cancer, Disrupt endocrine systems
Toluene	<0.69	Nervous system, Kidney or Liver problems, Disrupt endocrine systems
Bicarbonate		No health hazard
Phenol		Systemic poison and constitutes a serious health hazard, Weak endocrine disrupters
Ethylbenzene	<0.036	Liver or kidneys problems, Disrupt endocrine systems
Xylenes		Toxic on inhalation, Disrupt endocrine systems
Cs		Nausea, Vomiting, Diarrhea and Bleeding
U	23.2	Increased risk of cancer, Kidney toxicity
Ra		Increased risk of cancer
Methane	$32*10^3$	Headache, Dizziness, Weakness, Nausea, Vomiting, and loss of coordination

APPENDIX J

UNSAFE DRINKING WATER VULNERABILITY MODEL


Level 1
Unsafe Drinking Water Vulnerability
Level 2
Chemical Analysis
Industrial Infrastructure
Urban Infrastructure
Socio-Economic Factors
Environmental Factors
Level 3
BTEX+Arsenic 5 Independent Variables
10 Variables
10 Variables
11 Variables
DRASTIC Model 7 Variables
Level 4
Reclassify Nominal
Reclassify Ordinal
Reclassify Ordinal
Reclassify Ordinal
Reclassify Interval & Ordinal
Level 5
Weight OncoLogic 8.0
Weight AHP
Weight AHP
Weight AHP
Weight DRASTIC
Level 6
Combine Layers-Top 5 Weighted Variables
Level 7
GIS Based Analysis
Level 8
ID Areas of Highest Vulnerability/Final Products
Level 9
Comparison of Communities / Policy Recommendations

APPENDIX P

DRASTIC MODEL WEIGHTING METHOD

Drastic Parameter	Source Data	Data Form in GIS	Classes	Rates	Weights
Depth to groundwater: D (mm)	Monthly monitoring of shallow wells	Vector point data	0 - 1.5	10	5
			1.5 - 4.5	9	
			4.5 - 9	7	
			9 - 15	5	
			15 - 23	3	
			23 - 31	2	
			>31	1	
Net recharge: R (mm)	Hydrogeological map	Vector polygon data	100 - 180	6	4
			50 - 100	3	
			0 - 50	1	
Aquifer type: A	Geological map	Vector polygon data	Medium sand sandstone	6	3
			Fine sand sandstone	4	
			Clay	3	
Soil type: S	Soil map (1: 50,000)	Vector polygon data	Sandy and sandy loam	6	2
			Sandy clayey	4	
			Silty caley and clay	3	
Topography: T (Slope (%))	Topographic maps (1:50,000)	Raster data	12 - 18	10	1
			6 - 12	9	
			2 - 6	5	
			<2	3	
Impact of vadoze zone: I	Geological map	Polygon data	Medium sand sandstone	6	5
			fine sand sandstone	4	
			Clay	3	
Hydraulic conductivity: C (m/j)	Geophysical surveys	Point data	41 - 82	8	3
			29 - 41	2	
			<4	1	

Table 1. Weights given to each DRASTIC Parameter (Aller, 1987).

Parameters	DRASTC Weight
D - Depth to groundwater water: Deep water tables consider safer from pollutants then shallow water tables.	5
R - Annual Recharge: high recharge rate indicates more contamination infiltrate towards groundwater water.	4
A - Aquifer media: the aquifer media determines chances resistance against contaminant transport	3
S - Soil media: the soil media exposes pollutants moving time from surface to water table	2
T - Topography: a high slope results in rapid runoff, which indicates less chance to infiltrate contamination into ground.	1
I - Impact of the vadose zone: the vadose zone thickness and matrix are affect contamination intensity and transport timing	5
C - Hydraulic Conductivity: the hydraulic conductivity of the aquifer indicates the quantity of water percolating through the aquifer	3

APPENDIX R

FINAL UNSAFE DRINKING WATER VULNERABILITY AHP WEIGHTING

AHP Entire Model

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Environmental Factors	25.6%	2
2	Socio-Economic Factors	40.8%	1
3	Urban Infrastructure	8.6%	5
4	Industrial Infrastructure	10.0%	4
5	Chemical Analysis	15.0%	3

Number of comparisons = 10
Consistency Ratio CR = 7.0%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4	5
1	1	1.00	4.00	2.00	1.00
2	1.00	1	7.00	6.00	2.00
3	0.25	0.14	1	1.00	1.00
4	0.50	0.17	1.00	1	1.00
5	1.00	0.50	1.00	1.00	1

Principal eigen value = 5.314
Eigenvector solution: 6 iterations, delta = 4.4E-9

AHP priorities	2017.05.16 14:38:10				
5					
Environmental Factors	Socio-Economic Factors	Urban Infrastructure	Industrial Infrastructure	Chemical Analysis	
1	1	4	2	1	
1	1	7	6	2	
0.25	0.142857	1	1	1	
0.5	0.166667	1	1	1	
1	0.5	1	1	1	
0.255752	0.408026	0.086277	0.100139	0.149806	
5.313667	0.069732				

APPENDIX S

TABLE OF MINIMUM DISTANCE REQUIREMENTS

SCHEDULE C

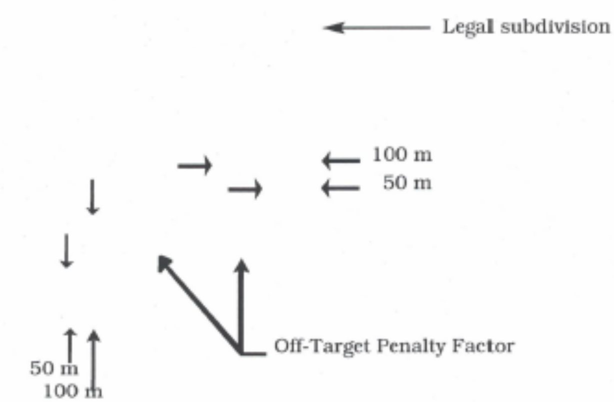
(Subsections 9(1), 75(4) and 85(1))
Table of Minimum Distance Requirements

Note: The distances in the table are expressed in metres.

To: / From:	Well	Flame Type Equipment	Internal Combustion Engine		Flare Pit and Flare Stack	Oil Storage Tank	Surface Improvement Except Well Flow Line or Road Allowance	Water Covered Area	Road Allowance — Provincial or Municipal
			Air Shut Off	No Air Shut Off					
Well	5	25	5	10	25	25	75	100	45
BOP Manifold	3	—	—	—	15	—	—	—	45
BOP Remote Control	15	—	—	—	15	—	—	—	45
Flame Type Equipment	25	—	—	—	25	25	—	—	45
Drilling Fluid Pit or Tank	5	25	—	—	10	—	75	100	45
Flare Pit and Flare Stack	25	25	5	10	—	—	100	100	45
Emergency Storage Pit	25	25	—	—	25	—	75	100	45
Service or Test Tank	25	25	5	10	25	—	75	100	45
Oil Storage Tank	25	25	5	10	25	—	75	100	45
Vented Salt Water Tank	10	5	5	5	25	—	75	100	45
Process Vessel	25	—	—	—	25	25	75	100	45

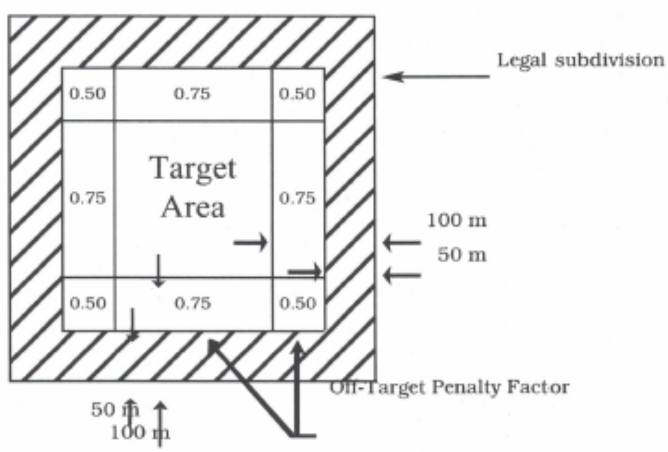
M.R. 116/2001

Diagram A



Drilling Restrictions. See subsection 9(1).

Diagram B



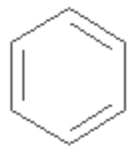
Drilling Restrictions. See subsection 9(1).

M.R. 145/98

APPENDIX T

CHEMICAL JUSTIFICATION WEIGHTING REPORTS

OncoLogic Justification Report



SUMMARY :

CODE NUMBER : Benzene

SUBSTANCE ID : Part of BTEX Volatile compounds found in petroleum products.

NAME(S) :
Benzene

CAS # : 71-43-2

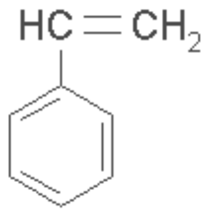
The final level of carcinogenicity concern for this compound is HIGH.

JUSTIFICATION

There is clear evidence that the compound is a human and animal carcinogen. The concern level is based on consideration of the weight of the evidence and the carcinogenic potency of the compound.

The final level of concern is HIGH.

OncoLogic Justification Report



SUMMARY :

CODE NUMBER : Ethylbenzene

SUBSTANCE ID : Part of BTEX group of VOCs.

NAME(S) :
Styrene

CAS # : 100-42-5

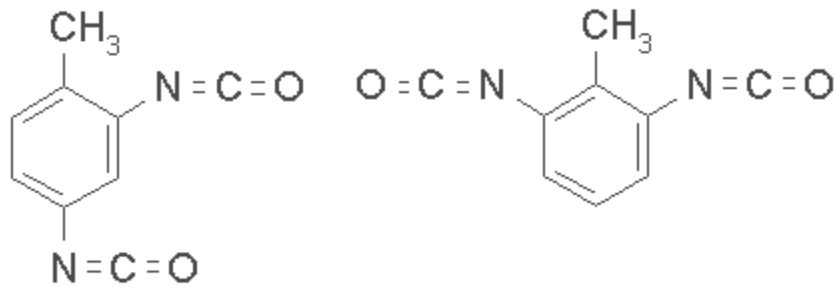
The final level of carcinogenicity concern for this compound is LOW-MODERATE.

JUSTIFICATION

There is limited evidence that the compound is carcinogenic in experimental animals. Extensive epidemiological studies have thus far not provided conclusive evidence in support of or against its carcinogenicity in humans. The concern level is based on consideration of the weight of the evidence and the carcinogenic potency of the compound.

The final level of concern is LOW-MODERATE.

OncoLogic Justification Report



SUMMARY :

CODE NUMBER : 108883

SUBSTANCE ID : Btex group of VOCs.

NAME(S) :
Toluene diisocyanates

CAS # : 26471-62-5

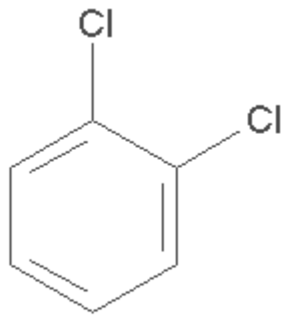
The final level of carcinogenicity concern for this compound is MODERATE.

JUSTIFICATION

There is clear evidence that the mixture consisting of 2,4-toluene diisocyanate(80%) and 2,6-toluene diisocyanate (20%) is carcinogenic in experimental animals. The concern level is based on consideration of the weight of the evidence and the carcinogenic potency of the mixture.

The final level of concern is MODERATE.

OncoLogic Justification Report



SUMMARY :

CODE NUMBER : Xylene

SUBSTANCE ID : Part of BTEX group of VOCs

NAME(S) :
1,2-Dichlorobenzene

CAS # : 95-50-1

The final level of carcinogenicity concern for this compound is MARGINAL.

JUSTIFICATION

Halogenated aromatics include the following type of halogenated compounds: benzenes, naphthalenes, biphenyls, terphenyls, diphenyl ethers, diphenyl sulfides, dibenzo-p-dioxins, dibenzofurans, dibenzothiophenes, and diphenyl alkanes and alkenes. Although a number of halogenated aromatics have been shown to be carcinogenic in experimental animals, the mechanism of their carcinogenic action is not clearly understood. However, there is a prevalent view that these chemicals may be carcinogenic through epigenetic mechanisms rather than by direct action on DNA. For instance, there is considerable evidence showing that the initial event involved in 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) carcinogenesis is binding to the cytosolic Ah receptor. The subsequent translocation of the TCDD-receptor complex into the nucleus leads to a modulation of gene expression which is believed to be responsible for the various biochemical (e.g. induction of the cytochrome P-450 1A family) and toxicological effects (including tumorigenesis) of the compound. Since the key requirement for the binding of TCDD to the cytosolic Ah receptor is a planar molecule with the halogens at the lateral position (i.e., 2,3,7,8-position of TCDD), it has been suggested that other halogenated aromatics with a molecular shape isosteric with TCDD may act by a mechanism similar to that of TCDD. Indeed, like TCDD, a number of halogenated biphenyls and naphthalenes with halogens at the lateral positions are also inducers of the cytochrome P-450 1A family. Other halogenated biphenyls, naphthalenes and benzenes, which induce the cytochrome P-450 2B family, on the other hand, have been postulated to act via inhibition of "intercellular communication" (also called "metabolic cooperation"). Other epigenetic mechanisms that have been linked to carcinogenesis of halogenated aromatics include (i) hormone imbalance (e.g. estrogen mimics), (ii) immunosuppresion, and (iii) cytotoxicity.

Halogenation of the aromatics renders them more lipid-soluble, more slowly metabolized, and therefore more persistent in animal tissues. In general, the rate of oxidative metabolism decreases as the degree of halogenation increases because of steric hindrance by the halogen atoms. Moreover, the position of halogenation plays an important role in determining the rate of oxidative metabolism. For instance, it has been shown that chlorinated and brominated benzenes having two adjacent unsubstituted carbon atoms are more rapidly metabolized than those without adjacent unsubstituted carbon atoms, despite a similar degree of halogenation. Hence, in addition to the type of halogens, the degree and position of halogenation are important factors in evaluating the carcinogenicity potential of halogenated aromatics.

The carcinogenicity concern levels of these compounds are determined based on structure-activity relationship analysis as well as metabolism and mechanism considerations.

There is no adequate carcinogenicity data on this compound. The concern level derived for this compound is based on structure-activity relationships analysis.

The final level of concern is MARGINAL.

NIOSH Arsenic Report

Arsenic (inorganic compounds, as As)	Formula: As (metal)	CAS#: 7440-38-2 (metal)	RTECS#: CG0525000 (metal)	IDLH: Ca [5 mg/m³ (as As)]
Conversion:	DOT: 1558 152 (metal); 1562 152 (dust)			

Synonyms/Trade Names: **Arsenic metal:** Arsenia
Other synonyms vary depending upon the specific As compound. [**Note:** OSHA considers "Inorganic Arsenic" to mean copper acetoarsenite & all inorganic compounds containing arsenic except ARSINE.]

Exposure Limits:	Measurement Methods (see Table 1):
NIOSH REL: Ca C 0.002 mg/m³ [15-minute] See Appendix A **OSHA PEL:** [1910.1018] TWA 0.010 mg/m³	**NIOSH** 7300, 7301, 7303, 9102, 7900 **OSHA** ID105
Physical Description: Metal: Silver-gray or tin-white, brittle, odorless solid.	

Chemical & Physical Properties:	Personal Protection/Sanitation (see Table 2):	Respirator Recommendations (see Tables 3 and 4):
MW: 74.9 **BP:** Sublimes **Sol:** Insoluble **Fl.P:** NA **IP:** NA **Sp.Gr:** 5.73 (metal) **VP:** 0 mmHg (approx) **MLT:** 1135°F (Sublimes) **UEL:** NA **LEL:** NA	**Skin:** Prevent skin contact **Eyes:** Prevent eye contact **Wash skin:** When contam/Daily **Remove:** When wet or contam **Change:** Daily **Provide:** Eyewash Quick drench	**NIOSH** **¥:** ScbaF:Pd,Pp/SaF:Pd,Pp:AScba **Escape:** GmFAg100/ScbaE See Appendix E (page 351)

Metal: Noncombustible Solid in bulk form, but a slight explosion hazard in the form of dust when exposed to flame.

Incompatibilities and Reactivities: Strong oxidizers, bromine azide
[**Note:** Hydrogen gas can react with inorganic arsenic to form the highly toxic gas arsine.]

