THE NEGATIVE IMPACT OF ABANDONED COAL MINE WORKINGS ON DRINKING WATER QUALITY AND THE HEALTH OF RESIDENTS ON VANCOUVER ISLAND

by

Karla Joy Biagioni
B.A., University of Victoria, 2002

A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF ARTS

In the Department of Geography

Supervisory Committee

Dr. Harold D. Foster
Dr. Denise Cloutier-Fisher
Dr. Leslie Foster
Dr. Peter Stephenson

ABSTRACT

The Nanaimo Coalfield was a major coal producer between 1852 and 1968. During this time, coal was mined extensively in the area of South Wellington. The quality of groundwater in South Wellington may be adversely affected as mine site abandonment causes a deterioration of the hydrological system. This thesis employed a case-control study and examined the quality of drinking water and geographic variations in health of residents in two communities on Vancouver Island, South Wellington and Cinnabar. The control group, situated in Cinnabar, derives its water from the City of Nanaimo. However private groundwater wells supply drinking water to the study group, South Wellington. Abandoned coal mine workings degrade groundwater and in turn may affect the public through non-point source pollution. Disease and ill health are more common in South Wellington than in Cinnabar. The analyses of well water samples in South Wellington have revealed high levels of total dissolved solids and total coliform, aluminum, antimony, arsenic, cadmium, iron, lead, selenium, sodium and thallium. Each of these elements has been linked to various diseases and disorders and may be predictive of ill health in South Wellington.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

Objectives of this thesis

It has been established that pathogenic contamination of drinking water has resulted in countless outbreaks of disease and ill health. Exposure to nonpathogenic, toxic contaminants through drinking water however, also is a significant and threatening health risk to humans (Ritter Len et al. 2002). Yet, the public health effects of organic compounds and metals associated with drinking water are unclear (National Research Council (NRC) 1980(a)). Surveys by the Environmental Protection Agency (EPA) have "confirmed the presence of several organic petroleum and solvent types of compounds in drinking water affected by mine operations". Among these pollutants are "suspect carcinogens" (National Research Council (NRC) 1980(a)). One area affected by such a potential health threat is South Wellington, located to the south of Nanaimo, on Vancouver Island.

This research project focuses on the potential positive and negative impacts of groundwater, the quality of which may be influenced by abandoned coal mine workings, on the health of residents in South Wellington, Nanaimo, British Columbia. It compares the health of a study group in South Wellington drinking well water, with a control group, in nearby Cinnabar, drinking water from the city water mains. Drinking water from both the mains supply and domestic wells has been collected and analyzed for a variety of possible contaminants. Health data from the study and control groups have been obtained using a structured questionnaire. These two sources of information, therefore, permitted statistical correlations of health and water quality variables in order to provide insights into major research questions.

Research Questions

The first questions addressed by this thesis are “how different are the diseases and disorders suffered by the inhabitants of South Wellington and Cinnabar” and “are there general health differences?” Interviews using a questionnaire were conducted in both the study and the control areas in an attempt to address the issue. The first portion of this questionnaire collected detailed health information on both groups. Variations in the drinking water quality were then used in attempts to explain observed differences in population health.

The second question addressed was more tentative and assumed that many diseases and/or disorders would be found to be higher in South Wellington than in Cinnabar. If this was so, it would be important to identify which factors were predictive of such elevated levels of diseases and/or disorders in South Wellington. A major component of this study, therefore, involved the collection of specific information on the populations of South Wellington and Cinnabar including their behavioral, lifestyle and socioeconomic characteristics. These data were then analyzed statistically in an attempt to compare the general population characteristics and the health of both groups.

The final research question addressed was “is there a relationship or a correlation between diseases and/or disorders in South Wellington and the consumption of well water?” In other words, what is the significance of the water quality on human health in South Wellington? There are many known links between water quality and disease. For example, water can be toxic if it contains elevated iron (Ministry of Water, Land and Air

Protection 1998)[1] . According to Health Canada, at levels above the standard for drinking water quality of 0.3 mg/L, iron may be associated with the development of neoplasms. Studies have also shown that elevated nitrate is perhaps associated with the development of Sudden Infant Death Syndrome (George 2001). High levels of monomeric aluminium have been linked with several forms of dementia, including Alzheimer's disease (Foster 2002, 2004). The health effects of many other elements, however, are unclear. There have been few studies for example, on the impacts of hydrogen sulphide in drinking water (Health Canada 1987(a)), yet hydrogen sulphide is commonly found in the groundwater near coal mines (Bickford 2003). This gas is known to cause detrimental respiratory illness in humans (Health Canada 1987(a)). Yet, the systemic effects of ingesting hydrogen sulphide are obscure, and studies correlating hydrogen sulphide to health have been restricted to lab animals (Health Canada 1987(a)). In an effort to identify the significance to health of organic compounds that have been found at elevated levels in the drinking water of South Wellington, a detailed literature review and thorough analysis of the water quality data was undertaken.

Water samples have been collected from the study area, and analyzed by Caledonian Water Systems Ltd. in Duncan for a wide variety of known toxins and substances. To illustrate, groundwater flowing through abandoned coal mines often has depressed pH levels and typically contains elevated hydrogen sulphide, iron, aluminium and nitrates (Bickford 2003). Such water is also typically high in copper, zinc, mercury, and lead (Meadows and Carpenter 1997). The analysis conducted has established that much of the water consumed in the South Wellington study area contains noxious

---

[1] The Ministry of Environment (MOE) is formerly known as, and referred to throughout this thesis as the Ministry of Water, Land and Air Protection (MWLAP). The MWLAP was reorganized into the MOE (from June 2001-June 2003).

substances that exceed the recommended water quality guidelines laid out by the Ministry of Water, Land and Air Protection (WLAP).

The Study Area

South Wellington is a large, rural area South of the city of Nanaimo. It is a mix of industrial, residential and commercial land use along the Trans Canada Highway and is located within the Regional Electoral District Area “Nanaimo A”. In 2001 this area supported 1,955 families with a total population of 6,420 (Census Canada 2001).

The City of Nanaimo and most surrounding areas receive piped water from the Nanaimo Lakes and the Nanaimo River (City of Nanaimo 2001(a)). Approximately 20km from the city boundary, water is transported from the South Fork Dam and Jump Creek Reservoir, to the village south of Extension and the city of Nanaimo via two parallel pipelines (City of Nanaimo 2001(a)). However, the main pipeline does not service South Wellington, located to the south of the City of Nanaimo. This area still relies entirely on groundwater wells for domestic water purposes, as there are no community water or sewer services to this area. Sewer services are also absent in South Wellington as residents rely on individual septic tanks.

Aquifers are vulnerable to contamination from varying sources depending on the nature of the overlying bedrocks including their type, thickness and depth. Several aquifers are located within electoral district area A, including the Cassidy aquifer which “is situated 4.5 to 6 meters below the groundwater surface and is particularly susceptible to contamination.” (City of Nanaimo 2001). Soils are thin and fractured bedrock is common in certain parts of this area. As a result, “both surface and groundwater sources may be sporadic and unreliable” (City of Nanaimo 2001). The unreliability of the domestic water source, and the limited capacity of the water supply have caused residents of this area to experience water shortages. As a result, “both groundwater and surface water quality and quantity is especially important to the residents of Electoral Area A” (City of Nanaimo 2001).

Most domestic wells in South Wellington have been drilled to depths ranging from 15.24m to 60.96m (WLAP 2003). Details of these differing lithologies can be obtained from the Water Land and Air Protection well database accessible from the Ministry’s website. As would be expected, these data show that, since there are three distinct coal seams in the South Wellington area, some wells have been drilled directly into the abandoned coal mines or coal seams.

Geography and History of Coal in South Wellington

The discovery of coal in the mid 1800’s attracted immigrants to British Columbia’s third oldest city, Nanaimo (Leduc 2004). The black fuel of the 19th century contributed significantly to the heritage and the history of Nanaimo and its surrounding areas. In 1852, after the discovery of coalfields in Nanaimo, the Hudson’s Bay Company (HBC) transferred its mining activities to the area and the Nanaimo Coalfield became a major coal producer between 1852 and 1968 (Davis 1986).

Due to lack of capital, the HBC joined the Vancouver Coal Mining and Land Co. Ltd. to begin production. During the years of exploration and excavation, between 1852 and 1968, coal was the primary fuel for the Western world and production at the Nanaimo coalfields proved exceptionally financially rewarding. The HBC mines at Nanaimo proved to be very productive and by 1859 were the source of 6,000 tons of coal annually (Ministry of Energy and Mines 1999). This coal was shipped from Nanaimo and sold in Victoria before being redistributed to other cities (Ministry of Energy and Mines 1999). Robert Dunsmuir, a pioneer in the coal industry at the time, encouraged exploration for coal in the Nanaimo area and the Wellington seam, the thickest and most extensive of the coal seams in the area was soon discovered.

There are three major seams within the Nanaimo Coalfield; the Wellington, Newcastle and Douglas. The HBC developed the Douglas, the uppermost mineable seam (Gardner 1999). The Douglas Mines included those referred to as the Black Track Mines, which had seams averaging over 1.524m thick (Gardner 1999). Included in the Black Track Mines in South Wellington are: the Alexander slope, South Wellington no.5 slope and South Wellington no.10 slope. South Wellington no.10 slope was one of the prime mines within the Douglas seam, producing 2.7 million tonnes between 1937 and 1952 (Davis 1986). These three mines are those most likely to have a significant impact on groundwater in South Wellington.

The Nanaimo coalfield and the location of coal exploration, is shown in Figure 1. The bedrock geology of the major coal seams in Nanaimo and South Wellington is portrayed in Figures 2 and 3. These maps illustrate the thickness of the coal seams and the bedrock geology in South Wellington nearest the three major coal seams, South Wellington no.10 slope, the Alexander slope, and South Wellington no.5 slope.

Located near Extension Road, the Alexander Slope was opened in 1884 (Murray 1986). It closed in 1901 after filling with water, and reopened in 1930 (Murray 1986). Problems relating to spontaneous combustion caused it to shut down for a second time in 1935 (Murray 1986). According to the Ministry of Energy and Mines in Nanaimo, this specific mine had ‘lots of problems with water’ (Murray 1986).