Exposure Routes, Symptoms, Target Organs (see Table 5):	First Aid (see Table 6):
ER: Inh, Abs, Con, Ing **SY:** Ulceration of nasal septum, derm, GI disturbances, peri neur, resp irrit, hyperpig of skin, [carc] **TO:** Liver, kidneys, skin, lungs, lymphatic sys [lung & lymphatic cancer]	**Eye:** Irr immed **Skin:** Soap wash immed **Breath:** Resp support **Swallow:** Medical attention immed

APPENDIX U

GEOMATRIX SOCIO-ECONOMIC SUB-MODEL CENSUS DATA

Geomatrix Socio-Economic Sub-Model Census Data

2006CensusData_VirdenWallace_BrandonCornwallisElton_19May2017.csv

Topic	Characteristics	Virden - Town (Census subdivision)	Wallace - Rural municipality (Census subdivision)	Brandon - City (Census subdivision)	Cornwallis - Rural municipality (Census subdivision)	Elton - Rural municipality (Census subdivision)
Age characteristics	Total population	3010	1500	41510	4055	1285
Age characteristics	0 to 4 years (%)	5	5	6	8	3
Age characteristics	5 to 9 years (%)	5	8	5	7	5
Age characteristics	10 to 14 years (%)	6	8	6	7	10
Age characteristics	15 to 19 years (%)	7	10	7	7	9
Age characteristics	65 to 69 years (%)	4	4	4	4	3
Age characteristics	70 to 74 years (%)	5	3	3	2	3
Age characteristics	75 to 79 years (%)	6	2	3	1	2
Age characteristics	80 to 84 years (%)	6	1	3	0	2
Age characteristics	85 years and over (%)	6	1	3	0	1
Age characteristics	Total Percent Vulnerable Population 0 to 20 and 65 and over	49	43	40	37	37
Selected family characteristics	Number of female lone-parent families	70	15	1480	90	20
Selected family characteristics	Number of male lone-parent families	10	10	295	15	0
Selected family characteristics	Median income in 2005 - Female lone-parent families ($)	21545	0	27681	28314	0
Selected family characteristics	Median income in 2005 - Male lone-parent families ($)	0	0	40509	57485	0
Selected household characteristics	Median monthly payments for rented dwellings ($)	442	0	581	600	701
Selected household characteristics	Median monthly payments for owner-occupied dwellings ($)	437	355	676	560	776
Income in 2005	% in low income before tax - All persons	6	10	17	7	6
Income in 2005	% in low income after tax - All persons	4	5	13	5	2

APPENDIX VI

VIRDEN ANNUAL WATER REPORTS 2007

Public Water System
Annual Report
-2007-

Public Water System: ***Virden Water Treatment Plant***
Water Treatment Classification III
Distribution Classification II

Telephone: ***1-204-748-3434***

Name of legal owner: ***Town of Virden***

Phone during business hours: Monday-Friday 8:30am to 4:30pm

Telephone: ***1-204-748-2440***

Fax: ***1-204-748-2501***

E-mail: www.virden.ca

Contacts: ***Rhonda Stewart- C.A.O***

Operators: ***Cornie Peters- Manager of Works & Utilities***
Certification: Level III WT, Level II WD

Ryan Mathieson – Water & Wastewater Foreman
Certification: Level III WT, Level II WD

Allan Sinclair – Plant operator
Certification: Level I WT, Level I WD

Kevin Barkley – Operator in training

After hours emergency phone: ***1-204-851-5540***

Table of Contents

1. Water Treatment Process Description:

1.1 Raw water supply

- *The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. The wells are both 60 feet deep with a 60HP, submersible turbine pump in each well*

1.2 Water treatment process

- *The raw water is pumped into the water plant at a rate of 25 to 26 litres/second, with a total plant capacity of 45 litres/second. The water upon reaching the plant is treated with ozone to oxidize the iron and manganese, and arsenic. After the ozonation a chemical (sodium metabisulfite) is added to bind the oxygen in the water to stop the biological growth of iron bacteria. The water then goes through a set of dual media gravity filters containing greensand/granular activated carbon for the partial removal of the oxidized iron, manganese and arsenic. Due to the arsenic left in the treated water approximately 40% of the filtered water is pumped to a nanofiltration unit to reduce the arsenic to below the drinking water standards. An antiscalant (Flocon 260) is added to the nano feedwater to prevent the fouling of the membranes this extends the life of the filters and increases their performance. The filtered water leaving the nano unit is extremely corrosive because of all of the minerals which have been removed from the water and the permeate (filtered water) has to be treated with soda ash to increase the pH back to a range of 7.3 to 7.5*

- *Three chemicals are injected into the blended water prior to it entering the reservoir*
    1. *gaseous chlorine for primary disinfection*
    2. *C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion*
    3. *hydrofluorosilicic acid (fluoride) for dental caries*

- *The on site reservoir holds approximately 450,000 imperial gallons of water, and an elevated tower which holds approximately 85,000 imperial gallons, gives the town a fire fighting back up supply and a 1.5 to 2 day reserve for domestic use.*

- *Sodium hypochlorite (liquid chlorine) is added to the treated water prior to being pumped into the distribution system. The distribution*

system consists of a mixture of PVC and cast iron piping totaling approximately 36.6kms.

- *The water leaving the plant is controlled in two different ways*
    1. *Water tower level: which is a percentage signal received over the phone line via a modem at the tower to another modem at the water treatment plant. This signal turns the distribution pumps on and off and determines the number of pumps required directly related to the tower level.*
    2. *Flow control: this controls the pumps by a pressure signal which is produced at the plant dependant on demand in the distribution piping. This signal also controls the number of pumps required to be running and is used as a back-up to the water tower, in cases where the tower is required to be taken off line for service or repair.*

2. Water testing

The Town of Virden currently performs various tests to ensure the safety of the water leaving the plant to the consumer's tap. Under Provincial Legislation the following testing is preformed.

*2.1 **Bacteriological sampling**: the raw water supply and the treated water are tested bi-weekly for total coliform and Escherichia coli (E-coli) by ALS LABS a government approved lab. These tests are necessary to ensure the system is free of any pathogens (disease causing bacteria) which ensures a safe drinking water source for the consumer. Average results are listed at the end of this report in table #1*

*2.2 **Disinfection residuals:** a test is done at designated locations in the distribution system to ensure a free chlorine residual of 0.1 mg/L at the farthest point in the distribution system. If the 0.1 mg/L is not met the system is flushed by opening fire hydrants until the chlorine levels reach the desired level. Average results are listed at the end of this report in table #2*

*2.3 **Arsenic tests**: arsenic tests are done every 3 months on the raw water, RO permeate, and the distribution. Our current treatment process is unable to meet the drinking water standards, which have been set at 0.01 mg/L (ppm-parts per million) Results are listed at the end of this report in table #3*

*3. **In house testing:***

3.1 Chlorine tests

- *Total chlorine: a measure of all chlorine compounds in the water*
- *Free chlorine: a measure of the actual Cl_2 remaining in the water for disinfection after all chemical reactions with chlorine are complete*

3.2 TCU (true colour units): a measure of the colour of the water after being passed through a 5 micron filter. By passing the water through the filter it eliminates measuring any suspended materials such as iron and manganese in the sample and gives a more accurate reading of the actual discoloration of the water.

3.3 Iron (Fe): a measurement of both the Ferric & Ferrous iron in the water, although iron is not a health related parameter it can cause severe staining in laundry and fixtures, usually leaving brownish discolouration. Can also cause taste & odour complaints.

3.4 Manganese (Mn): is not a health related parameter but like iron can cause staining of fixtures and laundry, usually leaving blackish discolouration.

3.5 Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.

Averages for test results can be found at the end of this report in table #4

4.Current status of the WTP and future plans:

Currently our plant is not producing the water quality we would prefer to provide to the consumer, due to a combination of problems within the facility itself. The primary treatment which is ozone is unable to provide the necessary oxidation and colour removal that it was intended for and is creating an unforeseen problem by original designers in providing an oxygen enriched environment for bacterial growth within the plant. This scenario had to be corrected by the addition of an anti-oxidant chemical addition prior to the water entering the gravity filters. The bacterial growth although not eliminated has been reduced to a manageable degree. This bacterial growth has also caused fouling problems in the nano filtration system which diminishes its capacity for treatment. The plant is still able to produce a safe drinking water to the consumer, but is not meeting the current drinking water parameters for TCU, AS, and FE. Due to these ongoing problems at the plant, a pilot study was undertaken starting in October of 2007. This pilot is intended to prove or disprove the feasibility of using strictly RO for the treatment of the raw water, and should be completed in early 2008.The pilot project has been contracted to DWG Process out of Edmonton, Alberta, and the on site operation and testing will be done by Town of Virden staff. The results are being monitored by Genivar Engineering and a final report and recommendation will be forthcoming after completion of the piloting.

Future plans for the plant include the ongoing piloting of the RO system, and the study indicating which direction the town will be taking to correct the ongoing treatment shortcomings. The current piloting will be in neighborhood of $15,000 after completion, but will provide us with clear direction for future upgrades to the plant.

5. Provincial test result averages:

5.1-Bacteriological tests

Month	*Standard* *0-Tot Coli O-E.Coli*	*System average*	*Meet standard*	*Corrective action*
Jan	*0*	*0*	*Yes*	
Feb	*0*	*0*	*Yes*	
Mar	*0*	*0*	*Yes*	
Apr	*0*	*0*	*Yes*	
May	*0*	*0*	*Yes*	
Jun	*0*	*0*	*Yes*	
Jul	*0*	*0*	*Yes*	
Aug	*0*	*0*	*Yes*	
Sep	*0*	*0*	*Yes*	
Oct	*0*	*0*	*Yes*	
Nov	*0*	*0*	*Yes*	
Dec	*0*	*0*	*Yes*	

5.2-Distribution disinfection residuals (free chlorine)

Month	*Standard mg/L*	*System average*	*Meet standard*	*Corrective action*
Jan	*0.1*	*0.1*	*Yes*	
Feb	*0.1*	*0.1*	*Yes*	
Mar	*0.1*	*0.1*	*Yes*	
Apr	*0.1*	*0.1*	*Yes*	
May	*0.1*	*0.1*	*Yes*	
Jun	*0.1*	*0.2*	*Yes*	
Jul	*0.1*	*0.1*	*Yes*	
Aug	*0.1*	*0.05*	*No*	*Flush hydrant in area to raise level & retest*
Sep	*0.1*	*0.05*	*No*	*Flush hydrant in area to raise level & retest*
Oct	*0.1*	*0.1*	*Yes*	
Nov	*0.1*	*0.2*	*Yes*	
Dec	*0.1*	*0.2*	*Yes*	

5.3-Arsenic tests

Month	Standard	Distribution average	Meet standard	Corrective action
Jan	0.01	0.032	no	**Due to lowered standards our plant is**
Feb	0.01	0.033	no	**currently unable to meet the new levels**
Mar	0.01	0.032	no	
Apr	0.01	0.037	no	
May	0.01	0.039	no	Engineers start feasibility study of the WTP
Jun	0.01	0.044	no	
Jul	0.01	0.034	no	
Aug	0.01	0.034	no	Contact DWG to start with RO pilot study
Sep	0.01	0.035	no	
Oct	0.01	0.038	no	RO pilot started
Nov	0.01	0.037	no	Pilot testing
Dec	0.01	0.037	no	Pilot testing

6.In House Testing

6.1 WTP disinfection residuals (free chlorine)

Month	Standard mg/L	System average	Meet standard	Corrective action
Jan	0.5	1.4	Yes	
Feb	0.5	1.3	Yes	
Mar	0.5	1.1	Yes	
Apr	0.5	0.6	Yes	
May	0.5	0.9	Yes	
Jun	0.5	1.3	Yes	
Jul	0.5	1.1	Yes	
Aug	0.5	1.1	Yes	
Sep	0.5	1.2	Yes	
Oct	0.5	0.8	Yes	
Nov	0.5	0.4	No	Installation of liquid chlorine feed pump
Dec	0.5	1.2	Yes	Installation of feed system complete

6.2 Fe (iron) averages

Month	Objective mg/l	System average	Meet objective	Corrective action
Jan	0.3	0.1	Yes	
Feb	0.3	0.1	Yes	
Mar	0.3	0.3	Yes	
Apr	0.3	0.4	No	Chemical pump failure
May	0.3	0.4	No	"
Jun	0.3	0.4	No	"
Jul	0.3	0.4	No	"
Aug	0.3	0.4	No	"
Sep	0.3	0.4	No	"
Oct	0.3	0.4	No	New pump installed
Nov	0.3	0.4	No	Chemical pump failure
Dec	0.3	0.4	No	"

6.3 Mn (manganese) averages –raw water

Month	Objective mg/l	System average	Meet objective	Corrective action
Jan	0.05	0.029	Yes	
Feb	0.05	0.027	Yes	
Mar	0.05	0.048	Yes	
Apr	0.05	0.048	Yes	
May	0.05	0.034	Yes	
Jun	0.05	0.038	Yes	
Jul	0.05	0.028	Yes	
Aug	0.05	0.031	Yes	
Sep	0.05	0.021	Yes	
Oct	0.05	0.027	Yes	
Nov	0.05	0.022	Yes	
Dec	0.05	0.020	yes	

6.4 Turbidity averages Distribution

Month	Objective NTU	System average	Meet objective	Corrective action
Jan	0.3	0.3	Yes	
Feb	0.3	0.3	Yes	
Mar	0.3	0.3	Yes	
Apr	0.3	0.3	Yes	
May	0.3	0.4	No	Increase filter backwash
Jun	0.3	0.5	No	Check filter media
Jul	0.3	0.4	No	Pilot new filter media
Aug	0.3	0.4	No	"
Sep	0.3	0.4	No	
Oct	0.3	0.4	No	Start RO pilot
Nov	0.3	0.4	No	
Dec	0.3	0.4	No	

6.5 TCU (true colour units) averages

Month	Objective TCU	System average	Meet objective	Corrective action
Jan	8	19	No	Ozone failure
Feb	8	18	No	
Mar	8	20	No	
Apr	8	20	No	
May	8	11	No	
Jun	8	9	No	New ozone system installed
Jul	8	12	No	
Aug	8	18	No	Ozone system failure
Sep	8	15	No	
Oct	8	14	No	Ozone generator repairs
Nov	8	10	No	
Dec	8	9	No	

Conclusion:

This report was prepared by the Town of Virden to provide its rate payers with an overview of the water treatment facility current status. If you have any comments or concerns please call the town office during business hours, and we will try to answer any questions you may have. For a complete list of all test results, records are available at the office and will be posted on our website in the very near future.

Prepared by: Cornie Peters- Manager of Utilities & Works
Telephone: 1-204-748-2440 ext. 223
Dated: September 30, 2008

APPENDIX Vii

VIRDEN ANNUAL WATER REPORTS 2008

Public Water System
Annual Report

Water Treatment Process Description:

Raw water supply

- *The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. The wells are both 60 feet deep with a 60HP, submersible turbine pump in each well*

Water treatment process

- *The raw water is pumped into the water plant at a rate of 25 to 26 litres/second, with a total plant capacity of 45 litres/second. The water upon reaching the plant is treated with ozone to oxidize the iron and manganese, and arsenic. After the ozonation a chemical (sodium metabisulfite) is added to bind the oxygen in the water to stop the biological growth of iron bacteria. The water then goes through a set of dual media gravity filters containing greensand/granular activated carbon for the partial removal of the oxidized iron, manganese and arsenic. Due to the arsenic left in the treated water approximately 40% of the filtered water is pumped to a nanofiltration unit to reduce the arsenic to below the drinking water standards. An antiscalant (Flocon 260) is added to the nano feedwater to prevent the fouling of the membranes this extends the life of the filters and increases their performance. The filtered water leaving the nano unit is extremely corrosive because of all of the minerals which have been removed from the water and the permeate (filtered water) has to be treated with soda ash to increase the pH back to a range of 7.3 to 7.5*
- *Three chemicals are injected into the blended water prior to it entering the reservoir*
    1. *gaseous chlorine for primary disinfection*
    2. *C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion*
    3. *hydrofluorosilicic acid (fluoride) for dental caries*
- *The on site reservoir holds approximately 450,000 imperial gallons of water, and an elevated tower which holds approximately 85,000 imperial gallons, gives the town a fire fighting back up supply and a 1.5 to 2 day reserve for domestic use.*
- *Sodium hypochlorite (liquid chlorine) is added to the treated water prior to being pumped into the distribution system. The distribution*

system consists of a mixture of PVC and cast iron piping totaling approximately 36.6kms.

- *The water leaving the plant is controlled in two different ways*
    1. *Water tower level: which is a percentage signal received over the phone line via a modem at the tower to another modem at the water treatment plant. This signal turns the distribution pumps on and off and determines the number of pumps required directly related to the tower level.*
    2. *Flow control: this controls the pumps by a pressure signal which is produced at the plant dependant on demand in the distribution piping. This signal also controls the number of pumps required to be running and is used as a back-up to the water tower, in cases where the tower is required to be taken off line for service or repair.*

Water testing

The Town of Virden currently performs various tests to ensure the safety of the water leaving the plant to the consumer's tap.

***Bacteriological sampling**: the raw water supply and the treated water are tested bi-weekly for total coliform and Escherichia coli (E-coli) by ALS LABS a government approved lab. These tests are necessary to ensure the system is free of any pathogens (disease causing bacteria) which ensures a safe drinking water source for the consumer. Average results are listed at the end of this report in table #1*

***Disinfection residuals:** a test is done at designated locations in the distribution system to ensure a free chlorine residual of 0.1 mg/L at the farthest point in the distribution system. If the 0.1 mg/L is not met the system is flushed by opening fire hydrants until the chlorine levels reach the desired level. Average results are listed at the end of this report in table #2*

***Trihalomethane sampling (THM)**: THMs are formed when chlorine is combined with organics in the water. THMs are considered to be carcinogens (cancer causing compounds) and therefore are regulated by the province. Results are listed at the end of this report in table #3*

***Turbidity tests**: measured in NTU (nephelometric turbidity units). This test is done on the raw water, to determine whether or not there are any changes in the water supply, and is a measure of the cloudiness or clarity of the water. Average results are listed at the end of this report in table #4*

***Onsite testing**:*

Chlorine tests

- *Total chlorine: a measure of all chlorine compounds in the water*

- *Free chlorine: a measure of the actual Cl_2 remaining in the water for disinfection after all chemical reactions with chlorine are complete*

TCU (true colour units): a measure of the colour of the water after being passed through a 5 micron filter. By passing the water through the filter it eliminates measuring any suspended materials such as iron and manganese in the sample and gives a more accurate reading of the actual discoloration of the water.

Iron (Fe): a measurement of both the Ferric & Ferrous iron in the water, although iron is not a health related parameter it can cause severe staining in laundry and fixtures, usually leaving brownish stains. Can also cause taste & odour complaints.

Manganese (Mn): is not a health related parameter but like iron can cause staining of fixtures and laundry.

Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.
Averages for test results can be found at the end of this report in table #5

Current status of the WTP and future plans:

Currently our plant is not producing the water quality we would prefer to provide to the consumer, due to a combination of problems within the facility itself. The primary treatment which is ozone is unable to provide the necessary oxidation and colour removal that it was intended for and is creating an unforeseen problem by original designers in providing an oxygen enriched environment for bacterial growth within the plant. This scenario had to be corrected by the addition of an anti-oxidant chemical addition prior to the water entering the gravity filters. The bacterial growth although not eliminated has been reduced to a manageable degree. This bacterial growth has also caused fouling problems in the nano filtration system which diminishes its capacity for treatment. The plant is still able to produce a safe drinking water to the consumer, but is not meeting the current drinking water parameters for THMs, TCU, Fe, and TOC. Due to these ongoing problems at the plant, a pilot study was undertaken starting in October of 2007 and completed in February of 2008, to determine what improvements or changes could be done to the treatment process in order to meet or even exceed the current and or future standards for drinking water. The study was conducted by DWG Process (Edmonton, Alberta), and the Town of Virden, under the direction of GENIVAR Engineering. The results were conclusive, indicating that our current process would not be able to be made to work, and that a new process was required for our treatment plant. This prompted the piloting of a new reverse osmosis (RO) system, running our raw water directly through the RO without any prior pretreatment. The results of the piloting were studied by DWG and Genivar Engineering and a recommendation to change our process to RO was given by Genivar and approved by town council. We are currently awaiting the final design of the system, at which time requests for tenders will be sent to different *manufacturers for pricing. The preliminary results and design show that the existing facility will be sufficient for housing the new equipment and little changes other than piping, electrical, and removal of existing equipment will be required. The new process will also include water stabilization, which is scheduled for piloting in February of 2009 and will be run for approximately one month, this process is necessary to establish the proper pH of the treated water to avoid any corrosion of the main water lines, and services to individual residence.*

The projected cost for the upgrade to the existing water treatment process is estimated to be approximately two million dollars, and a projected time frame for installation is 2009.

5. Provincial test result averages:

5.1-Bacteriological tests

Month	*Standard* 0-Tot Coli O-E.Coli	*System average*	*Meet standard*	*Corrective action*
Jan	*0*	*0*	*Yes*	
Feb	*0*	*0*	*Yes*	
Mar	*0*	*0*	*Yes*	
Apr	*0*	*0*	*Yes*	
May	*0*	*0*	*Yes*	
Jun	*0*	*0*	*Yes*	
Jul	*0*	*0*	*Yes*	
Aug	*0*	*0*	*Yes*	
Sep	*0*	*0*	*Yes*	
Oct	*0*	*0*	*Yes*	
Nov	*0*	*0*	*Yes*	
Dec	*0*	*0*	*Yes*	

***5.2-Distribution disinfection residuals** (free chlorine)*

Month	*Standard mg/L*	*System average*	*Meet standard*	*Corrective action*
Jan	*0.1*	*0.1*	*Yes*	
Feb	*0.1*	*0.2*	*Yes*	
Mar	*0.1*	*0.1*	*Yes*	
Apr	*0.1*	*0.1*	*Yes*	
May	*0.1*	*0.1*	*Yes*	
Jun	*0.1*	*0.2*	*Yes*	
Jul	*0.1*	*0.09*	*Yes*	*Flush hydrant in area, level = 0.15 after flushing*
Aug	*0.1*	*0.1*	*No*	
Sep	*0.1*	*0.1*	*No*	
Oct	*0.1*	*0.1*	*Yes*	
Nov	*0.1*	*0.1*	*Yes*	
Dec	*0.1*	*0.1*	*Yes*	

5.3-Arsenic tests

Month	*Standard*	*Distribution average*	*Meet standard*	*Corrective action*
Jan	*0.01*	*0.041*	*no*	*Continue pilot testing*
Feb	*0.01*	*0.042*	*no*	*Pilot testing complete*
Mar	*0.01*	*0.043*	*no*	
Apr	*0.01*	*0.033*	*no*	
May	*0.01*	*0.034*	*no*	***Due to lowered standards our plant is***
Jun	*0.01*	*0.043*	*no*	***currently unable to meet the new levels***
Jul	*0.01*	*0.039*	*no*	
Aug	*0.01*	*0.040*	*no*	
Sep	*0.01*	*0.044*	*no*	
Oct	*0.01*	*0.041*	*no*	
Nov	*0.01*	*0.040*	*no*	
Dec	*0.01*	*0.044*	*no*	

6.In House Testing

6.1 WTP disinfection residuals (free chlorine)

Month	*Standard mg/L*	*System average*	*Meet standard*	*Corrective action*
Jan	*0.5*	*1.4*	*Yes*	
Feb	*0.5*	*1.3*	*Yes*	
Mar	*0.5*	*1.1*	*Yes*	
Apr	*0.5*	*0.6*	*Yes*	
May	*0.5*	*0.9*	*Yes*	
Jun	*0.5*	*1.3*	*Yes*	
Jul	*0.5*	*1.1*	*Yes*	
Aug	*0.5*	*1.1*	*Yes*	
Sep	*0.5*	*1.2*	*Yes*	
Oct	*0.5*	*0.8*	*Yes*	*Installation of liquid chlorine feed pump*
Nov	*0.5*	*0.4*	*No*	*Installation of feed system complete*
Dec	*0.5*	*1.2*	*Yes*	

6.2 Fe (iron) averages

Month	Objective mg/l	System average	Meet objective	Corrective action
Jan	0.3	0.1	Yes	Pilot testing of new process
Feb	0.3	0.1	Yes	
Mar	0.3	0.3	Yes	
Apr	0.3	0.4	No	
May	0.3	0.4	No	
Jun	0.3	0.4	No	
Jul	0.3	0.4	No	
Aug	0.3	0.4	No	
Sep	0.3	0.4	No	
Oct	0.3	0.4	No	
Nov	0.3	0.4	No	
Dec	0.3	0.4	No	

6.3 Mn (manganese) averages –raw water

Month	Objective mg/l	System average	Meet objective	Corrective action
Jan	0.05	0.029	Yes	
Feb	0.05	0.027	Yes	
Mar	0.05	0.048	Yes	
Apr	0.05	0.048	Yes	
May	0.05	0.034	Yes	
Jun	0.05	0.038	Yes	
Jul	0.05	0.028	Yes	
Aug	0.05	0.031	Yes	
Sep	0.05	0.021	Yes	
Oct	0.05	0.027	Yes	
Nov	0.05	0.022	Yes	
Dec	0.05	0.020	yes	

6.4 Turbidity averages Distribution

Month	Objective NTU	System average	Meet objective	Corrective action
Jan	0.3	0.3	Yes	Pilot testing of new process
Feb	0.3	0.3	Yes	
Mar	0.3	0.3	Yes	
Apr	0.3	0.3	Yes	
May	0.3	0.4	No	
Jun	0.3	0.5	No	
Jul	0.3	0.4	No	
Aug	0.3	0.4	No	
Sep	0.3	0.4	No	
Oct	0.3	0.4	No	
Nov	0.3	0.4	No	
Dec	0.3	0.4	No	

6.5 TCU (true colour units) averages

Month	Objective TCU	System average	Meet objective	Corrective action
Jan	8	19	No	Pilot testing of new process
Feb	8	18	No	
Mar	8	20	No	
Apr	8	20	No	
May	8	11	No	
Jun	8	9	No	
Jul	8	12	No	
Aug	8	18	No	
Sep	8	15	No	
Oct	8	14	No	
Nov	8	10	No	
Dec	8	9	No	

Conclusion:

This report was prepared by the Town of Virden to provide its rate payers with an overview of the water treatment facility current status. If you have any comments or concerns please call the town office during business hours, and we will try to answer any questions you may have. For a complete list of all test results, records are available at the office and will be posted on our website by the end of March 2009 for the period of this report.

Prepared by: Cornie Peters- Manager of Utilities & Works
Telephone: 1-204-748-2440 ext. 223
Dated: January 21, 2009

APPENDIX Viii

VIRDEN ANNUAL WATER REPORTS 2009

Public Water System
Annual Report

Water Treatment Process Description:

Raw water supply

- *The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. The wells are both 60 feet deep with a 60HP, submersible turbine pump in each well*

Water treatment process

- *The raw water is pumped into the water plant at a rate of 25 to 26 litres/second, with a total plant capacity of 45 litres/second. The water upon reaching the plant is treated with ozone to oxidize the iron and manganese, and arsenic. After the ozonation a chemical (sodium metabisulfite) is added to bind the oxygen in the water to stop the biological growth of iron bacteria. The water then goes through a set of dual media gravity filters containing greensand/granular activated carbon for the partial removal of the oxidized iron, manganese and arsenic. Due to the arsenic left in the treated water approximately 40% of the filtered water is pumped to a nanofiltration unit to reduce the arsenic to below the drinking water standards. An antiscalant (Flocon 260) is added to the nano feedwater to prevent the fouling of the membranes this extends the life of the filters and increases their performance. The filtered water leaving the nano unit is extremely corrosive because of all of the minerals which have been removed from the water and the permeate (filtered water) has to be treated with soda ash to increase the pH back to a range of 7.3 to 7.5*
- *Three chemicals are injected into the blended water prior to it entering the reservoir*
  1. *gaseous chlorine for primary disinfection*
  2. *C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion*
  3. *hydrofluorosilicic acid (fluoride) for dental caries*
- *The on site reservoir holds approximately 450,000 imperial gallons of water, and an elevated tower which holds approximately 85,000 imperial gallons, gives the town a fire fighting back up supply and a 1.5 to 2 day reserve for domestic use.*
- *Sodium hypochlorite (liquid chlorine) is added to the treated water prior to being pumped into the distribution system. The distribution*

system consists of a mixture of PVC and cast iron piping totaling approximately 36.6kms.

- *The water leaving the plant is controlled in two different ways*
    1. *Water tower level: which is a percentage signal received over the phone line via a modem at the tower to another modem at the water treatment plant. This signal turns the distribution pumps on and off and determines the number of pumps required directly related to the tower level.*
    2. *Flow control: this controls the pumps by a pressure signal which is produced at the plant dependant on demand in the distribution piping. This signal also controls the number of pumps required to be running and is used as a back-up to the water tower, in cases where the tower is required to be taken off line for service or repair.*

Water testing

The Town of Virden currently performs various tests to ensure the safety of the water leaving the plant to the consumer's tap.

***Bacteriological sampling**: the raw water supply and the treated water are tested bi-weekly for total coliform and Escherichia coli (E-coli) by ALS LABS a government approved lab. These tests are necessary to ensure the system is free of any pathogens (disease causing bacteria) which ensures a safe drinking water source for the consumer. Average results are listed at the end of this report in table #1*

***Disinfection residuals:** a test is done at designated locations in the distribution system to ensure a free chlorine residual of 0.1 mg/L at the farthest point in the distribution system. If the 0.1 mg/L is not met the system is flushed by opening fire hydrants until the chlorine levels reach the desired level. Average results are listed at the end of this report in table #2*

***Trihalomethane sampling (THM)**: THMs are formed when chlorine is combined with organics in the water. THMs are considered to be carcinogens (cancer causing compounds) and therefore are regulated by the province. Results are listed at the end of this report in table #3*

***Turbidity tests**: measured in NTU (nephelometric turbidity units). This test is done on the raw water, to determine whether or not there are any changes in the water supply, and is a measure of the cloudiness or clarity of the water. Average results are listed at the end of this report in table #4*

***Onsite testing**:*

Chlorine tests

- *Total chlorine: a measure of all chlorine compounds in the water*

- *Free chlorine: a measure of the actual Cl_2 remaining in the water for disinfection after all chemical reactions with chlorine are complete*

TCU (true colour units): a measure of the colour of the water after being passed through a 5 micron filter. By passing the water through the filter it eliminates measuring any suspended materials such as iron and manganese in the sample and gives a more accurate reading of the actual discoloration of the water.

Iron (Fe): a measurement of both the Ferric & Ferrous iron in the water, although iron is not usually considered to be a health related mineral, it can cause severe staining in laundry and fixtures, usually leaving brownish stains. Can also cause taste & odour complaints.

Manganese (Mn): is not a health related parameter but like iron can cause staining of fixtures and laundry.

Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.
Averages for test results can be found at the end of this report in table #5

Current status of the WTP and future plans:

Currently our plant is not producing the water quality we would prefer to provide to the consumer, due to a combination of problems within the facility itself. The primary treatment which is ozone is unable to provide the necessary oxidation and colour removal that it was intended for and is creating an unforeseen problem by original designers in providing an oxygen enriched environment for bacterial growth within the plant. This scenario had to be corrected by the addition of an anti-oxidant chemical addition prior to the water entering the gravity filters. The bacterial growth although not eliminated has been reduced to a manageable degree. This bacterial growth has also caused fouling problems in the nano filtration system which diminishes its capacity for treatment. The plant is still able to produce a safe drinking water to the consumer, but is not meeting the current drinking water parameters for THMs, TCU, Fe, and TOC. Due to these ongoing problems at the plant, a pilot study was undertaken starting in October of 2007 and completed in February of 2008, to determine what improvements or changes could be done to the treatment process in order to meet or even exceed the current and or future standards for drinking water. The study was conducted by DWG Process (Edmonton, Alberta), and the Town of Virden, under the direction of GENIVAR Engineering. The results were conclusive, indicating that our current process would not be able to be made to work, and that a new process was required for our treatment plant. This prompted the piloting of a new reverse osmosis (RO) system, running our raw water directly through the RO without any prior pretreatment. The results of the piloting were studied by DWG and Genivar Engineering and a recommendation to change our process to RO was given by Genivar and approved by town council.