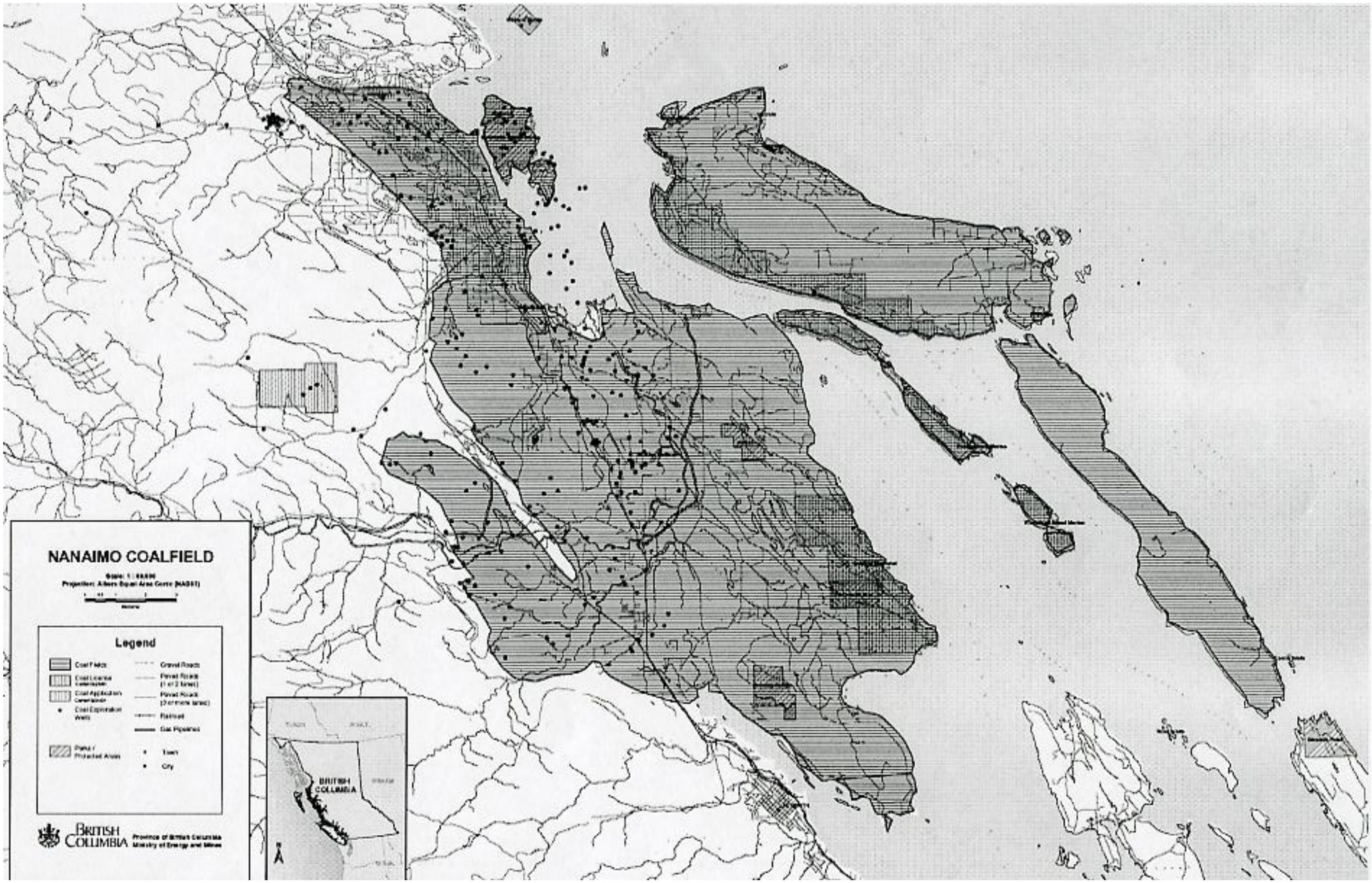

Figure 1: The Nanaimo Coalfield and Location of Coal Exploration.

Source: British Columbia Ministry of Energy and Mines. Website. Coalbed Methane Project

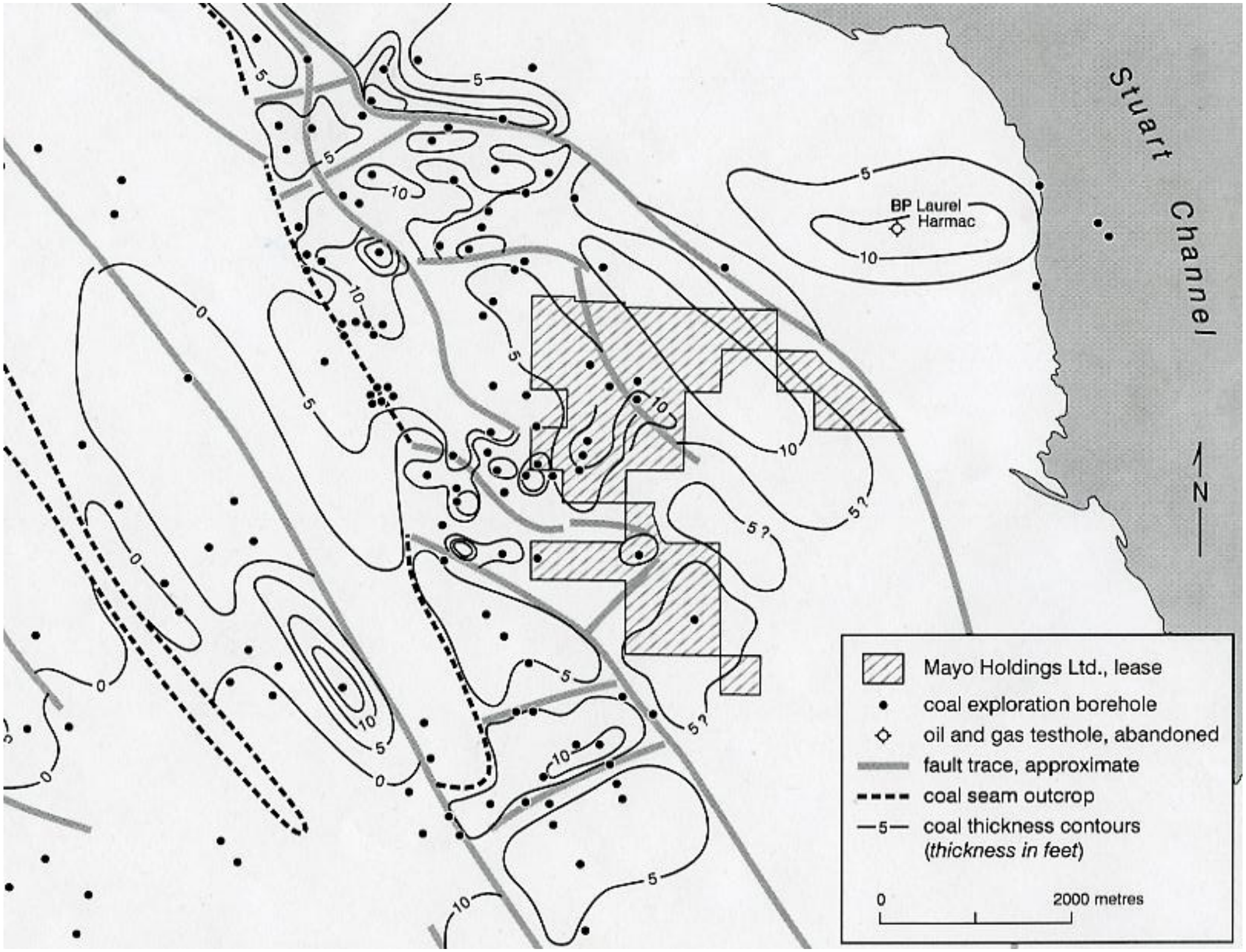

Figure 2: Coal Thickness Contours of Major Coal Seams in Nanaimo. Source: Vancouver Island Gas Co.Ltd. Nanaimo. Calbed Methane Project: Coal Seam Structure. Contoured on the Douglas Seam (east) and Wellington seam (west). D. Keith Murry Consulting Geologist (CPGS No. 446). Golden, Colorado. Aug 1986.