The equipment contract for the new RO process has been awarded to GE Osmonics, from Minnetonka, Minnesota.

The projected cost for the upgrade to the existing water treatment process is estimated to be approximately 1.8 million dollars, and a projected time frame for installation is February of 2010. The demolition/removal of the existing treatment process was started in December of 2009, and interim treatment of pre filter chlorination and post filter chlorination initiated, on December23, 2009.

5. Provincial test result averages:

5.1-Bacteriological tests

Month	Standard 0-Tot Coli O-E.Coli	System average	Meet standard	Corrective action
Jan	0	0	Yes	
Feb	0	0	Yes	
Mar	0	0	Yes	
Apr	0	0	Yes	
May	0	0	Yes	
Jun	0	0	Yes	
Jul	0	0	Yes	
Aug	0	0	Yes	
Sep	0	0	Yes	
Oct	0	0	Yes	
Nov	0	0	Yes	
Dec	0	0	Yes	

5.2-Distribution disinfection residuals (free chlorine)

Month	Standard mg/L	System low	Meet standard	Corrective action
Jan	0.1	0.13	Yes	
Feb	0.1	0.13	Yes	
Mar	0.1	0.12	Yes	
Apr	0.1	0.11	Yes	
May	0.1	0.10	Yes	
Jun	0.1	0.10	Yes	
Jul	0.1	0.05	No	Flush hydrant in area, result = 0.07mg/L
Aug	0.1	0.07	No	Flush hydrant in area, result = 0..19mg/L
Sep	0.1	0.10	Yes	
Oct	0.1	0.04	No	Flush hydrant in area, result = 0.12mg/L
Nov	0.1	0.10	Yes	
Dec	0.1	0.10	yes	

5.3-Arsenic tests

Month	Standard	Distribution average	Meet standard	Corrective action
Jan	0.01	0.040	No	Plant upgrade in 2010
Feb	0.01	0.047	No	"
Mar	0.01	0.046	No	"
Apr	0.01	0.044	No	"
May	0.01	0.040	No	"
Jun	0.01	0.046	No	"
Jul	0.01	0.041	No	"
Aug	0.01	0.043	No	"
Sep	0.01	0.043	No	"
Oct	0.01	0.040	No	"
Nov	0.01	0.044	No	"
Dec	0.01	0.040	No	"

6.In House Testing

6.1 WTP disinfection residuals (free chlorine)

Month	Standard mg/L	System average	Meet standard	Corrective action
Jan	0.5	0.61	Yes	
Feb	0.5	0.75	Yes	
Mar	0.5	0.52	Yes	
Apr	0.5	0.75	Yes	
May	0.5	0.55	Yes	
Jun	0.5	0.52	Yes	
Jul	0.5	0.52	Yes	
Aug	0.5	0.67	Yes	
Sep	0.5	0.25	No	Sep 13, divert RO permeate flow to reservoir Sep 14 residual =0.5mg/L
Oct	0.5	0.30	No	Oct 30, increase chlorine feed, Oct 31residual = 0.54mg/L
Nov	0.5	1.03	Yes	
Dec	0.5	1.67	Yes	

6.2 Fe (iron) averages

Month	Objective mg/l	System average	Meet objective	Corrective action
Jan	0.3	0.42	No	Upgrade to plant for 2010
Feb	0.3	0.47	No	"
Mar	0.3	0.43	No	"
Apr	0.3	0.49	No	"
May	0.3	0.46	No	"
Jun	0.3	0.45	No	"
Jul	0.3	0.40	No	"
Aug	0.3	0.39	No	"
Sep	0.3	0.37	No	"
Oct	0.3	0.38	No	"
Nov	0.3	0.37	No	"
Dec	0.3	0.24	yes	"

6.3 Mn (manganese) averages –raw water

Month	Objective mg/l	System average	Meet objective	Corrective action
Jan	0.05	0.036	Yes	
Feb	0.05	0.037	Yes	
Mar	0.05	0.045	Yes	
Apr	0.05	0.045	Yes	
May	0.05	0.042	Yes	
Jun	0.05	0.040	Yes	
Jul	0.05	0.040	Yes	
Aug	0.05	0.040	Yes	
Sep	0.05	0.060	No	Regenerate filters
Oct	0.05	0.030	Yes	
Nov	0.05	0.045	Yes	
Dec	0.05	0.037	Yes	

6.4 Turbidity averages Distribution

Month	Objective NTU	System average	Meet objective	Corrective action
Jan	0.3	0.42	No	Upgrade to plant for 2010
Feb	0.3	0.42	No	"
Mar	0.3	0.40	No	"
Apr	0.3	0.38	No	"
May	0.3	0.43	No	"
Jun	0.3	0.38	No	"
Jul	0.3	0.38	No	"
Aug	0.3	0.40	No	"
Sep	0.3	0.50	No	"
Oct	0.3	0.36	No	"
Nov	0.3	0.41	No	"
Dec	0.3	0.33	No	"

6.5 TCU (true colour units) averages

Month	Objective TCU	System average	Meet objective	Corrective action
Jan	8	12	No	Upgrade to plant for 2010
Feb	8	13	No	"
Mar	8	12	No	"
Apr	8	12	No	"
May	8	9	No	"
Jun	8	13	No	"
Jul	8	11	No	"
Aug	8	8	Yes	"
Sep	8	11	No	"
Oct	8	8	Yes	"
Nov	8	9	No	"
Dec	8	6	yes	"

Conclusion:

This report was prepared by the Town of Virden to provide its rate payers with an overview of the water treatment facility current status. If you have any comments or concerns please call the town office during business hours, and we will try to answer any questions you may have. For a complete list of all test results, records are available at the office and will be posted on our website by the end of March 2010 for the period of this report.

Prepared by: Cornie Peters- Water and Waste Foreman
Telephone: 1-204-748-2440
Dated: January 21, 2010

APPENDIX Viv

VIRDEN ANNUAL WATER REPORTS 2010

Public Water System
2010 Annual Report

Water Treatment Process Description:

Raw water supply

- The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. The wells are both 60 feet deep with a 60HP, submersible turbine pump in each well

Water treatment process

- Reverse osmosis water filtration is a process in which dissolved salts and metal ions, along with organic compounds and bacteria are removed from the feed (raw) water. High pressure pumps force the feed water through a semi-permeable membrane which filters out the contaminants, allowing only the purified water through.
- Three chemicals are injected into the blended water prior to it entering the reservoir
    1. Sodium hypochlorite (liquid chlorine) for primary disinfection
    2. C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion
    3. hydrofluorosilicic acid (fluoride) for dental caries
- The on site reservoir holds approximately 450,000 imperial gallons of water, and an elevated tower which holds approximately 85,000 imperial gallons, gives the town a fire fighting back up supply and a 1.5 to 2 day reserve for domestic use.
- The water leaving the plant is controlled in two different ways
    1. Water tower level: which is a percentage signal received over the phone line via a modem at the tower to another modem at the water treatment plant. This signal turns the distribution pumps on and off and determines the number of pumps required directly related to the tower level.
    2. Flow control: this controls the pumps by a pressure signal which is produced at the plant dependant on demand in the distribution piping. This signal also controls the number of pumps required to be running and is used as a back-up to the water tower, in cases where the tower is required to be taken off line for service or repair.

Water testing

The Town of Virden currently performs various tests to ensure the safety of the water leaving the plant to the consumer's tap.

Bacteriological sampling: the raw water supply and the treated water are tested bi-weekly for total coliform and Escherichia coli (E-coli) by ALS LABS a government approved lab. These tests are necessary to ensure the system is free of any pathogens (disease causing bacteria) which ensures a safe drinking water source for the consumer.

Disinfection residuals: a test is done at designated locations in the distribution system to ensure a free chlorine residual of 0.1 mg/L at the farthest point in the distribution system. If the 0.1 mg/L is not met the system is flushed by opening fire hydrants until the chlorine levels reach the desired level.

Trihalomethane sampling (THM): THMs are formed when chlorine is combined with organics in the water. THMs are considered to be carcinogens (cancer causing compounds) and therefore are regulated by the province.

Turbidity tests: measured in NTU (nephelometric turbidity units). This test is done on the raw water, to determine whether or not there are any changes in the water supply, and is a measure of the cloudiness or clarity of the water.

Onsite testing:

Chlorine tests

- Total chlorine: a measure of all chlorine compounds in the water
- Free chlorine: a measure of the actual Cl_2 remaining in the water for disinfection after all chemical reactions with chlorine are complete

TCU (true colour units): a measure of the colour of the water after being passed through a 5 micron filter. By passing the water through the filter it eliminates measuring any suspended materials such as iron and manganese in the sample and gives a more accurate reading of the actual discoloration of the water.

Iron (Fe): a measurement of both the Ferric & Ferrous iron in the water, although iron is not a health related parameter it can cause severe staining in laundry and fixtures, usually leaving brownish stains. Can also cause taste & odour complaints.

Manganese (Mn): is not a health related parameter but like iron can cause staining of fixtures and laundry.

Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.

Bacteriological Tests

Month	Standard mg/L	System low	Meet Standard	Corrective Action
Jan	0	0	Yes	
Feb	0	0	Yes	
Mar	0	0	Yes	
Apr	0	0	Yes	
May	0	0	Yes	
Jun	0	0	Yes	
Jul	0	0	Yes	
Aug	0	0	Yes	
Sep	0	0	Yes	
Oct	0	0	Yes	
Nov	0	0	Yes	
Dec	0	0	Yes	

Distribution Disinfection Residuals (free chlorine)

Month	Standard mg/L	System low	Meet Standard	Corrective Action
Jan	0.1	.89	Yes	
Feb	0.1	1.21	Yes	
Mar	0.1	.49	Yes	
Apr	0.1	.86	Yes	
May	0.1	.57	Yes	
Jun	0.1	.63	Yes	
Jul	0.1	.59	Yes	
Aug	0.1	.76	Yes	
Sep	0.1	.97	Yes	
Oct	0.1	1.17	Yes	
Nov	0.1	1.33	Yes	
Dec	0.1	2.1	Yes	

Arsenic Tests

Month	Standard	System Average	Meet Standard	Corrective Action
Jan	0.01	During Construction		
Feb	0.01	During Construction		
Mar	0.01	During Construction		
Apr	0.01	During Construction		
May	0.01	During Construction		
Jun	0.01	0.009	Yes	
Jul	0.01	0.0092	Yes	
Aug	0.01	0.0119	No	
Sep	0.01	0.0122	No	
Oct	0.01	0.0098	Yes	
Nov	0.01	0.013	No	
Dec	0.01	0.014	No	

WTP Disinfection Residuals (free chlorine)

Month	Standard mg/L	System average	Meet Standard	Corrective Action
Jan	0.5	2.92	Yes	
Feb	0.5	4.41	Yes	
Mar	0.5	2.18	Yes	
Apr	0.5	2.45	Yes	
May	0.5	2.73	Yes	
Jun	0.5	1.41	Yes	
Jul	0.5	1.34	Yes	
Aug	0.5	1.51	Yes	
Sep	0.5	1.89	Yes	
Oct	0.5	1.88	Yes	
Nov	0.5	2.41	Yes	
Dec	0.5	4.56	Yes	

Fe (Iron) Averages

Month	Objective mg/L	System average	Meet Objective	Corrective Action
Jan	0.3			
Feb	0.3			
Mar	0.3			
Apr	0.3			
May	0.3			
Jun	0.3			
Jul	0.3			
Aug	0.3			
Sep	0.3			
Oct	0.3			
Nov	0.3			
Dec	0.3			

Mn (Manganese) Averages – Raw Water

Month	Objective mg/L	System average	Meet Objective	Corrective Action
Jan	0.5			
Feb	0.5			
Mar	0.5			
Apr	0.5			
May	0.5			
Jun	0.5			
Jul	0.5			
Aug	0.5			
Sep	0.5			
Oct	0.5			
Nov	0.5			
Dec	0.5			

Turbidity Averages Distribution

Month	Objective NTU	System average	Meet Objective	Corrective Action
Jan	0.3			
Feb	0.3			
Mar	0.3			
Apr	0.3			
May	0.3			
Jun	0.3			
Jul	0.3			
Aug	0.3			
Sep	0.3			
Oct	0.3			
Nov	0.3			
Dec	0.3			

Current Operator: **Kevin Enns**
Water Treatment – Class II
Water Distribution – Class II
Wastewater Treatment – Class II
Wastewater Collection Operator – Class II

Operator-in-Training: **Brian Johnson**
Water Treatment – Class I
Water Distribution – Class I
Wastewater Treatment – Class I

Water Treatment Plant Classification: Class II

Distribution System Level: Class II

For further information, please contact Kevin Enns, Manager of Utilities, at 748-2440.

APPENDIX Vv

VIRDEN ANNUAL WATER REPORTS 2011

Public Water System
2011 Annual Report

Water Treatment Process Description:

Raw water supply

- The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. The wells are both 60 feet deep with a 60HP, submersible turbine pump in each well

Water treatment process

- Reverse osmosis water filtration is a process in which dissolved salts and metal ions, along with organic compounds and bacteria are removed from the feed (raw) water. High pressure pumps force the feed water through a semi-permeable membrane which filters out the contaminants, allowing only the purified water through.
- Three chemicals are injected into the blended water prior to it entering the reservoir
    1. Sodium hypochlorite (liquid chlorine) for primary disinfection
    2. C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion
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Disinfection residuals: a test is done at designated locations in the distribution system to ensure a free chlorine residual of 0.1 mg/L at the farthest point in the distribution system. If the 0.1 mg/L is not met the system is flushed by opening fire hydrants until the chlorine levels reach the desired level.

Trihalomethane sampling (THM): THMs are formed when chlorine is combined with organics in the water. THMs are considered to be carcinogens (cancer causing compounds) and therefore are regulated by the province.

Turbidity tests: measured in NTU (nephelometric turbidity units). This test is done on the raw water, to determine whether or not there are any changes in the water supply, and is a measure of the cloudiness or clarity of the water.

Onsite testing:

Chlorine tests

- Total chlorine: a measure of all chlorine compounds in the water
- Free chlorine: a measure of the actual Cl_2 remaining in the water for disinfection after all chemical reactions with chlorine are complete

TCU (true colour units): a measure of the colour of the water after being passed through a 5 micron filter. By passing the water through the filter it eliminates measuring any suspended materials such as iron and manganese in the sample and gives a more accurate reading of the actual discoloration of the water.

Iron (Fe): a measurement of both the Ferric & Ferrous iron in the water, although iron is not a health related parameter it can cause severe staining in laundry and fixtures, usually leaving brownish stains. Can also cause taste & odour complaints.

Manganese (Mn): is not a health related parameter but like iron can cause staining of fixtures and laundry.

Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.

Bacteriological Tests

Month	Standard 0-Tot Coli 0 – E. Coli	System Average	Meet Standard	Corrective Action
Jan	0	0	Yes	
Feb	0	0	Yes	
Mar	0	0	Yes	
Apr	0	0	Yes	
May	0	0	Yes	
Jun	0	0	Yes	
Jul	0	0	Yes	
Aug	0	0	Yes	
Sep	0	0	Yes	
Oct	0	0	Yes	
Nov	0	0	Yes	
Dec	0	0	Yes	

Distribution Disinfection Residuals (free chlorine)

Month	Standard mg/L	System low	Meet Standard	Corrective Action
Jan	0.1	1.87	Yes	
Feb	0.1	1.01	Yes	
Mar	0.1	1.08	Yes	
Apr	0.1	1.42	Yes	
May	0.1	.62	Yes	
Jun	0.1	.93	Yes	
Jul	0.1	.90	Yes	
Aug	0.1	.63	Yes	
Sep	0.1	.60	Yes	
Oct	0.1	.52	Yes	
Nov	0.1	.72	Yes	
Dec	0.1	.69	Yes	

Arsenic Tests

Month	Standard	Distribution Average	Meet Standard	Corrective Action
Jan	0.01			
Feb	0.01	0.013	No	
Mar	0.01	0.015	No	
Apr	0.01	0.018	No	
May	0.01			
Jun	0.01	0.0157	No	
Jul	0.01	0.0155	No	
Aug	0.01	0.0154	No	
Sep	0.01	0.0145	No	
Oct	0.01	0.0135	No	
Nov	0.01	0.0142	No	
Dec	0.01	0.0112	No	

WTP Disinfection Residuals (free chlorine)

Month	Standard mg/L	System average	Meet Standard	Corrective Action
Jan	0.5	2.39	Yes	
Feb	0.5	1.48	Yes	
Mar	0.5	1.29	Yes	
Apr	0.5	1.58	Yes	
May	0.5	1.26	Yes	
Jun	0.5	1.21	Yes	
Jul	0.5	1.33	Yes	
Aug	0.5	1.22	Yes	
Sep	0.5	1.27	Yes	
Oct	0.5	1.23	Yes	
Nov	0.5	1.39	Yes	
Dec	0.5	1.19	Yes	

Fe (Iron) Averages

Month	Objective mg/L	System average	Meet Objective	Corrective Action
Jan	0.3	0.17	Yes	
Feb	0.3	0.002	Yes	
Mar	0.3			
Apr	0.3	0.022	Yes	
May	0.3	0.020	Yes	
Jun	0.3	0.019	Yes	
Jul	0.3	0.022	Yes	
Aug	0.3	0.017	Yes	
Sep	0.3	0.01	Yes	
Oct	0.3	0.02	Yes	
Nov	0.3	0.015	Yes	
Dec	0.3	0.03	Yes	

Mn (Manganese) Averages – Raw Water

Month	Objective mg/L	System average	Meet Objective	Corrective Action
Jan	0.5	0.0	Yes	
Feb	0.5	0.002	Yes	
Mar	0.5			
Apr	0.5	0.002	Yes	
May	0.5	0.001	Yes	
Jun	0.5	0.002	Yes	
Jul	0.5	0.003	Yes	
Aug	0.5	0.016	Yes	
Sep	0.5	0.002	Yes	
Oct	0.5	0.002	Yes	
Nov	0.5	0.015	Yes	
Dec	0.5	0.01	Yes	

Turbidity Averages Distribution

Month	Objective NTU	System average	Meet Objective	Corrective Action
Jan	0.3	0.35	No	
Feb	0.3	0.21	Yes	
Mar	0.3	4.6 – R.O off	No	
Apr	0.3	0.25	Yes	
May	0.3	0.27	Yes	
Jun	0.3	0.37	No	
Jul	0.3	0.25	Yes	
Aug	0.3	0.12	Yes	
Sep	0.3	0.17	Yes	
Oct	0.3	0.15	Yes	
Nov	0.3	0.25	Yes	
Dec	0.3	0.17	Yes	

Current Operator: **Kevin Enns**
Water Treatment – Class II
Water Distribution – Class II
Wastewater Treatment – Class II
Wastewater Collection Operator – Class II

Operator-in-Training: **Brian Johnson**
Water Treatment – Class I
Water Distribution – Class I
Wastewater Treatment – Class I

Water Treatment Plant Classification: Class II

Distribution System Level: Class II

For further information, please contact Kevin Enns, Manager of Utilities, at 748-2440.

APPENDIX Vvi

VIRDEN ANNUAL WATER REPORTS 2012

Public Water System
2012 Annual Report

Water Treatment Process Description:

Raw water supply

- The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. The wells are both 60 feet deep with a 60HP, submersible turbine pump in each well

Water treatment process

- Reverse osmosis water filtration is a process in which dissolved salts and metal ions, along with organic compounds and bacteria are removed from the feed (raw) water. High pressure pumps force the feed water through a semi-permeable membrane which filters out the contaminants, allowing only the purified water through.
- Three chemicals are injected into the blended water prior to it entering the reservoir
    1. Sodium hypochlorite (liquid chlorine) for primary disinfection
    2. C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion
    3. hydrofluorosilicic acid (fluoride) for dental caries
- The on site reservoir holds approximately 450,000 imperial gallons of water, and an elevated tower which holds approximately 85,000 imperial gallons, gives the town a fire fighting back up supply and a 1.5 to 2 day reserve for domestic use.
- The water leaving the plant is controlled in two different ways
    1. <u>Water tower level</u>: which is a percentage signal received over the phone line via a modem at the tower to another modem at the water treatment plant. This signal turns the distribution pumps on and off and determines the number of pumps required directly related to the tower level.
    2. <u>Flow control</u>: this controls the pumps by a pressure signal which is produced at the plant dependant on demand in the distribution piping. This signal also controls the number of pumps required to be running and is used as a back-up to the water tower, in cases where the tower is required to be taken off line for service or repair.

Water testing

The Town of Virden currently performs various tests to ensure the safety of the water leaving the plant to the consumer's tap.

Bacteriological sampling: the raw water supply and the treated water are tested bi-weekly for total coliform and Escherichia coli (E-coli) by ALS LABS a government approved lab. These tests are necessary to ensure the system is free of any pathogens (disease causing bacteria) which ensures a safe drinking water source for the consumer.

Disinfection residuals: a test is done at designated locations in the distribution system to ensure a free chlorine residual of 0.1 mg/L at the farthest point in the distribution system. If the 0.1 mg/L is not met the system is flushed by opening fire hydrants until the chlorine levels reach the desired level.

Trihalomethane sampling (THM): THMs are formed when chlorine is combined with organics in the water. THMs are considered to be carcinogens (cancer causing compounds) and therefore are regulated by the province.

Turbidity tests: measured in NTU (nephelometric turbidity units). This test is done on the raw water, to determine whether or not there are any changes in the water supply, and is a measure of the cloudiness or clarity of the water.

Onsite testing:

Chlorine tests

- Total chlorine: a measure of all chlorine compounds in the water
- Free chlorine: a measure of the actual Cl_2 remaining in the water for disinfection after all chemical reactions with chlorine are complete

Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.

Bacteriological Tests

Month	Standard 0-Tot Coli 0 – E. Coli	System Average	Meet Standard	Corrective Action
Jan	0	0	Yes	
Feb	0	0	Yes	
Mar	0	0	Yes	
Apr	0	0	Yes	
May	0	0	Yes	
Jun	0	0	Yes	
Jul	0	0	Yes	
Aug	0	0	Yes	
Sep	0	0	Yes	
Oct	0	0	Yes	
Nov	0	0	Yes	
Dec	0	0	Yes	

Distribution Disinfection Residuals (free chlorine)

Month	Standard mg/L	System low	Meet Standard	Corrective Action
Jan	0.1	1.31	Yes	
Feb	0.1	1.35	Yes	
Mar	0.1	1.24	Yes	
Apr	0.1	1.18	Yes	
May	0.1	1.38	Yes	
Jun	0.1	1.38	Yes	
Jul	0.1	1.45	Yes	
Aug	0.1	1.69	Yes	
Sep	0.1	1.49	Yes	
Oct	0.1	1.43	Yes	
Nov	0.1	1.30	Yes	
Dec	0.1	1.42	Yes	

Arsenic Tests

Month	Standard	Distribution Average	Meet Standard	Corrective Action
Jan	0.01	0.011	No	
Feb	0.01	0.013	No	
Mar	0.01		No	
Apr	0.01		No	
May	0.01	0.013	No	
Jun	0.01	0.017	No	
Jul	0.01	0.016	No	
Aug	0.01	0.013	No	
Sep	0.01	0.015	No	
Oct	0.01	0.017	No	
Nov	0.01	0.015	No	
Dec	0.01	0.015	No	

WTP Disinfection Residuals (free chlorine)

Month	Standard mg/L	System average	Meet Standard	Corrective Action
Jan	0.5	1.46	Yes	
Feb	0.5	1.51	Yes	
Mar	0.5	1.27	Yes	
Apr	0.5	1.28	Yes	
May	0.5	1.47	Yes	
Jun	0.5	1.36	Yes	
Jul	0.5	1.49	Yes	
Aug	0.5	1.61	Yes	
Sep	0.5	1.43	Yes	
Oct	0.5	1.46	Yes	
Nov	0.5	1.27	Yes	
Dec	0.5	1.47	Yes	

Turbidity Averages Distribution

Month	Objective NTU	System average	Meet Objective	Corrective Action
Jan	0.3	0.07	No	
Feb	0.3	0.08	Yes	
Mar	0.3	0.08	No	
Apr	0.3	0.08	Yes	
May	0.3	0.08	Yes	
Jun	0.3	0.05	No	
Jul	0.3	0.07	Yes	
Aug	0.3	0.09	Yes	
Sep	0.3	0.12	Yes	
Oct	0.3	0.25	Yes	
Nov	0.3	0.28	Yes	
Dec	0.3	0.33	Yes	

Current Operator: **Kevin Enns**
Water Treatment – Class II
Water Distribution – Class II
Wastewater Treatment – Class II
Wastewater Collection – Class II

Operator: **Brian Johnson**
Water Treatment – Class I
Water Distribution – Class I
Wastewater Treatment – Class I
Water Collection – Class I

Operator in Training: **Johnny Co**

Operator in Training: **Trevor Robideux**

Operator in Training: **Bo Yeomans**

Water Treatment Plant Classification: Class II

Distribution System Level: Class II

For further information, please contact Kevin Enns, Manager of Utilities, at 748-2440.

APPENDIX Vvii

VIRDEN ANNUAL WATER REPORTS 2013

Public Water System
2013 Annual Report

Water Treatment Process Description:

Raw water supply

- The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. The wells are both 60 feet deep with a 60HP, submersible turbine pump in each well

Water treatment process

- Reverse osmosis water filtration is a process in which dissolved salts and metal ions, along with organic compounds and bacteria are removed from the feed (raw) water. High pressure pumps force the feed water through a semi-permeable membrane which filters out the contaminants, allowing only the purified water through.
- Three chemicals are injected into the blended water prior to it entering the reservoir
    1. Sodium hypochlorite (liquid chlorine) for primary disinfection
    2. C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion
    3. hydrofluorosilicic acid (fluoride) for dental caries
- The on site reservoir holds approximately 450,000 imperial gallons of water, and an elevated tower which holds approximately 85,000 imperial gallons, gives the town a fire fighting back up supply and a 1.5 to 2 day reserve for domestic use.
- The water leaving the plant is controlled in two different ways
    1. Water tower level: which is a percentage signal received over the phone line via a modem at the tower to another modem at the water treatment plant. This signal turns the distribution pumps on and off and determines the number of pumps required directly related to the tower level.
    2. Flow control: this controls the pumps by a pressure signal which is produced at the plant dependant on demand in the distribution piping. This signal also controls the number of pumps required to be running and is used as a back-up to the water tower, in cases where the tower is required to be taken off line for service or repair.

Water testing

The Town of Virden currently performs various tests to ensure the safety of the water leaving the plant to the consumer's tap.

Bacteriological sampling: the raw water supply and the treated water are tested bi-weekly for total coliform and Escherichia coli (E-coli) by ALS LABS a government approved lab. These tests are necessary to ensure the system is free of any pathogens (disease causing bacteria) which ensures a safe drinking water source for the consumer.

Disinfection residuals: a test is done at designated locations in the distribution system to ensure a free chlorine residual of 0.1 mg/L at the farthest point in the distribution system. If the 0.1 mg/L is not met the system is flushed by opening fire hydrants until the chlorine levels reach the desired level.

Trihalomethane sampling (THM): THMs are formed when chlorine is combined with organics in the water. THMs are considered to be carcinogens (cancer causing compounds) and therefore are regulated by the province.

Turbidity tests: measured in NTU (nephelometric turbidity units). This test is done on the raw water, to determine whether or not there are any changes in the water supply, and is a measure of the cloudiness or clarity of the water.

Onsite testing:

Chlorine tests

- Total chlorine: a measure of all chlorine compounds in the water
- Free chlorine: a measure of the actual Cl_2 remaining in the water for disinfection after all chemical reactions with chlorine are complete

Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.

Bacteriological Tests

Month	Standard 0-Tot Coli 0 – E. Coli	System Average	Meet Standard	Corrective Action
Jan	0	0	Yes	
Feb	0	0	Yes	
Mar	0	0	Yes	
Apr	0	0	Yes	
May	0	0	Yes	
Jun	0	0	Yes	
Jul	0	0	Yes	
Aug	0	0	Yes	
Sep	0	0	Yes	
Oct	0	0	Yes	
Nov	0	0	Yes	
Dec	0	0	Yes	

Distribution Disinfection Residuals (free chlorine)

Month	Standard mg/L	System low	Meet Standard	Corrective Action
Jan	0.1	0.63	Yes	
Feb	0.1	0.52	Yes	
Mar	0.1	0.81	Yes	
Apr	0.1	0.96	Yes	
May	0.1	1.40	Yes	
Jun	0.1	1.20	Yes	
Jul	0.1	0.88	Yes	
Aug	0.1	0.70	Yes	
Sep	0.1	0.84	Yes	
Oct	0.1	0.32	Yes	
Nov	0.1	0.64	Yes	
Dec	0.1	0.78	Yes	

Arsenic Tests

Month	Standard	Distribution Average	Meet Standard	Corrective Action
Jan	0.01	0.017	No	
Feb	0.01		No	
Mar	0.01	0.013	No	
Apr	0.01	0.013	No	
May	0.01	0.019	No	
Jun	0.01	0.017	No	
Jul	0.01	0.018	No	
Aug	0.01	0.018	No	
Sep	0.01	0.017	No	
Oct	0.01	0.018	No	
Nov	0.01	0.02	No	
Dec	0.01	0.021	No	

WTP Disinfection Residuals (free chlorine)

Month	Standard mg/L	System average	Meet Standard	Corrective Action
Jan	0.5	0.96	Yes	
Feb	0.5	0.89	Yes	
Mar	0.5	1.10	Yes	
Apr	0.5	1.25	Yes	
May	0.5	1.02	Yes	
Jun	0.5	0.83	Yes	
Jul	0.5	1.07	Yes	
Aug	0.5	1.08	Yes	
Sep	0.5	0.63	Yes	
Oct	0.5	1.12	Yes	
Nov	0.5	0.52	Yes	
Dec	0.5	0.80	Yes	

Turbidity Averages Distribution

Month	Objective NTU	System average	Meet Objective	Corrective Action
Jan	0.3	0.313	No	
Feb	0.3	0.265	Yes	
Mar	0.3	0.199	Yes	
Apr	0.3	0.230	Yes	
May	0.3	0.314	No	
Jun	0.3	0.249	Yes	
Jul	0.3	0.217	Yes	
Aug	0.3	0.221	Yes	
Sep	0.3	0.256	Yes	
Oct	0.3	0.247	Yes	
Nov	0.3	0.270	Yes	
Dec	0.3	0.260	Yes	

Current Operator: **Kevin Enns**
Water Treatment – Class II
Water Distribution – Class II
Wastewater Treatment – Class II
Wastewater Collection – Class II

Operator: **Brian Johnson**
Water Treatment – Class I
Water Distribution – Class I
Wastewater Treatment – Class I
Water Collection – Class I

Operator in Training: **Johnny Co**

Operator in Training: **Trevor Robideux**

Operator in Training: **Bo Yeomans**

Water Treatment Plant Classification: Class II

Distribution System Level: Class II

For further information, please contact Kevin Enns, Manager of Utilities, at 748-2440.

APPENDIX Vviii

VIRDEN ANNUAL WATER REPORTS 2014

2014 Annual Drinking Water Report

March.23.2015

TABLE OF CONTENTS

LIST OF FIGURES

1 Source Water

Raw water supply:

The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. Both wells are approximate 60 feet deep equipped with a 60HP submersible turbine pump in each well and the combined capacity of the wells is rated at 37.6 L/s. The well site is equipped with PLC controls, and a standby generator.

The raw water is considered non-GUDI (not Groundwater Under Direct Influenced of surface water). A non-GUDI well indicates the groundwater is more secure from seasonal changes and threats of infiltrated contamination, in comparison to community's water source provided by GUDI or surface water supplies.

Groundwater can contain iron and manganese neither are a health related risk, but at elevated levels can create operational and aesthetic issues.

- Iron (Fe): iron in the water, although not a health related parameter, can cause staining in laundry and fixtures, and hot water tanks, usually leaving brownish stains. It can cause taste & odour complaints, it is described as a metallic taste.

- Manganese (Mn): is not a health related parameter but like iron can cause staining of fixtures and laundry, it can cause unpleasant taste and odour at high levels.

From the wells the water is injected with sodium bisulphite at the pumphouse to minimize the oxidation of iron and manganese in the pipeline to the WTP, prior to entering the RO (reverse Osmosis Treatment Process.