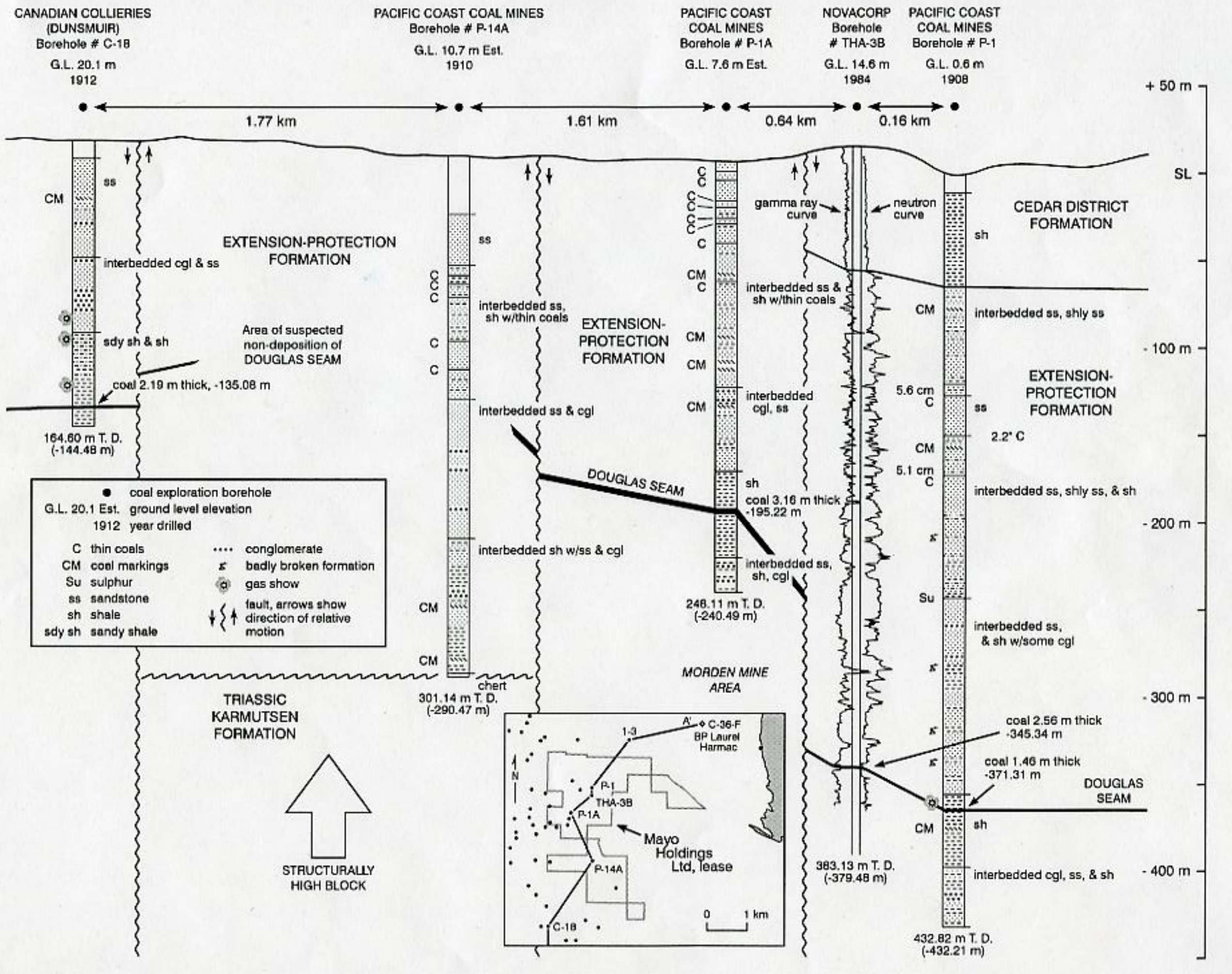

Figure 3: Bedrock Geology of the Major Coal Seams in South Wellington.

Source: Vancouver Isand Gas Co. Ltd. Nanaimo, BC. Coalbed Methane Project: Southwest-Northeast.

South Wellington no.5 slope is located to the north of Becks Lake. This mine opened in 1917, and displayed extreme variations in coal thickness (Murray 1986). With the development of fuel oil and spontaneous combustion within the shafts, the mine closed in 1935 (Murray 1986).

In 1937 South Wellington slope no.10 opened to the south of the no.5 slope (Murray 1986). Although mostly low-quality coal, seams in this modern mine ranged from 2.45m – 6.1m thick in diameter (Murray 1986). This mine remained open from 1937 until 1952, when explosions and ventilation problems prompted its closure (Murray 1986).

CHAPTER TWO: MEDICAL GEOGRAPHY

Interest in the geographical aspects of disease, nutrition and health care has existed since Hippocrates, who wrote:

> Whoever wishes to investigate medicine properly, should proceed thus: in the first place to consider the seasons of the year, and what effects each of them produces… Then the winds, the hot and the cold, especially such as are common to all countries, and then such as are peculiar to each locality. We must also consider the qualities. In the same manner, when one comes into a city to which he is a stranger, he ought to consider its situation, how it lies as to the winds and the rising of the sun: for its influence is not the same whether it lies to the north or the south, to the rising or to the setting sun. These things one ought to consider most attentively, and concerning the water which the inhabitants use, whether they be marshy and soft, or hard, and running from elevated and rocky situations, and then if saltish and unfit for cooking, and the groundwater, whether it be naked and deficient in water, or wooded and well watered, and whether it lies in a hollow, confined situation, or is elevated and cold: and the mode in which the inhabitants live, and what are their pursuits, whether they are fond of drinking and eating to excess, and given to indolence, or are fond of exercise and labour, and not given to excess in eating and drinking (Adams 1849).

As pointed out by Light (1944) "the influence of environment upon health and disease, and on life itself, has long been observed by medical scientists, and for the past century and a half a separate branch of study has existed called medical geography" (Light 1944). Medical geography then has evolved more recently, being recognized as a sub-discipline for some 200 years. According to Pacione (1986, xi) this branch of geography involves "the analysis of the human-environmental relationship of disease, nutrition and medical care systems in order to elucidate its interrelationships in space." As early as 1792, the prominent medical geographer, Leonard Ludwig Finke, published a three-volume study in which he emphasized the relationships between disease and the environment. He wrote, to "which diseases and evils is man exposed, because he lives here and not somewhere else, because he breathes this and no other air, he eats this and no other food, drinks this and no other water, has this and no other way of living and so on" (qtd. in Light 1944, 636). This philosophical approach to medicine continued to hold dominance, in the Developed World, until the wide acceptance of the germ theory in the second half of the nineteenth century. Meade and Earikson (2000), for example, point out that for "2,000 years medicine was concerned with geographical variations in air, water, soil, government, and economy." However the widespread acceptance of a new paradigm, the germ theory, also known as the "doctrine of specific etiology", caused such holistic views to be abandoned in the last fifty years of the nineteenth century. However, paradigms again seem to be changing. Since the mid-nineteenth century physicians had tended to place emphasis on specific etiology, ignoring the multiple variables involved in the etiologies of each disease complex. May (1950), in contrast, stressed the importance of "organic survival" in a particular environment and diverted the object of study away from a single organism to a multi-faceted causality. This holistic approach allows exploration beyond the surface of causality, as "nothing happens in the visible field that does not stem from deep, invisible, and unknown roots" (May 1961).

Medical geographers continue to look beyond infectious pathogens and genetics in an attempt to explain the origins of health and disease. Meade and Earikson (2000), for example, recently developed the Triangle of Human Ecology, with its emphasis on three main factors (see Figure 4). These are considered to be further influenced by sub-factors which "form the vertices of a triangle that enclose the state of human health" (Meade and Earikson 2000). Firstly, gender, age and genetics interrelate to affect the biological balance of a population or an individual. Secondly, the behavior of this population is an observable aspect of culture and is derived from "cultural precepts, economic restraints, social norms, and individual psychology.” (Meade and Earickson 2000, 1). The three co-existing factors that determine the behavior of a population, or an individual are: beliefs, technology, and social organization. Thirdly, these two authors argue that through behavior people create a social habitat.

The multi-dimensional causal relationship that encompasses disease ecology has been extensively explored, and well integrated into the Triangle of Human Ecology. Medical geography is a sub-discipline of geography not a sub-field, because sub-fields generally have a central theoretical paradigm (Brown 1998) and medical geography uses a wide variety of theoretical perspectives. Similar to most sub-disciplines within the field of geography, it has been developed by drawing relevant models from many other disciplines.

Over the past fifty years, medical geography has evolved into a multidimensional repository of knowledge regarding the spatial aspects of human health (Pacione 1986). Its evolution has relied heavily on interdisciplinary concepts and perspectives, and it has bridged a gap between the biological and physical sciences. This has raised difficulties because "most diseases are known to be multi-factorial in aetiology the relevant factors for study rapidly approach infinity and some form of selection is necessary." (McGlashan 1972). Nonetheless, medical geographers often strive to answer questions with similar methodologies and techniques. Studying disease ecology, for example, typically involves disease mapping and statistical analysis.

Disease mapping is one method of creating a visual representation of geographical distribution and the identification and representation of multi-factored disease complexes. Mapping has become one of the most valuable tools for revealing the spatial diffusion of disease. An early example of mapping in medical geography was the work of John Snow who studied the epidemiology of cholera in London. Through careful observation, Snow created a 'dot map' of the residence of victims of the 1854 cholera epidemic (Lawson 2001). With this tool Snow was able to indicate that the spread of cholera was probably the result of drinking contaminated water from a pump in Broad Street (Lawson 2001).

Modern technology, such as Geographical Information Systems, has had a major impact on mapping and spatial statistical tools as well. As a consequence, medical geography has become a prominent discipline. In China, for example, many advances in health have been achieved by applying its research results. To illustrate, several studies have examined the prevention and treatment of endemic diseases such as Keshan disease and Kaschin-Beck disease (Jian'an 1990). Both of these diseases have been shown to be very prevalent in low-selenium environments. It is not surprising then, that soil and table salt supplementation with selenium has greatly reduced the incidences of Keshan and Kaschin-Beck diseases (Jian'an 1990). In addition, many regions of China are iodine deficient because this trace element is often leached from the soils of high mountain areas. Iodine deficient diseases such as goitre and cretinism were common, but are now being controlled through the promotion of iodized salt in affected areas (Jian'an 1990).

Medical Geography Research

Medical geography has been conventionally defined as a sub-discipline involving the spatial distribution and geographical variations of disease, and access to health care (Parr 2003). The research project described in this thesis focuses on geographic variations of disease and an associative analysis of the health of individuals from two distinct communities. Spatial relationships are involved since an analysis of individuals from two geographically separate areas is conducted. The study group is situated in South Wellington and drinks groundwater water from wells that may be affected by abandoned coal mines. The control group is located in the city of Nanaimo and uses city reservoir water. Both South Wellington and Cinnabar are shown in Appendix 1.1 and 1.2 and air photos of the Regional District of Nanaimo are shown in Appendix 1.3 and 1.4.

CHAPTER THREE: LITERATURE REVIEW

Coal Mining and Groundwater

Relatively little is known about the post-mining of coal and its effects on groundwater. However, it is generally understood that the influence of mine site abandonment has adverse effects on the quality of groundwater (Barrie 1988). Aside from mining activities, it has also been accepted that undisturbed coal deposits release and contaminate water supplies with heavy metals and organic compounds (Orem 2003).

Due to mining induced fracturing of bedrock, abandoned coal mines have the ability to cause the loss of overlying perched aquifers (Bickford 2003). A study by Epps (1978) reports that in coal mining regions, groundwater supplies are susceptible to pollution from percolation. With great porosity and permeability, abandoned coal mines become aquifers in themselves. “It is well known that coalmines are aquifers and that the yield of the aquifer is controlled by the degree of fracturing.” (Barrie 1988). Moreover, it is suspected that a portion of the residential wells in South Wellington draw water straight from the mines (Bickford 2003).

With degrading effects on groundwater, abandoned mines significantly affect the general public through the discharge of non-point source pollution (Meadows and Carpenter 1997). Well water becomes highly susceptible to Acid Mine Drainage (AMD) with the flow of water through abandoned coal mines. AMD is referred to as “drainage flowing from or caused by surface mining, deep mining or coal refuse piles that is typically highly acidic with elevated levels of dissolved metals.” (Meadows and Carpenter 1997).

AMD typically occurs whenever groundwater moves or leaks into a mine. The water becomes highly acidic due to the presence of hydrogen ions and dissolved metals such as iron, aluminum and manganese (Johnson 2002) . With the oxidation of sulphide minerals, inorganic sulphur compounds are commonly found and give rise to acidity in groundwater affected by coal mines (Johnson 2002). While coal mines are in operation, groundwater is constantly being pumped to prevent flooding of the work area. When mine operations cease, however, so does the pumping of water. With the absence of the undergroundwater pump the groundwater will naturally begin to rise, dissolving iron oxides, sulphates and proton acidity, all of which are products of pyrite oxidation (Sherwood 1997).

AMD occurs when water and oxygen react with pyrite or sulphide-containing minerals. The water may become contaminated with coal and mineral matter and with the soluble oxidation products of pyrite in this fossil fuel (Soliman 1998).

When iron sulphide minerals and pyrite (which is found naturally in the seams of coal) are exposed to air and water, ferrous sulphate and sulphuric acid are produced (National Research Council (NRC) 1980(a)). Coal contains "up to 10% sulphur, about half of which is commonly pyrite." (Johnson 2002). Sulphur is present in coal as partly organic and inorganic compounds, and upon combustion it is converted into sulphur dioxide (Commission on Energy and the Environment 1981). This gas is very soluble in water, and creates a highly acidic environment. The groundwater system is then adversely affected, as "sulphuric acid dissolves heavy metals, such as lead, zinc, copper, and mercury" (Meadows and Carpenter 1997).

Arsenic is commonly found throughout the Earth's crust and is a natural contaminant of groundwater, often leaching into drinking water through mining waste (Weir 2002). Arsenic has been found at elevated levels in several Canadian Provinces including Nova Scotia, Manitoba, Ontario and British Columbia (Ritter Len et al. 2002). Levels of arsenic, well above the Canadian Drinking Water Quality Guidelines, were recently found in a number of wells in Sechelt, British Columbia (Ministry of Health 1995). Arsenic, when exposed to air and water through activities such as drilling wells and mining, turns into arsenate and arsenite, becoming toxic to humans (Santini 2004).

Previous studies have shown that in coal mining areas, the quality of groundwater decreases with depth. In Alberta, the quality of groundwater near coal mines has been adversely affected by numerous substances (Barrie 1988). Nitrate, iron, fluoride, sulphide, sodium and alkalinity levels all exceeded the recommended daily guidelines for drinking water (Barrie 1988). A study of the Estevan valley aquifer in Saskatchewan also showed incongruously high levels of iron. In 1961, iron levels in this aquifer were measured at 2.1 mg/L, significantly above the Canadian water quality guidelines of 0.3mg/L (Barrie 1988).

In analytical reports of observation wells, the Ministry of Water Land and Air Protection (WLAP) annually calculates the quality and quantity of well water throughout the province of British Columbia. Of the three observation wells located in Nanaimo, the Cassidy well (well #228) is the nearest to South Wellington. The analytical report for August 2002 shows that this particular well is high in both iron and sulphur. The iron content is extremely high at 6.79 mg/L, which greatly exceeds the recommended allowable level of iron in drinking water which is 0.3 mg/L (Health Canada 1987(b)). The sulphur content of this Cassidy well is also very high at 1.2 mg/L. According to WLAP, the recommended intake of sulphide (the chemical compound containing sulphur) is 50ug/L, which is only 0.05 mg/L. The detectable sulphide, in addition to high iron and manganese, may suggest an anoxic (depleted dissolved oxygen) groundwater condition (MacFarlane 2003). If anoxic conditions are present, they are likely to be caused by coal shale or by AMD (MacFarlane 2003). If the source of elevated iron and sulphide is caused by AMD, one would also expect to find elevated aluminum, manganese, sulphate, decreased alkalinity (elevated acidity), low pH and an elevation of other heavy metals (MacFarlane 2003).

According to Ed Copes (2003) at Caledonia Water Treatment Services in Duncan, the groundwater in South Wellington is also abnormally saline. This seems related to deep coal mines, which often contain substantial levels of chloride, giving rise to exceptionally saline waters (World Coal Institute 1991).

Groundwater in South Wellington may be further impacted by pollution stemming from septic tanks. Many properties within the Regional District of Nanaimo are not connected to sewer collection systems and rely on individual septic tanks (Greater Nanaimo Regional District 2003). Previous studies have shown that high levels of organics from septic systems can contaminate groundwater and cause serious problems for communities that rely on private wells for drinking water.

Septic tank problems are commonly overlooked, potentially causing the contamination of drinking water. The area of absorption is where discharged effluent water drains from the septic tanks through the subsoil and into the groundwater. Without proper maintenance sludge may overflow from the absorption area, contaminating groundwater (Boda 1998). Septic tanks may also leak, adding unsafe levels of nitrates and coliform bacteria to groundwater.

In Canada, the greatest point-source discharge for nitrogen and phosphorus is from household sewage (Ritter Len et al. 2002). Briggins and Moerman (1995) studied pesticide, nitrate and coliform bacterial contamination in 102 farms in an agricultural area of Nova Scotia. In this study they found that nitrate levels exceeded the maximum acceptable allowance for Canadian drinking water quality in 13% of the wells tested (Moerman 1995).

The problems associated with household sewage and contaminants in drinking water may be very widespread. To illustrate, in the United States “fifty-seven percent of private water supplies have some detectable nitrate.”(Mackin 1992). In New York State, water tests have shown that one quarter of drilled wells have been contaminated with fecal material and other bacterial organisms (Mackin 1992). In 2002, the Arizona Department of Environmental Quality found high levels of nitrates in Lake Havasu City’s groundwater, prompting a plan to remove all existing septic tanks (Landers 2002). Due to high bacterial counts and elevated levels of nitrate the Department banned all construction within four areas of the city, “unless the property owners build a costly on-site denitrification system” (Landers 2002).

South Wellington is a rural area, which relies heavily on both farming and agriculture. Total coliform levels in groundwater may be the result of fecal contamination, septic tank leakage or animal waste from farming practices. Pesticides and fertilizers too may contribute to groundwater contamination. The monitoring of pesticides and chemicals in drinking water varies from municipality to municipality throughout Canada (Ritter Len et al. 2002). In the past, the monitoring of pesticides has been infrequent, often only once per year (Ritter Len et al. 2002). Pollution from these sources however, depends on the types and amounts of chemicals used and their application. Pesticides, however, are manufactured to be toxic and fertilizers contain several contaminants, such as nitrogen, that have been proven to have ill effects on humans.

The health risks associated with these pollutants are greatest in rural areas, with bacterial contamination of drinking water from private wells. Goss and Barry (1998) conducted a survey of the impact on groundwater from agriculture in an area of Ontario where families rely almost entirely on private wells for drinking water. This study examined the impact of major groundwater contaminants, including nitrates, pesticides and pathogenic microorganisms, on 1292 rural farm wells (M. J. Goss 1998). Of the wells tested, 40% exceeded the maximum acceptable level for these contaminants, 34% exceeded the maximum acceptable level in coliform bacteria and 14% exceeded in nitrates (M. J. Goss 1998).

Groundwater Quality and Health

Agricultural and farming practices may cause a number of pathogens to enter private wells through surface runoff or groundwater. When present in drinking water these pathogens, including Escherichia coli, may have adverse effect on human health. Conboy and Goss (1999) tested the bacterial quality of drinking water of over 300 wells in Southern Ontario. They found that over fifty percent of the wells tested exceeded the drinking water quality guidelines of fecal and total coliform levels (Conboy 1999). They also noted however, an association between the drinking water quality and an increase in gastrointestinal upsets and diarrhea amongst individuals consuming the well water (Conboy 1999).

Aside from pathogens, several contaminants including; magnesium, iron, zinc and other metals are also found in groundwater. More importantly, these contaminants are commonly found in the groundwater of British Columbia (Ministry of Health 1995). Many such substances have known adverse health effects (EPA 2003) but, for the purpose of this thesis, only those typically found in groundwater located near or within coal seams will be discussed.

Iron is the fourth commonest element in the earth's crust, and the most abundant heavy metal (Health Canada 1987(b)). With respect to abandoned coal mines, the occurrence of iron levels increase with AMD (Health Canada 1987(b); MacFarlane 2003). It is not surprising then that, as previously mentioned, the observation well in Cassidy, near South Wellington has an exceptionally high iron content of 6.79 mg/L (Ministry of Water, Land and Air Protection Analytical Services. Submitted by: Liboiron, Russ 2002). The Canadian drinking water quality guideline for iron is 0.3 mg/L.

The ingestion of large quantities of iron can have significant adverse effects on human health and may contribute to the development of haemochromatosis (Health Canada 1987(b)). This condition occurs when "normal regulatory mechanisms do not operate effectively, leading to tissue damage as a result of the accumulation of iron" (Health Canada 1987(b)). Moreover, when the iron concentration exceeds 0.3 mg/L, exposed individuals are known to be at greater risk of developing neoplasms (Health Canada 1987(b)).

Sulphur also occurs at higher than recommended levels in the Cassidy observation well. Sulphates, a combination of oxygen and sulphur, are naturally occurring compounds that dissolve over time and are released into groundwater (Varner 2003). The buildup of sulphate has a laxative effect on humans and can cause severe dehydration, which is of particular concern in infants (Varner 2003). Sulphur-reducing bacteria thrive in oxygen deficient environments, such as wells, and use available excess sulphur as an energy source. These bacteria produce large quantities of hydrogen sulphide (Varner 2003).