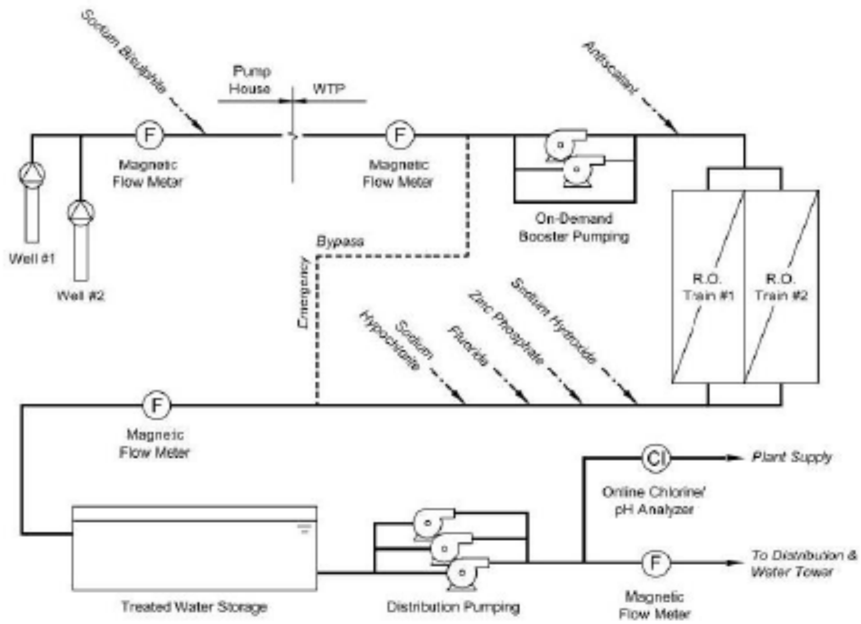
2 Water Treatment Process

The water treatment plant is equipped with a GE Reverse Osmosis membrane with two treatment trains. Reverse Osmosis is a process in which dissolved salts and metal ions, along with organic compounds and bacteria are removed from the feed (raw) water. High pressure pumps force the feed water through a semi-permeable membrane which filters out the contaminants, allowing only the purified water through.
Three chemicals are injected into the blended water prior to it entering the reservoir

1. Sodium hypochlorite (liquid chlorine) for primary disinfection
2. C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion
3. hydrofluorosilicic acid (fluoride) for dental care

The Water Treatment plant and valley well pump house both are equipped with diesel generator backup to ensure continuous operation during prolonged power outages.

Virden Water Treatment Process Source to Tap



(Figure 1)

3 Distribution System

The on-site reservoir holds approximately 2000 m^3 of water, and additionally an elevated tower which holds approximately 400 m^3, this provides the town a fire fighting capabilities, consistent pressure, and a reserve supply up to 2 day s for domestic use.

Virden's distribution system consists mainly of 150 mm diameter cast iron water mains, with newer sections in PVC, and services approximately 3,100 residents.

4 Water Testing

The Town of Virden currently performs various tests to ensure the safety of the water leaving the plant to the consumer's tap.

Bacteriological sampling: the raw water supply and the treated water are tested bi-weekly for total coliform and Escherichia coli (E-coli) by an accredited environmental labratory. These tests are necessary to ensure the system is free of any pathogens (disease causing bacteria) which ensures a safe drinking water source for the consumer.

Chemical Analysis: A complete chemical analysis of the raw and treated water is required to be analyzed by an accredited laboratory every three years. The last analysis was done in 2013 and results can be seen here.

Disinfection residuals: tests are completed daily at the water treatment plant and at designated locations throughout the distribution system to ensure a free chlorine residual of 0.1 mg/L is maintained throughout the distribution system. If the 0.1 mg/L is not met the localized area of the system is flushed by opening fire hydrants until the chlorine levels reach the desired level.

Turbidity tests: measured in NTU (nephelometric turbidity units). This test is done on the raw water, to determine whether or not there are any changes in the water supply, and is a measure of the cloudiness or clarity of the water.

Onsite testing:

- Total chlorine: a measure of all chlorine compounds in the water. This test is completed everyday by operators.
- Free chlorine: a measure of the actual chlorine remaining in the water for disinfection after all chemical reactions with chlorine are complete. This test is completed everyday by operators at the treatment plant and biweekly in the distribution system.
- Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.
- TCU (true colour units): a measure of the colour of the water after being passed through a 5 micron filter. By passing the water through the filter it eliminates measuring any suspended materials such as iron and manganese in the sample and gives a more accurate reading of the actual discoloration of the water.

5 Testing Results

Adverse Chlorine Events

Chlorine testing and sampling is completed daily by Town operators, it is critical to operations to maintain adequate chlorine levels to ensure public health and protection. Three events occurred in the 2014 year that resulted chlorine levels below the mandated levels. Two of the three events were results of mechanical failures; the third was due to a combination of a watermain break and high demands experienced during peak summer usage.

Day	Standard mg/l	Free Chlorine	Total Chlorine	Meet Standard	Corrective Actions
04/30/14	0.5	0.0182	2.17	No	Pipe failure at WTP, isolated, fully repaired and restored operations on 01/05/14
05/0114	0.5	0.0182	2.17	No	Pipe failure at WTP isolated, repaired, and returned to operation
08/04/14	0.5	0.17	2.69	No	Blending well water with treated due to high demand and mainbreak.

(Table 1)

Bacteriological Test Results

Month	Standard 0- T. Coli 0 – E. Coli	Results Raw	Results Treated	Results Dist	Meet Standard	Comments
Jan	0	0	0	0	Yes	
Feb	0	0	0	0	Yes	
Mar	0	0	0	0	Yes	
Apr	0	0	0	2 TC	No	Re-samples indicated false positive
May	0	0	0	0	Yes	
Jun	0	0	0	0	Yes	
Jul	0	0	0	0	Yes	
Aug	0	0	0	0	Yes	
Sep	0	0	0	0	Yes	
Oct	0	0	0	0	Yes	Additional sampling due to PBWA
Nov	0	0	0	0	Yes	
Dec	0	0	0	0	No	Frozen Samples (x2) on route to lab, lab results incomplete

(Table 2)

Arsenic Tests Results

Date	Raw	Standard	Treated Train 1	Treated Train 2	Meet Standard	Comments
01/28/14	0.0435	0.01	0.0182	0.0153	No	
02/25/14	0.0429	0.01	Off-line	0.0141	No	
03/26/14	0.0476	0.01	Off-line	0.0158	No	
04/24/14	0.0438	0.01	0.0164	0.0151	No	
06/04/14	0.0460	0.01	0.0182	0.0153	No	
06/17/14	0.0445	0.01	0.0159	0.0145	No	
07/29/14	0.049	0.01	Off-line	0.0100	Yes	
08/28/14	0.0419	0.01	0.0219	0.0121	No	
09/24/14	0.0482	0.01	Off-line	0.0242	No	
10/29/14	0.0437	0.01	0.0187	0.0150	No	
11/28/14	0.0455	0.01	0.0200	0.0160	No	
12/30/14	Frozen	0.01	Frozen	Frozen	No	Frozen Samples on route to lab, lab results incomplete.

(Table 3)

Fluoride Test Results

Month	Objective mg/L	System average	Meet Objective	Comments
02/27/14	0.7 – 1.2	0.62	Yes	
03/19/14	0.7 – 1.2	0.46	Yes	

04/10/14	0.7 – 1.2	0.30	Yes	
04/28/14	0.7 – 1.2	0.68	Yes	
05/08/14	0.7 – 1.2	0.55	Yes	
06/10/14	0.7 – 1.2	0.60	Yes	
06/11/14	0.7 – 1.2	0.62	Yes	
06/24/14	0.7 – 1.2	0.70	Yes	
07/11/14	0.7 – 1.2	0.60	Yes	
07/22/14	0.7 – 1.2	0.58	Yes	
08/06/14	0.7 – 1.2	0.51	Yes	
08/13/14	0.7 – 1.2	0.65	Yes	
08/28/14	0.7 – 1.2	0.58	Yes	
09/13/14	0.7 – 1.2	0.66	Yes	
09/16/14	0.7 – 1.2	0.66	Yes	
09/26/14	0.7 – 1.2	0.56	Yes	
10/06/14	0.7 – 1.2	0.59	Yes	
10/09/14	0.7 – 1.2	0.59	Yes	
10/31/14	0.7 – 1.2	0.53	Yes	
11/05/14	0.7 – 1.2	0.53	Yes	
12/03/14	0.7 – 1.2	0.62	Yes	
12/03/14	0.7 – 1.2	0.59	Yes	
12/17/14	0.7 – 1.2	0.53	Yes	
12/18/14	0.7 – 1.2	0.51	Yes	

(Table 4)

6 Precautionary Boil Water

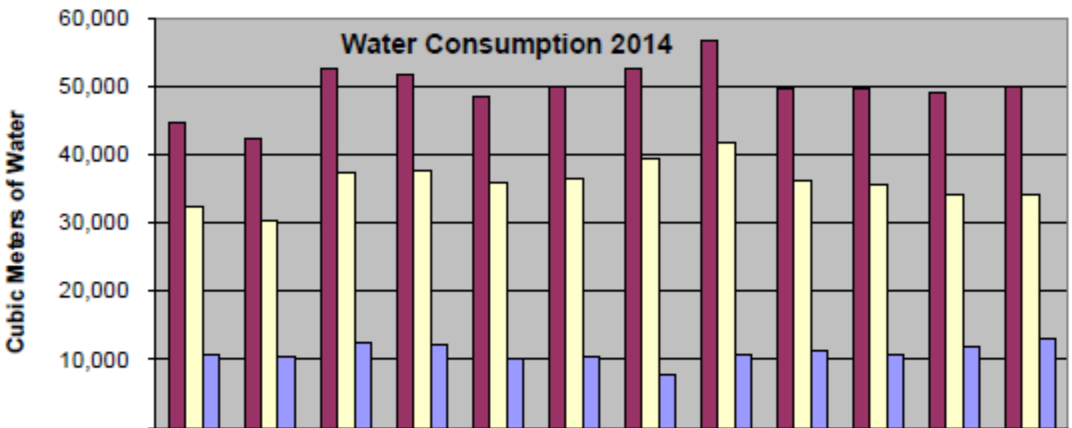
In October the town issued a localized precautionary boil water for one block of Chester Street during the installation of a new water service at the new head works of the wastewater treatment plant. During the installation the one block was depressurized; as a result 2 sets of bacteriological samples were analyzed and flushing was completed. This ensured no possible risk of contamination entering the distribution system. The Drinking Water Office was notified and the system was pressurized once satisfactory sample results were received.

7 Continuing Quality Improvement

In April 2012, the town was placed under a water quality advisory as a result of not meeting the Arsenic (MAC) maximum acceptable concentration of 0.01mg/l. In 2013 and 2014 pilot studies were completed to address the elevated Arsenic levels in the source water, and it is intended to go full scale in 2015. The results of the pilot study indicate that the town will be able to utilize existing filter beds and pumps that have been out of service since the introduction of the Reverse Osmosis system. With the introduction of a new filter media, some physical modifications and targeted rehabilitation of existing pumps, the town intends to implement a polishing filter stage after the Reverse Osmosis to assist with the arsenic removal. The town anticipates meeting the arsenic requirements in fall of 2015.

8 Review of Water Usage

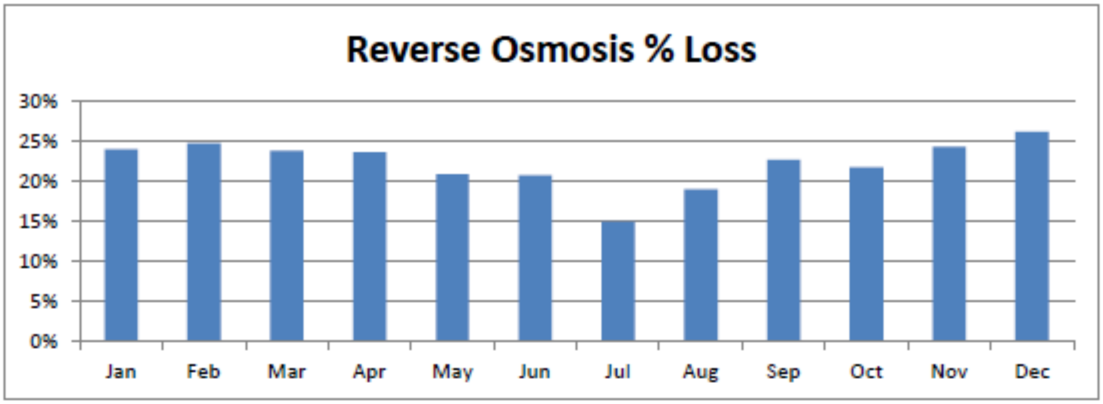
Annually a review of the quantity of water used allows the utility to determine performance of the water treatment plant and treatment equipment. It also helps determine the volume of water unmetered, or loss due to potential leaks. Water used to flush the system or due to fire flows are also captured in this value. In 2014 the total volume sent to distribution was 432,220 cubic meters m^3. A total volume of 699,254 m^3 of water was pulled from the 2 operating wells owned by the town. The peak flow month was August with 109,361 m^3 used.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Municipal (Raw)	44,770	42,526	52,594	51,861	48,514	50,161	52,710	56,730	49,635	49,859	49,223	50,162
Municipal (Distr)	32,438	30,459	37,463	37,650	35,853	36,627	39,547	41,845	36,353	35,577	34,108	34,300
Erco	10,723	10,517	12,521	12,242	10,116	10,390	7,834	10,786	11,238	10,831	11,952	13,109

(Figure 2)

The Reverse Osmosis treatment system in place used by the Town is an extensive treatment; this treatment does require high pressures, meaning higher energy and water loss as a part of the treatment process. The system is designed and operates at a 75% recovery of high quality water. As a result, on average, there is a 25% water loss during treatment. As identified in Figure #3 the average remains relatively constant ranging between 80-75% recovery with exception to July and August. The low peak in July and August 2014 was due to the high summer demands and the system blending raw to accommodate for quantity over quality. Since the summer's high demands the Town has made accommodations to increase treatment flows up to 24 m^3 per minute of treated water. This will help mitigate future need to blend raw well water with treated.



(Figure 3)

9 Operating Certification

The water treatment plant and water distribution are classified by the province as the following operating levels:

The Water Treatment Plant	Class II
Distribution System Level	Class II

These classifications require that the Town employ and operate the system with properly trained and certified operators. Operators are required to have a minimum education and experience level before achieving certification level to match the systems operation level. In addition the Town is required to employ an Operator in Charge that carries the same level of certification as the operating facility. To maintain the operator licenses staff is required to continuously complete training in the water industry that is approved by the province and a minimum level of operating experience is required to recertify.

10 Infrastructure Improvements

In 2014 work was completed to change a pit-less connection in well number 2, high lift 2 motor was replaced and the well and put back in operation. Reconstruction of Lacrosse St between eight Ave and Ninth Ave was scheduled; work was delayed and is to be completed early in 2015's construction season.

In 2015 the green sand filters are to be re-commissioned as a polishing treatment to remove the arsenic that is naturally occurring in the source water. The arsenic treatment changes to the water treatment plant are expected to cost approximately $200,000. A review of existing pumps is to be completed, with recommendations to continue to service the thirteen pumps that combine to make up the water system over the 2015 fiscal year. Improvements to the SCADA system will continue through the 2015 year, with plans to allow remote access and more reporting and trending features.

11 Contact Information

For more information on the Town of Virden's water treatment systems and operation please visit the website at www.virden.ca or contact the office at 204-748-2440.

This document was completed on Mar.24.2015 by,

Jake Doran
C.E.T, P.M.P
Utilities Manger
Town of Virden

APPENDIX Vix

VIRDEN ANNUAL WATER REPORTS 2015

2015 Annual Drinking Water Report

Feburary.2016

TABLE OF CONTENTS

LIST OF FIGURES & TABLES

1 Source Water

Raw water supply:

The Town of Virden water treatment plant receives its water from two wells located in the Assiniboine Valley approximately 4.5 miles from the town. Both wells are approximate 60 feet deep equipped with a 60HP submersible turbine pump in each well and the combined capacity of the wells is rated at 37.6 L/s. The well site is equipped with PLC controls, and a standby generator.

The raw water is considered non-GUDI (not Groundwater Under Direct Influenced of surface water). A non-GUDI well indicates the groundwater is more secure from seasonal changes and threats of infiltrated contamination, in comparison to community's water source provided by GUDI or surface water supplies.