Formed through the decomposition of organic matter, hydrogen sulphide is flammable and poisonous (Varner 2003). Although it largely affects the respiratory system, its presence “inhibits the enzyme that allows cells to use oxygen during energy metabolism” (Office of Environmental Health Assessments 2003). Through drinking water and oral ingestion, sulphides have been reported to cause nausea, headache, vomiting, epigastric pain, and irritation to mucous membranes (Health Canada 1987(a)). The Registry of Toxic Effects of Chemical Substances reported that after intravenously administering 6 mg/L of sulphide to male and female rabbits, five of the six animals died within less than two minutes (Health Canada 1987(a)). In a reproduction study using lab rats, hydrogen sulphide was found to be embryotoxic and to have adverse effects on reproduction functioning (Health Canada 1987(a)).

The analytical report of the Cassidy observation well did not include an analysis of nitrate. However, elevated nitrate and nitrogen levels have been found in numerous wells in agricultural areas throughout British Columbia including, Langley, Abbotsford, Osoyoos and Grand Forks (MWLAP 2001). The nitrate and nitrogen content in these wells exceeded the Canadian Drinking Water Quality Guidelines of 10mg/L. In one study, Robert Finkelman of the U.S. Geological Survey found elevated levels of several toxins, including nitrates, linked to coal deposits in the Balkans (Hecht 2001). Toxic wells sunk into shallow coal deposits have caused various ill health effects including high blood pressure, urinary-tract cancers and kidney failure, which has taken the lives of over 100,000 villagers (Hecht 2001). Interestingly, high levels of nitrate have been found in water samples from numerous wells in western British Columbia (Ministry of Health 2000). In New Brunswick, Canada, Arbuckle et al. (1988) conducted a study on the relationship between maternal exposure to nitrates in drinking water and health. This case-control study of 130 individuals revealed the correlation between exposure to nitrates and the increased risk of delivering a child with a central nervous system disorder (Arbuckle et al. 1988).

Nitrates are formed by the breakdown of organic matter, and under certain circumstances may accumulate in the environment (Harte 1991). Long (2000), has studied the deteriorating health of individuals in areas of Bulgaria, noting that some wells had “exceptionally high levels of nitrates” (Hecht 2001). In the human body, nitrates are converted into nitrites, which may be fatal at excessive levels (Harte 1991). This is especially true in infants where metohemoglobinemia occurs when excessive nitrites cause the blood to loose its ability to transport oxygen (Harte 1991). Sudden Infant Death Syndrome (SIDS) mortality, for example, is positively correlated with high concentrations of nitrate in drinking water (George 2001). Furthermore, when nitrites react with food in the gastrointestinal tract, they can form potent carcinogens known as nitrosamines (Harte 1991). A case-control study of nitrates in drinking water in

Minnesota revealed nitrate as a possible risk factor in the development of non-Hodgkin's lymphoma (Freedman 2000).

Although aluminum levels in the Cassidy observation well are not particularly high, this element often can be found abundantly in groundwater, especially in the presence of AMD (MacFarlane 2003). Aluminum has severe impacts on human health (Health Canada 1995). Evidence suggests that areas most harmful to human health are those in which drinking water contains little calcium and magnesium, but elevated levels of aluminum (Foster 2002, 2004). Aluminum has adverse effects on the nervous system and is responsible for various dementia disorders (Health Canada 1995). If exposed to high levels of aluminum in dialysis fluid machines, kidney patients develop dialysis encephalopathy, which is characteristic of speech and behavioral changes, tremors, convulsions and psychosis (Health Canada 1995). Other diseases of the nervous system that have also been associated with aluminum include Parkinson's disease, amyotrophic lateral sclerosis and Alzheimer's disease (Health Canada 1995).

When examining water quality and health, arsenic is of particular concern. Once ingested it travels through the circulatory system into the liver, kidneys, spleen, lungs, skin and other organs causing several health related issues (Health Canada 2001(b)). Symptoms of acute intoxication associated with the ingestion of well water containing arsenic include: abdominal pain, vomiting, diarrhea, pain, weakness and numbness in the muscles and extremities, flushing of the skin and deterioration in motor and sensory responses (Health Canada 2001(b)).

Chronic arsenic exposure has also been linked to non-cancerous conditions such as hypertension, cardiovascular-disease mortality and diabetes mellitus (Centeno 2002).

The NRC (1999) conducted a study in Taiwan and Bangladesh which revealed that the chronic ingestion of arsenic in drinking water increased rates of diabetes mellitus (National Research Council 1999). Reproductive and developmental effects may also be linked to arsenic exposure. In Texas, a hospital case study suggested that stillbirths were strongly correlated with proximity to arsenical pesticide production plants (Ihrig 1998). Other ill effects of long-term exposure to arsenic include; dermal (specifically Plantar hyperkeratosis), neurological, hematological, and hepatotoxic conditions (such as liver dysfunction, portal fibriosis and cirrhosis) (Committee on Toxicology 1999).

It is clear even without baseline studies and monitoring programs that coal mining causes a deterioration of the hydrological system. Methods, however, can be used to reduce and remove harmful elements from groundwater. Limestone and its derivatives are most frequently used for neutralizing acid mine water (Soliman 1998). However, limestone will only remove certain elements such as those with solubilities sensitive to pH, such as aluminum and iron (National Research Council (NRC) 1980(a)). Other ions such as calcium, magnesium and sulphate are less dependent on pH, and may actually increase with limestone neutralization (National Research Council (NRC) 1980(a)). The only solution offered by the Ministry of Health for excess nitrate is to "consider developing a new well in a different location" (Ministry of Health 1995(a)). Reverse osmosis is the most reliable way of removing most contaminants from drinking water, but this process is extremely costly, and in the case of private wells would be undertaken at the expense of the residents (Ministry of Health 1995(a)).

CHAPTER FOUR: RESEARCH METHODS AND DESIGN

For this case-control study, data were collected using a survey questionnaire (see Appendix 2.2), followed by the collection and analysis of water samples from both South Wellington and Cinnabar. A case-control study was chosen for this research because of its efficiency, requiring a smaller sample size than a cohort study and feasibility when the diseases studied occur only rarely (World Health Organization 1992). The study was designed to obtain information on the individual and household characteristics in both South Wellington and Cinnabar while measuring the general health of the two populations using a questionnaire, which addressed specific aspects of human health based on 'The Triangle of Human Ecology' (Meade 2000). The questionnaire was composed of three sections that addressed: (1) population and individual health data; (2) behavioral characteristics; and (3) social habitat.

South Wellington was targeted as the study area for this research project because of its geographical proximity to abandoned coal mines and given its use of groundwater for domestic consumption. In South Wellington, the study sample was chosen with relation to the three major coal seams; the Wellington, Newcastle and Douglas within the Nanaimo coalfield. One hundred houses nearest these seams were selected for the sample. Of this sample, 185 participants in 70 households responded. Selection biases were almost completely avoided in this study, as there were no problems specifying the study sample and the household non-response bias was very minimal (*n*=18). Of the non-responses, the primary respondents of seven households refused to participate in the survey, and the remaining 11 households were unaccounted for, as respondents were absent, or not at home. Cinnabar, used as a control on the other hand, was sampled systematically. Of the 2140 households in Cinnabar, every tenth household was selected until the required sample size of 70 households was reached (198 participants).

The source of drinking water (the variable being controlled for), location and socio-economic characteristics were the key factors in choosing the control area, Cinnabar. Cinnabar is located approximately 1.5 km to the North of South Wellington. However, unlike South Wellington, it derives its drinking water from the supply system of the City of Nanaimo, which extends its pipeline from the south fork of the Nanaimo River. Illustrations of both areas are shown in Appendix I.

Cinnabar is an area similar to South Wellington in socio-economic characteristics such as educational attainment, housing quality, income and population demographics. According to the 2001 census, the population of South Wellington was 6,411 with an average of 2.6 persons per house (Statistics Canada 2001). Approximately 26% of the population was between the ages of 0-19, and 18% were 65 years and older (Statistics Canada 2001). The population of Cinnabar was 5,085 with an average of 2.3 persons per house with 25% between the ages of 0-19 and 14%, age 65 and older. In 2001 the average house value in South Wellington was $174,138 with 1,905 owned houses and 370 rented houses (Statistics Canada 2001). In Cinnabar, the average house value ($109,054) and the number of owned houses (1,640) were slightly lower than South Wellington while the number of rented houses (500) was higher (Statistics Canada 2001). Furthermore, the average income level for dwellers in South Wellington was $26,605 compared to $21,684 in Cinnabar (Statistics Canada 2001).

This study employed a survey design with mainly descriptive and comparative elements. There are several advantages to conducting interview questionnaires and for this survey, conducting face-to-face interviews was the most appropriate method of collecting data. Face-to-face interviews are more personal than other interview methods, including telephone or mail surveys, as respondents may also be more willing to communicate longer with someone when being interviewed face-to-face than to an interviewer on the phone. Face-to-face interviews also allow the interviewer the use of visual aids and to permit the researcher to witness reactions of the respondent. Telephone surveys are limited to a window of time when calling is appropriate and it may be difficult to build trust with a respondent over the telephone (Dillman 1994). It is also difficult to motivate respondents through mail-out questionnaires and they may feel less obliged to complete the survey (Dillman 1994).

In this study, the interview questionnaire was the most appropriate method for gathering data and was used as one of the main instruments for this study. Once the questionnaire was designed, it was approved by the Human Subjects Ethical Review Board at the University of Victoria (see Appendix 2.1). Following approval, a pre-test amongst friends and co-workers was conducted, and an advance letter was mailed-out to notify participants that this research project was about to begin. A copy of the questionnaire is provided in Appendix II.

Biases may occur and can interfere at any stage and in all types of research. A well-designed questionnaire motivates the respondent to provide complete and accurate answers while minimizing errors, biases and leading questions (Dillman 1994). This questionnaire was designed to avoid all biases while minimizing the probability of response error: care was taken to ensure optimum wording and sequence of the questions in order to stimulate and maintain the respondent’s interest and attention while minimizing vagueness. Difficult and unbalanced response questions (with an equal number of positive and negative response choices) were avoided. Since there was no selection bias, non-response was extremely low.

All biases were assessed before conducting the interviews to try to ensure a maximum response rate and that respondents answered all questions truthfully and to the best of their abilities. Respondents were introduced to the project through a non-suggestive advance mail-out letter. This did not inform the expected respondents of the exact hypothesis being tested, as this would have openly invited error. Preconceived ideas about anticipated survey results were avoided in both the advance letter and the questionnaire. Neither the letter nor questionnaire suggested that environmental factors might have decreased the water quality in South Wellington. Respondents were simply told that the study was examining various types of drinking water in the Nanaimo area and local variations in health. Execution of the survey questionnaire was performed in a non-subjective tone and the interviews were short and simple. The typical interview took approximately fifteen minutes and responses were systematically organized so that a negative answer to one question could enable respondents to skip associated queries.

The Triangle of Human Ecology was designed in that "habitat, population, and behavior form the vertices of a triangle that encloses the state of human health" (Meade 2000). This model served as a conceptual framework for this study. As a result, the survey questionnaire was designed in three sections; population, behavior and habitat. The first section was concerned with "humans as biological organisms" in terms of population characteristics such as; age and gender. The second section explored habitat, or the physical, social and built environment, such as residential history and the current geographical area of residence. Behavior and lifestyle was examined in terms of social, cultural and economic variables in the last section. This survey questionnaire also follows similar models of health which have been established and accepted by medical geographers, such as; the Health Field Concept (Lalonde) where health is said to be influenced by human biology, the environment, life-style and the health care system. However, for the purpose of this study, the Triangle of Human Ecology was the most appropriate model.

To obtain an accurate sample size every member of all households surveyed were addressed in this questionnaire. However, to maximize the response rate and to obtain the most adequate results, the questionnaire had to be simple and short. Therefore, only one individual per household, the primary respondent, was interviewed. The primary respondent answered all of the questions in the survey for each member of the household to the best of their ability.

Since the primary respondent was responsible for answering all questions for every individual, the probability for error and bias increased. In most cases error and bias might have occured as the result of inaccurate information of household members provided by the primary respondent. The questions in the first section related to population characteristics such as gender and age and it was relatively easy for the primary respondent to provide accurate answers for the household. It is much easier, for example, to provide the gender of another household member, than it is to provide information on their fruit or vegetable consumption, or amount of weekly exercise. To minimize error, therefore, the second section of the survey only targeted the diseased population. Answers for these questions were only requested from the primary respondent and for household members with a history of diseases or disorders. To illustrate: if a household had three individuals, person one (the primary respondent), person two, and person three; and person one had no history of disease, person two has had cancer and person three has had no history of disease; the primary respondent would then only be asked questions on themselves and person two.

The first question of the survey was designed to allocate a person identification number and household number to each individual, while determining their gender and age. It was crucial to determine the age of each individual as "… age affects so many dimensions of health status, it needs to be accounted for in virtually every study of disease etiology" (Meade 2000). Gender also plays a significant role in an individuals' health. Women, for example are biologically vulnerable to ailments associated with reproduction such as urinary tract infections, and infertility (Koblinsky 1993). Gender is also associated with habitat and behavior. The most obvious habitat difference between males and females are social in nature. Social organization and differing social roles between men and women constitute behavioral differences. In other words, males and females are exposed to different risk factors by their behavior, which in turn affects health. Furthermore, sex hormones which differ in males and females, for example, play an important role in the biological metabolism of cholesterol and fats (Meade 2000). At the chromosomal level, gender and genetics are often linked. Hemophilia and color blindness, for example, occur primarily in males (Meade 2000).

Questions two through five in this survey, probed the health of each of the participants, with an emphasis on specific diseases and disorders that were related to the levels of specific organic and inorganic compounds in drinking water. To illustrate, questions two through four determined if anyone in the household formerly suffered from, or currently suffers from; bowel disorders, liver diseases or disorders or cancers and/or tumors. All other known acute or chronic illnesses were recorded in question five. Following the international classification of disease, answers for this open-ended question were categorized into specific classifications including; diseases of the blood, organ failure, high blood pressure, diseases of the nervous system and mental diseases/disorders. The primary respondent was then asked to indicate their perception of their own health.

The second section of the questionnaire addressed social habitat and behavioral characteristics. As mentioned previously, this portion of the survey addressed only the primary respondent and any of those household members who have been, or who are currently affected with an ailment. These questions focused on social and behavioral factors known to influence health. Questions relating to social habitat examined homeownership, residential history, well water consumption, monthly household income and occupational history. Behavioral questions relating to exercise, diet, smoking and alcohol intake were asked in the final section of this questionnaire.

It was important to establish the residential history and other social habitat factors for each individual. Homeownership was a nominal variable categorized into two variables: rent and own. The length of residency and residential history for the past 30 years was recorded for each household member. For each individual, every area of residence was recorded, along with the time spent at that location. This determined whether the household members were new residents (less than 5 years), short-term (greater than 5 years) or long-term (greater than 10 years) residents of either Cinnabar or

South Wellington. The source of the domestic water supply was also determined by this question and respondents were asked how much of their daily water consumption was derived from a private well. To control for as many variables as possible, income and occupational history were also recorded. In order to limit objections to providing responses, income was divided into several broad response categories.

Income is a significant risk factor in health status. Several diseases and disorders appear linked to levels of income, for example "(a)ll the stresses related to the poverty syndrome are especially relevant to cardiovascular disease" (Meade 2000). It was important, therefore, to determine the income levels for individuals in this study as social class plays an important role in health status. As an example, social class and obesity are inversely related, particularly for females. Brown and Konner (1998) showed that middle and upper class girls are heavier than poorer girls during childhood, however this association reverses after puberty, when lower class women become heavier than middle and upper class women (Brown 1998).

Behavioral risk factors were addressed in the last portion of the survey questionnaire, taking into account as many variables as possible. For example, some of the behavioral risk factors for cardiovascular disease include: cigarette smoking, alcohol consumption, diet, exercise, type of occupation, psychosocial insults and stress (Meade 2000). Weekly exercise and activities or types of exercise were recorded. Exercise types were categorized as light-intensity, high-intensity and vigorous-intensity, classifications used by the Center for Disease Control in Atlanta (Center for Disease Control 2005). Tobacco use was also recorded in terms of years spent smoking and the number of cigarettes smoked on average per day. Cigarette smoking has been linked to some fifty ailments including cancer and heart disease. There are, for example, several compounds found in cigarettes, such as cadmium, that raise blood pressure and increase the risk of heart disease (Meade 2000). Alcohol consumption was recorded in the same style as tobacco use and there is a well-known relationship between alcohol consumption and ill health (Sherlock 1995). If not moderated, the consumption of alcohol may trigger such ailments as cirrhosis of the liver or liver failure, heart disease, kidney failure or disorders of the endocrine system such as diabetes (Sherlock 1995; Epstein 1997). Respondents were willing to answer almost all questions addressed in this survey without hesitation. However, some respondents were apprehensive about providing information on their current employment status and many respondents refused to provide an answer to the question addressing household monthly income.

Lifestyle and behavioral characteristics were examined further with the inquiry about nutrition. This is closely related to health since nutritional deficiencies constitute diseases and malnourishment increases the susceptibility to disease. These questions were important in limiting confounding biases as, for example, nutrition is strongly related to several endocrine diseases. The consumption of fruit and/or vegetable juice, fruit and vegetables were the final three questions in this survey. Both exercise and malnutrition are related to health issues such as obesity, anorexia nervosa and other eating disorders.

Data Analysis

Once data were obtained by way of the questionnaire, it was entered into a database and then statistical analyses were performed to answer the underlying research questions addressed in this thesis including; (1) how does health differ between the communities of South Wellington and Cinnabar? (2) if disease is more common in either area, what are the major risk factors that seem to be associated with disease and ill health? (3) is there a correlation between disease in South Wellington and the consumption of well water?

The data were primarily ordinal, and analyzed with simple statistical methods, cross-tabulations and Chi-square analyses. The Chi-square test analyses were used throughout this study to carry out descriptive analyses.

To determine the difference in health between South Wellington and Cinnabar, cross-tabulations and Chi-square analysis compared the frequency and significance of each disease in the two areas. Ill health was measured by asking participants if they have ever had a particular disease or disorder. The questionnaire addressed a range of specific diseases and disorders including: bowel disease, diseases of the blood, cancer, diseases of the ear/sinus, diseases of the endocrine system, high blood pressure, cardiovascular disease, liver disease, mental/behavioral diseases, diseases of the musculoskeletal system, diseases of the nervous system, organ failure and diseases of the respiratory system.

The first stage in the data analyses involved the examination of the occurrence of disease in South Wellington and Cinnabar using descriptive statistics. This analysis was performed in order to determine whether individuals in the study and control area were significantly different in terms of health status. Descriptive statistics were used to show which of these diseases were more or less prominent in the study or the control area.

The International Classification of Disease (ICD-9) was used to determine categories of disease. Diseases of the blood, included anemia, haemochromatosis and all hemoglobin related disorders. Bowel Disease included Crohn’s disease, colitis, irritable bowel syndrome, ulcers, endometriosis and all other digestive disorders. Angina, heart failure, heart palpitations and strokes were categorized under a broad category of cardiovascular disease. Endocrine diseases included endocrine system complications, diabetes (type I and II) and problems with the thyroid gland. Musculoskeletal diseases included osteoporosis, and nervous system disorders included such ailments as Parkinson's disease and dementia.

While the frequency data showed the number of diseases in both areas, they did not provide information on the association between the variables and so Chi-square tests were performed. However, in order for Chi-square tests to produce adequate results, the observed frequencies should not be too small. Due to the relatively small sample size (n=383), there was a low prevalence of each of the diseases. Therefore, testing the significance of the frequency of each disease in the two areas could not be accomplished without collapsing the diseases into similar groups. These five groups of disease included; (1) bowel/liver disease, (2) cancer/heart disease, (3) endocrine/musculoskeletal diseases, (4) diseases of the ear/sinus and respiratory system, and (5) all other diseases. Diseases were grouped in accordance to similarity and the frequency of occurrence in this study. For example, diseases with similar classifications, such as ear, sinus and respiratory ailments, were grouped together. Diseases with low frequencies, less than six cases, were placed in the "other" category.