Groundwater can contain iron and manganese neither are a health related risk, but at elevated levels can create operational and aesthetic issues.

- Iron (Fe): iron in the water, although not a health related parameter, can cause staining in laundry and fixtures, and hot water tanks, usually leaving brownish stains. It can cause taste & odour complaints, it is described as a metallic taste.

- Manganese (Mn): is not a health related parameter but like iron can cause staining of fixtures and laundry, it can cause unpleasant taste and odour at high levels.

From the wells the water is injected with sodium bisulphite at the pumphouse to minimize the oxidation of iron and manganese in the pipeline to the WTP, prior to entering the RO (reverse Osmosis Treatment Process.

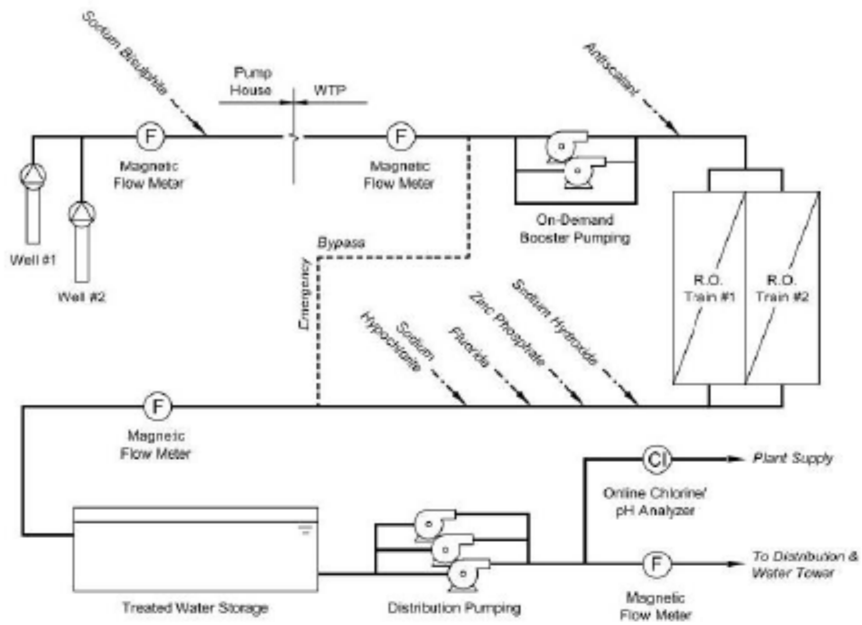
2 Water Treatment Process

The water treatment plant is equipped with a GE Reverse Osmosis membrane with two treatment trains. Reverse Osmosis is a process in which dissolved salts and metal ions, along with organic compounds and bacteria are removed from the feed (raw) water. High pressure pumps force the feed water through a semi-permeable membrane which filters out the contaminants, allowing only the purified water through.
Three chemicals are injected into the blended water prior to it entering the reservoir

1. Sodium hypochlorite (liquid chlorine) for primary disinfection
2. C-5 (polyphosphate) a sequestering agent for iron and manganese, and a coating for the interior walls of the distribution piping to prevent corrosion
3. hydrofluorosilicic acid (fluoride) for dental care (to be removed in 2016)
4. ferric chloride will be replacing fluoride, to treat elevated arsenic levels in 2016.

The Water Treatment plant and valley well pump house both are equipped with a standby generator backup to ensure continuous operation during prolonged power outages.

Virden Water Treatment Process Source to Tap



(Figure 1)

3 Distribution System

The on-site reservoir holds approximately 2000 m^3 of water, and additionally an elevated tower which holds approximately 400 m^3, this provides the town a fire fighting capabilities, consistent pressure, and a reserve supply up to 2 days for domestic use.

Virden's distribution system consists mainly of 150 mm diameter cast iron water mains, with newer sections in PVC, and services approximately 3,100 residents and approximately 1,500 connections.

4 Water Testing

The Town of Virden currently performs various tests to ensure the safety of the water leaving the plant to the consumer's tap.

Bacteriological sampling: the raw water supply and the treated water are tested bi-weekly for total coliform and Escherichia coli (E-coli) by an accredited environmental laboratory. These tests are necessary to ensure the system is free of any pathogens (disease causing bacteria) which ensures a safe drinking water source for the consumer.

Chemical Analysis: A complete chemical analysis of the raw and treated water is required to be analyzed by an accredited laboratory every three years. The last analysis was done in 2013, next schedule analysis is in 2016, and results can be seen on the website.

Disinfection residuals: tests are completed daily at the water treatment plant and at designated locations throughout the distribution system to ensure a free chlorine residual of 0.1 mg/L is maintained throughout the distribution system. If the 0.1 mg/L is not met the localized area of the system is flushed by opening fire hydrants until the chlorine levels reach the desired level.

Turbidity tests: measured in NTU (nephelometric turbidity units). This test is done on the raw water, to determine whether or not there are any changes in the water supply, and is a measure of the cloudiness or clarity of the water.

Onsite testing:

- Total chlorine: a measure of all chlorine compounds in the water. This test is completed everyday by operators.
- Free chlorine: a measure of the actual chlorine remaining in the water for disinfection after all chemical reactions with chlorine are complete. This test is completed everyday by operators at the treatment plant and biweekly in the distribution system.
- Turbidity: a measure of the clarity of the water. Too high a turbidity will interfere with disinfection by using up available chlorine in the water or protecting the bacteria in the water from coming in contact with the disinfection process.
- TCU (true colour units): a measure of the colour of the water after being passed through a 5 micron filter. By passing the water through the filter it eliminates measuring any suspended materials such as iron and manganese in the sample and gives a more accurate reading of the actual discoloration of the water.

5 Testing Results

Chlorine testing and sampling is completed daily by Town operators, it is critical to operations to maintain adequate chlorine levels to ensure public health and protection. No events occurred in the 2015 year that resulted chlorine levels below the mandated levels.

Day	Standard mg/l	Free Chlorine	Total Chlorine	Meet Standard	Corrective Actions

(Table 1)

Bacteriological Test Results

Month	Standard 0- T. Coli 0 – E. Coli	Results Raw	Results Treated	Results Dist	Meet Standard	Comments
Jan	0	0	0	0	Yes	
Feb	0	0	0	0	Yes	

Mar	0	0	0	0	Yes	
Apr	0	0	0	0	Yes	
May	0	0	0	0	Yes	
Jun	0	0	0	2TC	Yes	June 16, 2 coliform – Resamples good
Jul	0	0	0	0	No	
Aug	0	0	0	0	Yes	
Sep	0	0	0	0	Yes	
Oct	0	0	0	0	Yes	
Nov	0	0	0	0	Yes	
Dec	0	0	0	0	Yes	

(Table 2)

Arsenic Tests Results

Date	Raw	Standard	Treated Train 1	Treated Train 2	Meet Standard	Comments
01/13/15	0.0441	0.01	0.0205	0.0127	No	
01/28/15	0.0447	0.01	0.018	0.0143	No	
02/24/15	0.0434	0.01	0.0171	0.0165	No	
03/24/15	0.0473	0.01	0.0206	0.0116	No	
04/21/15	0.0492	0.01	0.0199	0.013	No	
05/20/15	0.0427	0.01	0.0175	0.014	No	
06/16/15	0.0489	0.01	0.0175	0.0133	No	
07/14/15	0.0493	0.01	0.0249	0.0218	No	
08/25/15	0.0486	0.01	0.0236	0.0221	No	
09/08/15	0.0498	0.01	0.025	0.0225	No	
10/06/15	0.042	0.01	0.0173	0.0198	No	
10/06/15	0.042	0.01	See comments		No	Distribution Samples: LRB 0.0198, Bolton Bay 0.0175, 412 Queen E 0.013mg/l
12/01/15	0.0425	0.01	0.0187	0.0165	No	
12/29/15	0.0443	0.01	0.0244	0.0136	No	

(Table 3)

Fluoride Test Results

Result Date	Objective mg/L	System average	Meet Objective	Comments
01/14/15	0.5 – 0.9	0.63	Yes	
01/24/15	0.5 – 0.9	0.57	Yes	
02/07/15	0.5 – 0.9	0.59	Yes	
02/25/15	0.5 – 0.9	0.58	Yes	

03/07/15	0.5 – 0.9	0.57	Yes	
03/20/15	0.5 – 0.9	0.60	Yes	
04/15/15	0.5 – 0.9	0.59	Yes	
04/25/15	0.5 – 0.9	0.52	Yes	
05/06/15	0.5 – 0.9	0.67	Yes	
05/16/15	0.5 – 0.9	0.60	Yes	
06/03/15	0.5 – 0.9	0.69	Yes	
06/13/15	0.5 – 0.9	0.61	Yes	
06/26/15	0.5 – 0.9	0.52	Yes	
07/10/15	0.5 – 0.9	0.58	Yes	
08/07/15	0.5 – 0.9	0.54	Yes	
08/21/15	0.5 – 0.9	0.47	No	
09/04/15	0.5 – 0.9	0.38	No	
09/18/15	0.5 – 0.9	0.47	No	
10/02/15	0.5 – 0.9	0.43	No	
10/21/15	0.5 – 0.9	0.45	No	
11/17/15	0.5 – 0.9	0.37	No	
12/11/15	0.5 – 0.9	0.48	No	Fluoride removed Dec.26.2015

(Table 4)

6 Water Outages and PBWA or BWA

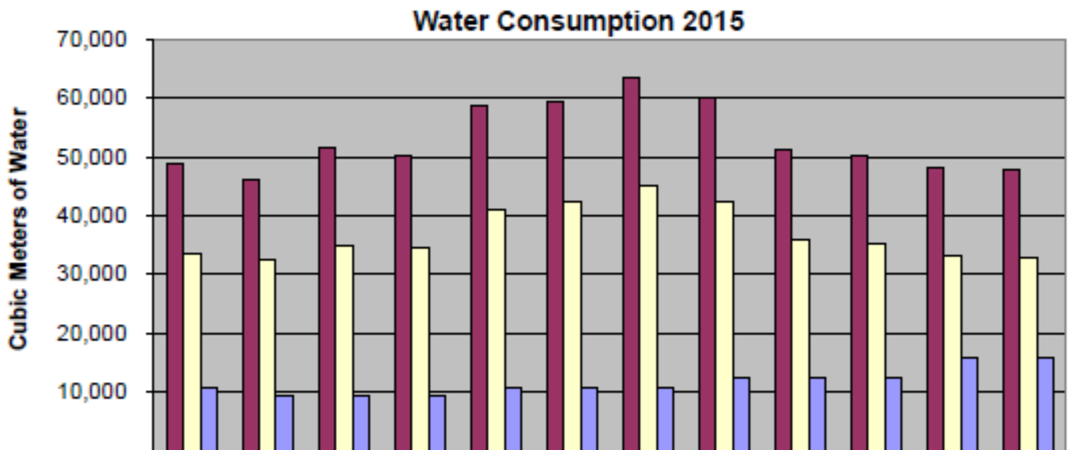
In May the town experiences a large main break and two blocks of Wellington St from Tenth to Queen along Gopher Creek, customers were out of water for approximately ½ to 1 day in length. Overland services were redirected from neighbours across the back lanes and a PBWA was avoided. During the repair the two blocks were depressurized; as a result 2 sets of bacteriological samples were analyzed and flushing was completed before overland servicing was removed and people were switched back to servicing off Wellington. This ensured no possible risk of contamination for those residences. The Drinking Water Office was notified and the system was pressurized once satisfactory sample results were received. In a second event, December 2015, the water tower developed a leak in the bottom half of the bowl, repairs were completed within 10 days by welding/fabrication on-site. During that time the water treatment plant operated on pump pressure only, few low pressure calls were received, approximately 3 rusty water complaints were identified as a result of the work. No PBWA's or BWA's occurred during the 2015 calendar year.

7 Continuing Quality Improvement

In April 2012, the town was placed under a water quality advisory as a result of not meeting the Arsenic (MAC) maximum acceptable concentration of 0.01mg/l. In 2013 and 2014 pilot studies were completed to address the elevated Arsenic levels in the source water, design, pricing and contract award was completed in 2015. The construction has begun and is to be completed in 2016. An additional hurdle to this work is the addition of a chemical, ferric chloride, required to treat elevated arsenic levels. Because of a lack of space in the water treatment plant, the Town decided to remove the fluoride treatment to make room for the required arsenic treatment. To help with this decision the town completed a survey detailing the situation and asking the residence's for feedback. The survey resulted in support of the fluoride removal to make roome for the arsenic treatment, and the Town is in the process of removing the fluoride.

8 Review of Water Usage

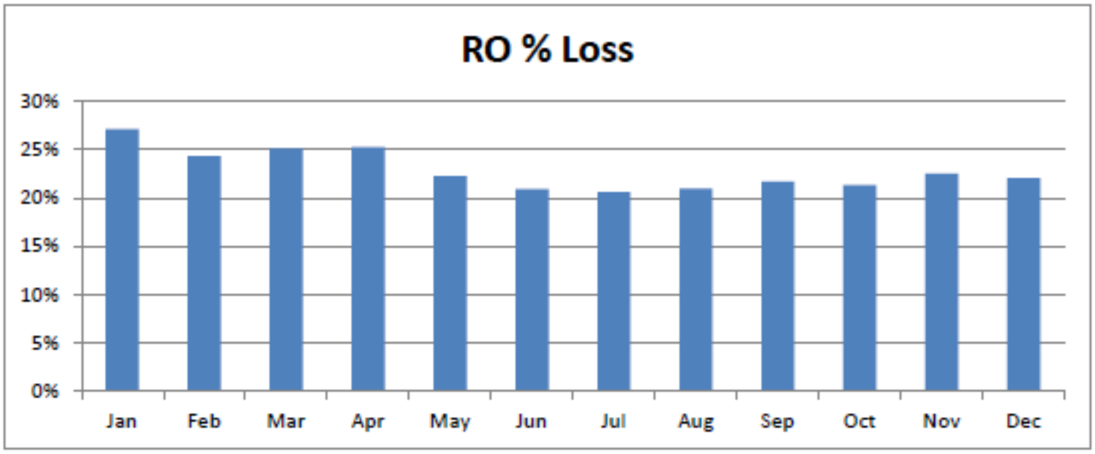
Annually a review of the quantity of water used allows the utility to determine performance of the water treatment plant and treatment equipment. It also helps determine the volume of water unmetered, or loss due to potential leaks. Water used to flush the system or due to fire flows are also captured in this value. In 2015 the total volume sent to distribution was 491,458 cubic meters m^3. A total volume of 776,455 m^3 of water was pulled from the 2 operating wells owned by the town. The peak flow month was July with 2,399 m^3 average day for July.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Municipal (Raw)	48,855	46,218	51,536	50,363	58,633	59,526	63,540	60,139	51,262	50,158	48,195	47,651
Municipal (Distr)	33,410	32,575	35,050	34,600	40,932	42,271	45,140	42,495	35,781	35,111	33,305	32,868
Erco	10,728	9,403	9,403	9,403	10,835	10,835	10,835	12,429	12,429	12,429	15,825	15,825

(Figure 2)

The Reverse Osmosis treatment system in place used by the Town is an extensive treatment; this treatment does require high pressures, meaning higher energy and water loss as a part of the treatment process. The system is designed and operates at a 75% recovery of high quality water. As a result, on average, there is a 25% water loss during treatment. As identified in Figure 3, below, shows the average remains relatively constant ranging between 80-75% recovery with exception to July and August. The low peak in July and August 2014 was due to the high summer demands and the system blending raw to accommodate for quantity over quality. The Town has made accommodations that enable operations to run 2 trains and increase treatment flows up to 24 m^3 per minute of treated water. This helps mitigate future need to blend raw well water with treated. Additionally a operations plan has been completed that details a water restriction/rationing protocol and a communication plan.



(Figure 3)

9 Operating Certification

The water treatment plant and water distribution are classified by the province as the following operating levels:

The Water Treatment Plant	Class II
Distribution System Level	Class II

These classifications require that the Town employ and operate the system with properly trained and certified operators. Operators are required to have a minimum education and experience level before achieving certification level to match the systems operation level. In addition the Town is required to employ an Operator in Charge that carries the same level of certification as the operating facility. To maintain the operator licenses staff is required to continuously complete training in the water industry that is approved by the province and a minimum level of operating experience is required to recertify.