To determine why health status was poorer in South Wellington than in Cinnabar, it was necessary to examine the population demographics, characteristics, and the exposure to risk factors in both settlements. Data from the survey questionnaire contained information that was organized according to habitat, population and behavior. Those data were used to compare the background characteristics and exposure to risk factors for the populations in South Wellington and Cinnabar. Study variables and risk factors presented in Table 1.

Habitat or environmental, behavioral and population risk factors were examined in this analysis. Habitat risk factors included homeownership and well water consumption. Behavioral risk factors included; the amount of participation in exercise per week, fruit consumption and juice consumption per day, whether they ever smoked cigarettes and if they consumed alcohol. Population risk factors analyzed included age and gender (Table 1 provides a description of each of these variables).

For this analysis, risk factors with a high percentage of missing cases were excluded. The number of cases with missing data for income was far too high for this sample size. Therefore, income was not included in this analysis.

After comparing the differences in health and population characteristics between South Wellington and Cinnabar, risk factors for ill health were examined in an attempt to explain the association between risk factors and the occurrence of disease in both areas. Chi-square analyses were performed to determine the association between risk factors and disease. Data from the survey questionnaire revealed information that was organized according to habitat, population and behavior. Those data were used to determine the significance of risk factors for ill health.

In the first analysis, risk factors were examined for all individuals in this study ($n = 383$), both healthy and diseased. Cross-tabulations and Chi-square analyses were performed to identify the possible risk factors associated with the presence of disease in the two communities. However, in this analysis only the risk factors relating to habitat and population were analyzed. These risk factors included age, gender, the geographical area

Table 1: Variable definitions

Population	Age	0-18
		19-39
		40-53
		54+
	Gender	Male vs. Female
Habitat	Water (aggregated percentage of water drank from a private well)	None 1-25% 26-50% 51-75% 76%-100%
	Homeownership	Rent vs. Own
	Income	Total household monthly income
	Geographical Area of Residence	South Wellington vs. Cinnabar
	Total years in current residential area	Total years in the area including relocation
Behavior	Alcohol	Do they consume alcohol? Yes/No
	Exercise	Aggregated days per week spent exercising 0-2 times per week/ 3 or more times per week
	Fruit	Amount of fruit consumed per day Once per day or less/ More than once per day
	Juice	Amount of fruit/vegetable juice consumed per day Once per day or less/ More than once per day
	Smoke	Do they smoke tobacco? Yes/No

of residence, residential moving patterns, length of residence, daily consumption of well water. Behavioral risk factors could not be analyzed for the entire sample, as these factors were only recorded (and therefore analyzed) for diseased individuals.

The second analysis examined the lifestyle and behavioral risk factors associated with the diseased population in this study. Since behavioral risk factors were only recorded for the diseased population, only diseased cases were selected in this second stage of analysis. All risk factors on health including behavior, habitat and population were examined. The relationship and significance of these risk factors amongst the population with disease were analyzed using cross-tabulations and Chi-square analysis. Chi-square analysis is used as a measure of association; it provides information about which groups are different on the basis of observed and expected frequencies. Following the Chi-square analysis, binary logistic regression was used to determine the direction of the relationship between the significant variables and disease.

The final stage in the data analyses was performed to determine whether there was a significant correlation between disease in South Wellington and the consumption of well water. Cross-tabulations and Chi-square analyses were performed to examine risk factors associated with disease for the population of South Wellington. Risk factors examined in this analysis included; age, alcohol consumption, participation in exercise per week, fruit and juice consumption, well water consumption, homeownership, income, length of residence, gender and smoking habits.

It is evident that water quality plays a significant role in health. Several varying health concerns may arise from the contamination of various elements and compounds found in drinking water. The questionnaire placed emphasis on specific diseases that have been strongly associated with the presence of trace elements found in drinking water associated with abandoned coal mine workings.

Due to seasonal constraints and budget, only six water samples were collected and analyzed. Appendix IV contains the water analysis test results from the observation wells and from Caledonian Water Systems. It should also be noted that groundwater quality is significantly impacted by seasonal fluctuations. Furthermore, it tends to be less contaminated during seasons when the water table is high. Ideally, collecting well water samples sequentially every few months would have provided the best data. However, because of the costs involved for this study water was collected only once, in the fall season. It has been established that the best time for water collection is when contamination is likely to be the greatest, including after an extended dry season (Health Canada, 2006).

In light of the apparent significance of this risk factor on health, the following chapter examines and highlights the major differences between well water in South Wellington and city water in Cinnabar.

CHAPTER FIVE: WATER QUALITY DATA ANALYSIS

Water samples for analysis were collected from six sources; the city of Nanaimo, three observation wells located within the Regional District of Nanaimo, and two samples from wells located within the South Wellington. The laboratory involved in analyzing these samples was Caledonian Water Systems in Duncan, BC. Table 2 shows general chemistry, metals and bacterial counts for the drinking water in the City of Nanaimo and for observation wells and sample wells within the Regional District of Nanaimo. The two sample wells are located within the South Wellington study area and the three observation wells are located very close to it.

This table allows for a comparison of the six samples against drinking water standards established by both Canada and the United States. The Maximum Acceptable Concentrations (MAC) were set by Health Canada (2004) under the “Guidelines for Canadian Drinking Water Quality”. The Maximum Contaminant Levels (MCL) have been established by the U.S. Environmental Protection Agency (EPA) as the maximum permissible level for a particular contaminant in drinking water. The EPA has also introduced Maximum Contaminant Level Goals (MCLG), non-enforceable public health objectives, which indicate “the level of a contaminant in drinking water below which there is no known or expected risk to health…allow[ing] for a margin of safety” (Environmental Protection Agency 2004).

In the United States, Congress passed the Safe Drinking Water Act in 1974 to legally establish drinking water quality standards for chemicals, which may cause health problems. Maximum Contaminant Level Goals (MCLG) were established as non-

Table 2: Water Quality Comparison Chart

General Chemistry Metals & Bacteria	Nanaimo Drinking Water	OBS Well #228 RDN (Cassidy)	OBS Well #330 RDN (Harmac)	OBS Well #312 RDN (Cassidy)	Well #2623 South Wellington	Well #2623.01 South Wellington	MCL Canada Water Quality Guidelines	EPA Water Quality Guidelines	
								MCLG	MCL
PH	7.29	7.2	6.59	6.7	7.28	6.2	6.5-8.5	6.5-8.5	6.5-8.5
Hardness MgCaC03/L	70.1	40.8	26.8	35.2	348	N/A	100 (AO)	N/A	N/A
Dissolved Solids	25	53	N/A	N/A	594	N/A	500	500	500
T. Coliform CFU/100ml	0	N/A	N/A	N/A	0	668	0	0	0
Alkalinity	13	37	24.3	25	N/A	N/A	N/A	N/A	N/A
Fluoride	<0.02	0.01	0.02	<0.10	0.18	N/A	1.5	2	2
Chloride	4.6	5.7	5.2	10.8	N/A	N/A	250 (AO)	250	250
Nitrate	<0.1	0.69	0.179	N/A	0	2.1	10	10	10
Nitrite	<0.1	0.003	<0.005	N/A	0.005	0.005	1	1	1
Sulphate	<1	3.4	4.1	N/A	69	8	500	250	250
Sulphide	<0.02	N/A	N/A	N/A	N/A	N/A	0.05 (AO)	N/A	N/A
Aluminum	0.012	0.03	0.16	0.04	0.129	N/A	0.1	0.05	0.05
Antimony	<0.0005	<0.05	<0.06	N/A	<0.5	N/A	0.006	0.006	0.006
Arsenic	<0.0005	0.4	<0.06	<0.04	0.00168	N/A	0.005	0	0.01
Barium	<0.02	0.003	0.002	0.016	0.128	N/A	1	2	2
Beryllium	<0.001	<.0002	<.001	<.001	<.003	N/A	N/A	0.004	0.004
Boron	<0.1	0.012	<0.01	0.081	0.686	N/A	5	N/A	N/A
Cadmium	<.00005	0.002	<0.006	<0.002	<0.100	N/A	0.005	0.005	0.005
Calcium	5.3	11.5	8.6	10.9	104	N/A	N/A	N/A	N/A
Chromium	<0.001	<0.005	0.01	0.004	<0.01	N/A	0.05	0.1	0.1
Cobalt	<0.0003	<0.005	0.01	0.004	<0.02	N/A	N/A	N/A	N/A
Copper	0.005	<0.005	0.008	<0.001	0.056	N/A	1 (AO)	1	1
Iron	0.22	6.79	0.442	7.2	0.179	0.1	0.3	0.3	0.3
Lead	<0.0005	<0.03	<0.06	<0.02	<0.5	N/A	0.01	0	0.015
Magnesium	0.5	2.93	1.6	2	21.4	N/A	100 (AO)	N/A	N/A
Manganese	0.0154	0.041	0.01	0.028	1.02	N/A	0.05 (AO)	0.05	0.05
Molybdenum	<0.001	<0.005	0.01	0.006	<0.02	N/A	N/A	N/A	N/A
Nickel	<0.001	<0.008	<0.02	<0.008	<0.05	N/A	N/A	N/A	N/A
Phosphorus	<0.3	<0.1	<0.1	<0.04	0.146	N/A	N/A	N/A	N/A
Potassium	<2.0	<1.0	0.3	0.8	5.31	N/A	N/A	N/A	N/A
Selenium	<0.001	<0.03	<0.06	<0.03	N/A	N/A	0.01	0.05	0.05
Silver	<.00002	<0.01	<0.01	<0.01	<0.01	N/A	N/A	0.1	0.1
Sodium	2	4.47	38.0*	5	119*	N/A	200	N/A	N/A
Strontium	0.021	0.036	0.04	0.068	1.13	N/A	N/A	N/A	N/A
Thallium	<0.0002	<0.03	N/A	<0.003	N/A	N/A	N/A	0.0005	0.002
Titanium	<0.01	<0.003	0.004	<0.003	<0.01	N/A	N/A	N/A	N/A
Vanadium	<0.03	<0.005	<0.01	0.005	<0.01	N/A	N/A	N/A	N/A
Zinc	<0.005	0.005	0.007	<0.002	0.015	N/A	5	5	5

All measurements are in mg/L (unless noted otherwise). Highlighted parameters exceed the MAC or the MCL. *20 mg/L for those on sodium restricted diets. AO = Aesthetic Objective. N/A no limits set **Maximum Acceptable Concentrations** (MAC) have been set by Health Canada (2004) under the "Guidelines for Canadian Drinking Water Quality". **Maximum Contamination Levels** (MCL) have been set by the Environmental Protection Agency (EPA) as the highest level that a contaminant is allowed in drinking water whereas the **Maximum Contaminant Level Goals** (MCLG) is defined as "the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals" EPA (2004).

enforceable levels, based on the exposure to chemicals with potential risk to health (Environmental Protection Agency 2004(a)).