10 Infrastructure Improvements

In 2015 work was completed to upgrade the pump, motor and check valve in well number 2, Lacrosse St watermain was rehabilitated between 8th and 9th Ave. The SCADA system was given an added feature so that it could be viewed remotely, allowing operations ability to monitor reservoir and tower levels during critical events.

In 2016 the green sand filters will be re-commissioned as a polishing treatment to remove the arsenic that is naturally occurring in the source water. Design has been completed and a contractor has been selected, work began in 2015 not to be complete until 2016. The arsenic treatment changes to the water treatment plant are expected to cost approximately $200,000. Other improvements to the system will continue through the 2016 year.

11 Contact Information

For more information on the Town of Virden's water treatment systems and operation please visit the website at www.virden.ca or contact the office at 204-748-2440.

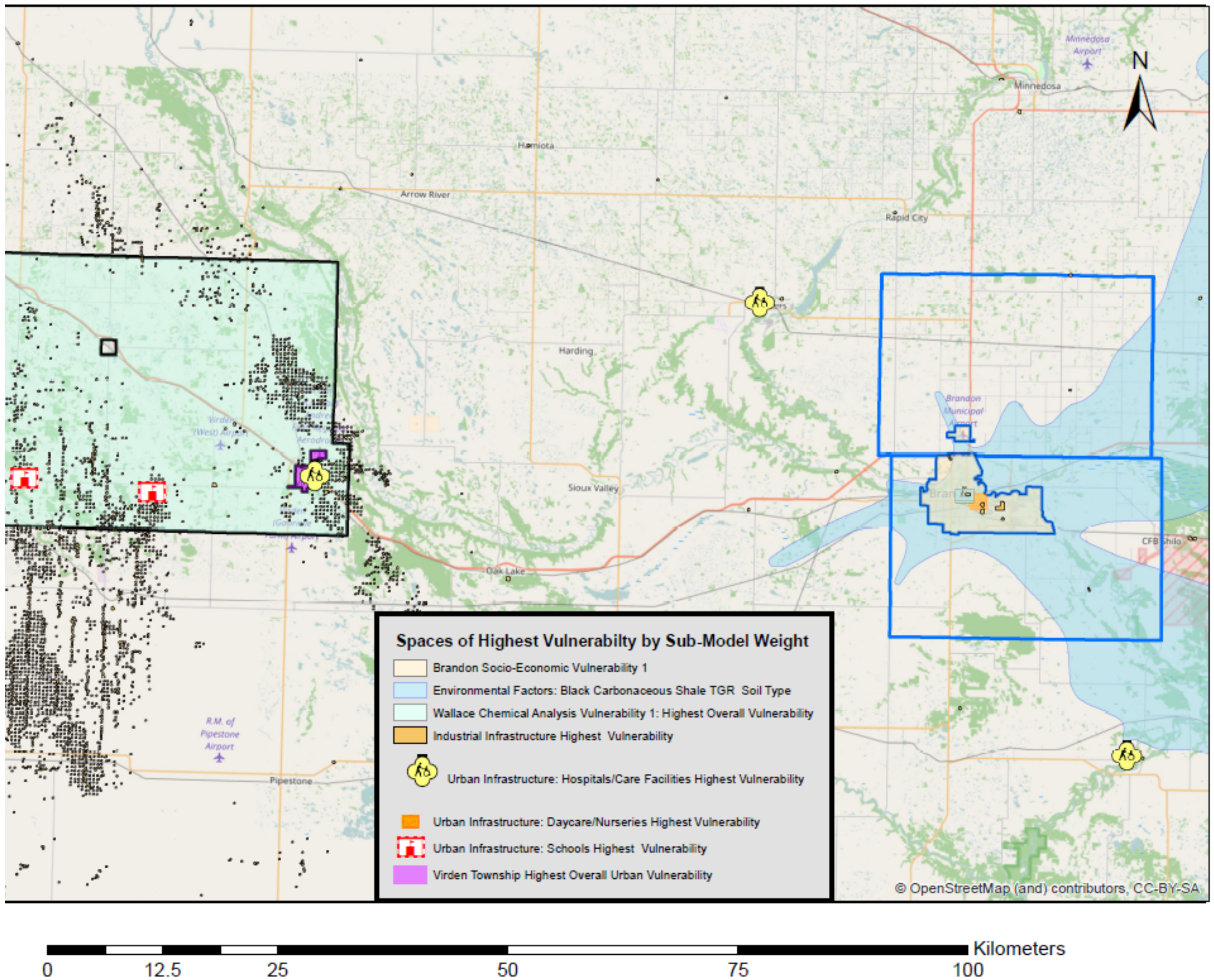
This document was completed February 2016 by,

Jake Doran
C.E.T, P.M.P
For the Town of Virden

APPENDIX W

GEOMATRIX DRINKING WATER HIGH VULNERABILITY SPATIAL ANALYSIS

Geomatrix Drinking Water High Vulnerability Spatial Analysis



APPENDIX X

SOCIO-ECONOMIC/INDUSTRIAL INFRASTRUCTURE/URBAN INFRASTRUCTURE SUBMODELS

AHP WEIGHTING

Socio-Economic AHP Weighting

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Age	11.9%	2
2	Gender	7.6%	8
3	Marital Status	9.3%	5
4	Income/Earnings	20.5%	1
5	Place of Work	6.0%	10
6	Shelter Costs	9.5%	4
7	Children (number and age)	10.3%	3
8	Education	7.8%	6
9	Employment Status	7.7%	7
10	Mobility	6.8%	9
11	Vocation	2.4%	11

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4	5	6	7	8	9	10	11
1	1	3.00	3.00	1.00	2.00	1.00	1.00	1.00	1.00	1.00	4.00
2	0.33	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
3	0.33	1.00	1	1.00	4.00	1.00	1.00	1.00	1.00	1.00	3.00
4	1.00	1.00	1.00	1	7.00	4.00	3.00	4.00	5.00	2.00	4.00
5	0.50	1.00	0.25	0.14	1	1.00	1.00	1.00	1.00	1.00	3.00
6	1.00	1.00	1.00	0.25	1.00	1	1.00	3.00	2.00	1.00	5.00
7	1.00	1.00	1.00	0.33	1.00	1.00	1	1.00	3.00	4.00	3.00
8	1.00	1.00	1.00	0.25	1.00	0.33	1.00	1	1.00	3.00	3.00
9	1.00	1.00	1.00	0.20	1.00	0.50	0.33	1.00	1	3.00	5.00
10	1.00	1.00	1.00	0.50	1.00	1.00	0.25	0.33	0.33	1	6.00
11	0.25	0.50	0.33	0.25	0.33	0.20	0.33	0.33	0.20	0.17	1

Number of comparisons = 55
Consistency Ratio CR = 9.0%

Principal eigen value = 12.353
Eigenvector solution: 6 iterations, delta = 2.3E-8

A1 | AHP priorities

	A	B	C	D	E	F	G	H	I	J	K	L
1	AHP prior	2017.05.14 14:44:28										
2	11											
3	Age	Gender	Marital St	Income/E	Place of W	Shelter Cc	Children (	Education	Employm	Mobility	Vocation	
4	1	3	3	1	2	1	1	1	1	1	4	
5	0.333333	1	1	1	1	1	1	1	1	1	2	
6	0.333333	1	1	1	4	1	1	1	1	1	3	
7	1	1	1	1	7	4	3	4	5	2	4	
8	0.5	1	0.25	0.142857	1	1	1	1	1	1	3	
9	1	1	1	0.25	1	1	1	3	2	1	5	
10	1	1	1	0.333333	1	1	1	1	3	4	3	
11	1	1	1	0.25	1	0.333333	1	1	1	3	3	
12	1	1	1	0.2	1	0.5	0.333333	1	1	3	5	
13	1	1	1	0.5	1	1	0.25	0.333333	0.333333	1	6	
14	0.25	0.5	0.333333	0.25	0.333333	0.2	0.333333	0.333333	0.2	0.166667	1	
15	0.11919	0.076492	0.093078	0.205363	0.060172	0.095289	0.102782	0.078272	0.077123	0.067872	0.024365	
16	12.35303	0.0895										
17												

Industrial Infrastructure AHP Weighting

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Waste Disposal Sites	15.3%	1
2	Sewage Sites	14.9%	2
3	Water Source Sites	10.8%	6
4	Water Treatment Facility Location	8.0%	7
5	Petroleum Storage Sites	14.3%	4
6	Livestock Waste Storage Sites	13.2%	5
7	Oil and Gas Well Locations	14.6%	3
8	Agriculture and Municipal Lagoons	3.9%	8
9	Septic System Locations	3.8%	9
10	Industrial Transportation Routes	1.3%	10

Number of comparisons = 45
Consistency Ratio CR = 7.5%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4	5	6	7	8	9	10
1	1	1.00	2.00	5.00	1.00	1.00	1.00	2.00	4.00	9.00
2	1.00	1	2.00	5.00	1.00	1.00	1.00	2.00	3.00	8.00
3	0.50	0.50	1	2.00	1.00	1.00	1.00	4.00	3.00	6.00
4	0.20	0.20	0.50	1	1.00	1.00	1.00	4.00	1.00	6.00
5	1.00	1.00	1.00	1.00	1	2.00	1.00	7.00	4.00	8.00
6	1.00	1.00	1.00	1.00	0.50	1	1.00	6.00	7.00	9.00
7	1.00	1.00	1.00	1.00	1.00	1.00	1	7.00	8.00	9.00
8	0.50	0.50	0.25	0.25	0.14	0.17	0.14	1	1.00	7.00
9	0.25	0.33	0.33	1.00	0.25	0.14	0.12	1.00	1	5.00
10	0.11	0.12	0.17	0.17	0.12	0.11	0.11	0.14	0.20	1

Principal eigen value = 11.007
Eigenvector solution: 7 iterations, delta = 1.7E-8

A1 | AHP priorities

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	AHP prior	2017.05.14 13:35:40											
2	10												
3	Waste Dis	Sewage Si	Water Sou	Water Tre	Petroleun	Livestock	Oil and Ga	Agricultur	Septic Sys	Industrial Transportation Routes			
4	1	1	2	5	1	1	1	2	4	9			
5	1	1	2	5	1	1	1	2	3	8			
6	0.5	0.5	1	2	1	1	1	4	3	6			
7	0.2	0.2	0.5	1	1	1	1	4	1	6			
8	1	1	1	1	1	2	1	7	4	8			
9	1	1	1	1	0.5	1	1	6	7	9			
10	1	1	1	1	1	1	1	7	8	9			
11	0.5	0.5	0.25	0.25	0.142857	0.166667	0.142857	1	1	7			
12	0.25	0.333333	0.333333	1	0.25	0.142857	0.125	1	1	5			
13	0.111111	0.125	0.166667	0.166667	0.125	0.111111	0.111111	0.142857	0.2	1			
14	0.153144	0.148523	0.107814	0.080477	0.142599	0.132111	0.145574	0.038893	0.037993	0.012871			
15	11.00659	0.075413											
16													

Urban Infrastructure AHP Weighting

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

Category		Priority	Rank
1	Hospitals/Care Homes	28.2%	1
2	Schools	15.1%	3
3	Nurseries/Childcare Facilities	22.6%	2
4	Settlements	5.8%	6
5	Urban Areas	4.4%	8
6	Public Parks/Camping Sites	6.2%	5
7	Public Swimming Sites	7.2%	4
8	Hotels/Motels/Hostels	5.2%	7
9	Public Use (malls, stores, halls)	4.0%	9
10	Public Transportation Routes	1.3%	10

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4	5	6	7	8	9	10
1	1	4.00	1.00	6.00	7.00	8.00	5.00	4.00	5.00	9.00
2	0.25	1	1.00	4.00	3.00	5.00	2.00	3.00	4.00	8.00
3	1.00	1.00	1	6.00	7.00	4.00	5.00	7.00	3.00	9.00
4	0.17	0.25	0.17	1	1.00	2.00	2.00	1.00	1.00	5.00
5	0.14	0.33	0.14	1.00	1	1.00	1.00	1.00	1.00	3.00
6	0.12	0.20	0.25	0.50	1.00	1	1.00	3.00	3.00	7.00
7	0.20	0.50	0.20	0.50	1.00	1.00	1	3.00	4.00	8.00
8	0.25	0.33	0.14	1.00	1.00	0.33	0.33	1	3.00	8.00
9	0.20	0.25	0.33	1.00	1.00	0.33	0.25	0.33	1	6.00
10	0.11	0.12	0.11	0.20	0.33	0.14	0.12	0.12	0.17	1

Number of comparisons = 45
Consistency Ratio CR = 8.7%

Principal eigen value = 11.163
Eigenvector solution: 6 iterations, delta = 6.1E-8

A1 | AHP priorities

	A	B	C	D	E	F	G	H	I	J	K	L
1	AHP prior	2017.05.14 13:58:45										
2	10											
3	Hospitals/	Schools	Nurseries	Settlemer	Urban Are	Public Par	Public Swi	Hotels/Mc	Public Use	Public Transportation Routes		
4	1	4	1	6	7	8	5	4	5	9		
5	0.25	1	1	4	3	5	2	3	4	8		
6	1	1	1	6	7	4	5	7	3	9		
7	0.166667	0.25	0.166667	1	1	2	2	1	1	5		
8	0.142857	0.333333	0.142857	1	1	1	1	1	1	3		
9	0.125	0.2	0.25	0.5	1	1	1	3	3	7		
10	0.2	0.5	0.2	0.5	1	1	1	3	4	8		
11	0.25	0.333333	0.142857	1	1	0.333333	0.333333	1	3	8		
12	0.2	0.25	0.333333	1	1	0.333333	0.25	0.333333	1	6		
13	0.111111	0.125	0.111111	0.2	0.333333	0.142857	0.125	0.125	0.166667	1		
14	0.282175	0.151037	0.225977	0.058201	0.043883	0.062251	0.071937	0.051566	0.039926	0.013046		
15	11.16262	0.087102										
16												

APPENDIX Y

NIOSH ARSENIC PROPERTIES

Arsenic (inorganic compounds, as As)	Formula: As (metal)	CAS#: 7440-38-2 (metal)	RTECS#: CG0525000 (metal)	IDLH: Ca [5 mg/m^3 (as As)]
Conversion:	DOT: 1558 152 (metal); 1562 152 (dust)			

Synonyms/Trade Names: **Arsenic metal:** Arsenia
Other synonyms vary depending upon the specific As compound. [**Note:** OSHA considers "Inorganic Arsenic" to mean copper acetoarsenite & all inorganic compounds containing arsenic except ARSINE.]

Exposure Limits:
NIOSH REL: Ca
C 0.002 mg/m^3 [15-minute]
See Appendix A
OSHA PEL: [1910.1018] TWA 0.010 mg/m^3

Measurement Methods (see Table 1):
NIOSH 7300, 7301, 7303, 9102, 7900
OSHA ID105

Physical Description: Metal: Silver-gray or tin-white, brittle, odorless solid.

Chemical & Physical Properties:
MW: 74.9
BP: Sublimes
Sol: Insoluble
Fl.P: NA
IP: NA
Sp.Gr: 5.73 (metal)
VP: 0 mmHg (approx)
MLT: 1135°F (Sublimes)
UEL: NA
LEL: NA

Personal Protection/Sanitation (see Table 2):
Skin: Prevent skin contact
Eyes: Prevent eye contact
Wash skin: When contam/Daily
Remove: When wet or contam
Change: Daily
Provide: Eyewash
Quick drench

Respirator Recommendations (see Tables 3 and 4):
NIOSH
¥: ScbaF:Pd,Pp/SaF:Pd,Pp:AScba
Escape: GmFAg100/ScbaE

See Appendix E (page 351)

Metal: Noncombustible Solid in bulk form, but a slight explosion hazard in the form of dust when exposed to flame.

Incompatibilities and Reactivities: Strong oxidizers, bromine azide
[**Note:** Hydrogen gas can react with inorganic arsenic to form the highly toxic gas arsine.]

Exposure Routes, Symptoms, Target Organs (see Table 5):
ER: Inh, Abs, Con, Ing
SY: Ulceration of nasal septum, derm, GI disturbances, peri neur, resp irrit, hyperpig of skin, [carc]
TO: Liver, kidneys, skin, lungs, lymphatic sys [lung & lymphatic cancer]

First Aid (see Table 6):
Eye: Irr immed
Skin: Soap wash immed
Breath: Resp support
Swallow: Medical attention immed