Since each person's body responds uniquely to contaminants, it is very difficult to predict the exact level at which a contaminant may cause ill health. However, the water quality data in Table 2 clearly establishes levels of specific contaminants and general chemistry levels in Nanaimo that do not meet the standards of the Maximum Acceptable Concentrations set by Health Canada or the Maximum Contaminant Levels of the US Environmental Protection Agency.

Antimony

Antimony is a bi-product of base metals and silver ores found in natural deposits that chemically and biologically resembles arsenic (even in terms of its health effects and toxicity) (Schroeder 1970). It is used in the manufacturing of ceramics and glass, batteries, pigments and flame-retardants (Environmental Protection Agency 2005). One of the most commonly know sources of antimony in drinking water comes from household plumbing (World Health Organization 2003).

In groundwater, the levels of antimony usually range from 0.001 to 0.002 mg/L and it is "…not likely to occur at significantly higher concentrations in natural waters, except in those areas affected by acid mine drainage" (World Health Organization 2003). The EPA (2005) has set antimony MCLs at 0.006 mg/L and argued that health problems may arise if it is found at levels greater than this. Health Canada (1999) has also set the MAC level for antimony in drinking water at 0.006 mg/L.

Exposure levels to antimony in Canadian drinking water, air and food have been calculated by Health Canada. On a daily basis, the average Canadian received 0.0046 mg of antimony from their diet, 0.00004mg from the air and 0.0028mg from drinking water (assuming an average daily water consumption of 1.5 L/day), receiving a total of 0.00744 mg of antimony per day (38% from drinking water). However, as Table 4 shows, antimony levels are much higher than the MACs in the drinking water of observation wells #228 and #330 and in well sample #2623 in South Wellington than in the City of Nanaimo drinking water. In well sample #2623 antimony is <0.5 mg/L. This is a rough figure as the exact level of antimony in this sample is unclear. However, if the maximum level of antimony in this case (0.5mg/L) was assumed, and if this figure were put into the above equation, then the intake of antimony on a daily basis would be much greater. Once more it will be assumed that for the average Canadian, food contributes to 0.0046 mg and air contributes to 0.0028 mg of antimony per day. If the average Canadian consumed 1.5 L of water/day, then with a level 0.5mg/L the daily consumption for antimony from water would be 0.75 mg. In other words, individuals consuming well water with antimony levels 0.5 mg/L would receive approximately 0.76 mg of antimony/day (roughly 99% of the daily intake of antimony would be received from drinking water alone). For human health reasons, Schroeder (1970) estimates that the human daily intake from antimony to be 0.1 mg.

Antimony binds to the red blood cells and travels to the spleen, liver, bone and to the skin and hair (World Health Organization 2003). The distribution and accumulation of antimony generally occurs in the thyroid, liver and spleen (National Research Council 1980(b)).

Acute intoxication, or exposure to antimony at levels greater than the MAC and MCL for only short periods of time cause nausea, abdominal pain, dehydration, muscular pain, shock, haemoglobinuria, anuria, uraemia and diarrhea (Health Canada 1999; Environmental Protection Agency 2005). After long-term or chronic exposure greater than the MAC and MCL, antimony is primarily associated with myocardial effects and is a potential human carcinogen (National Research Council 1980(b); Health Canada 1999; Environmental Protection Agency 2005). The ingestion of soluble antimony salts has been studied and shown to lead to gastrointestinal irritation, vomiting, abdominal cramps, diarrhea and cardiac toxicity (World Health Organization 2003). Toxicity generally occurs in the gastrointestinal tract, heart, respiratory tract, skin and liver. In the gastrointestinal tract, antimony toxicity causes nausea and cramps, anorexia, diarrhea and vomiting (National Research Council 1980(b)). In the heart, antimony causes fluctuations in blood pressure while increasing blood cholesterol levels and decreasing blood sugar (Schroeder 1970; National Research Council 1980(b)). Some of these health problems were identified in the interviews conducted in the study area.

Arsenic

"Abandoned mines are known to contaminate private water wells with toxic metals and arsenic" (Peplow 2004). Arsenic is naturally found throughout the crust of the Earth and may result from human or natural activities. It typically leaches into groundwater from orchard runoff, mining waste, glass and electronics production and natural processes (Environmental Protection Agency 2001). It has been estimated that, in Canada, the average arsenic level in drinking water is less than 0.005mg/L (Health Canada 2004(b)).

The MAC for arsenic according to the Canadian Water Quality Guidelines is 0.005 mg/L. This figure has been set based on the incidence of cancers "through the calculation of a lifetime unit risk" (Health Canada 2004(b)). Table 4 shows that arsenic levels are higher than the MAC in observation wells #228, #330 and #312. The highest level is 0.4 mg/L in observation well #228. The EPA however has recently lowered the U.S. MCL from 0.05 mg/L to 0.01 mg/L with a MCLG of zero. This level has been lowered to "maximize health risk reduction at a cost justified by the benefits" (Environmental Protection Agency 2001). This reduction, enforceable on January 23, 2006, will be beneficial in the prevention of:

> "[m]ore than 19-31 cases of, and 5-8 deaths from, bladder cancer each year; more than 19-25 cases of, and 16-22 deaths from, lung cancer each year; and a number of cases of cancerous and noncancerous diseases, such as skin cancer and heart diseases" (Environmental Protection Agency 2002).

It may be assumed that the average Canadian consumes 0.421 mg of arsenic/day from food and, although this figure is debatable, <0.001 mg from air (Health Canada 1992(a)). If the average Canadian then consumed 0.38mg of arsenic/day from water (based on the MAC level of 0.025 mg/L of arsenic and the figure provided by Health Canada of 1.5L of water consumed per day) the overall level of arsenic consumed would be 0.081 mg. However, if the arsenic level of 0.4 mg/L from the observation well sample were to replace the MAC level of 0.025 mg/L in this equation, then the daily arsenic level from the consumption of water would be 0.6mg (indicating a total arsenic consumption of 0.642 mg/day).

Arsenic, a human carcinogen, has not been proven to be essential to the human body (Health Canada 2004(b)). Shortly after ingestion, arsenic binds to hemoglobin in the circulatory system and is transported to the liver, kidneys, spleen, lungs and skin (Health

Canada 1992(a)). Arsenic is stored primarily in the skin, bones and muscles and is excreted in urine, sweat, skin, hair and nails (Health Canada 1992(a)).

After exposure for weeks or months to arsenic at levels of 0.04 mg/kg/day, health problems such as diarrhea, gastrointestinal cramping, hematological effects (including anemia and leukopenia), and peripheral neuropathy may occur (Board on Environmetal Studies and Toxicology 2001). Between 6 months to 3 years of ingesting 0.04 mg/kg/day, hyperpigmentation may result and toxic effects may result within 5 to 15 years of ingesting arsenic at 0.6 mg/day for an adult weighing 60kg (Board on Environmetal Studies and Toxicology 2001). Arsenic from drinking water alone may also cause chronic arsenicalism after 5-15 years of exposure to 0.7mg/L of arsenic (Health Canada 2004(b)).

In Mexico, arsenic exposure was studied amongst two rural populations. The study group was exposed to arsenic at 0.114 to 0.41 mg/L and the control group to levels between 0.007 and 0.005 mg/L (Health Canada 1992(a)). The study group had a much higher prevalence of nausea, epigastric pain and abdominal pain, colic and diarrhea, headaches and oedema (Health Canada 1992(a); Health Canada 2004(b)).

In high concentrations arsenic causes long-term health effects such as: skin disease, hypertension and cardiovascular disease, perturbed porphyrin metabolism, irreversible noncirrhotic hypertension, diabetes, and cancers of the lung, skin, bladder, kidney and liver (Karagas 1998; Ceneto 2002). A case-control study in Massachusetts associated exposure to arsenic in drinking water with increased rates of miscarriages (Health Canada 2004(b)).

Arsenic was linked to cancer as early as 1898 (Environmental Protection Agency 2002). In 1980, the International Agency for Research in Cancer identified arsenic as a carcinogen. In a study by Peplow and Edmonds (2004) the mortality risk was more than 1 in 10,000 from arsenic exposure at concentrations below .008 mg/L. Long-term exposure and ingestion of arsenic from drinking water is associated with several types of cancers including skin, lung and bladder {Karagas, 1998 #80;al., #82;al., 2004 #55}. A recent study amongst male smokers has also shown high concentrations of arsenic may cause bladder cancer {al., 2004 #55}. However, according to this study, "it is unclear whether low exposure to inorganic arsenic in drinking water (<100 microg/liter) is related to bladder cancer risk." {al., 2004 #55}.

The health effects of the consumption of well water containing arsenic have been documented in children in Antofagasta, Chile (Health Canada 1992(a)). Water with a mean concentration level of 0.6 mg/L caused problems associated with the skin, respiratory system, cardiovascular system, and digestive system in children under the age of 16 (Health Canada 1992(a)). The largest study of arsenic consumption was conducted in Taiwan amongst 40,421 people (Health Canada 1992(a)). This examined the relationship between arsenic exposures in well water to health. Groups with; high ≥0.60mg/L, medium 0.30 to 0.59 mg/L and low 0.01 to 0.29 mg/L arsenic consumption were examined and "[t]here was a clear dose-response relationship between exposure to arsenic and the frequency of dermal lesions, Blackfoot disease (a peripheral vascular disease) and skin cancer" (Health Canada 1992(a)).

Another study, in Taiwan, showed the relationship between arsenic and cancer. Exposures ranging from 0.1 to 0.29 mg/L and 0.20 to 0.59 mg/L and 0.60 mg/L showed a significant dose-response relationship between exposure, Blackfoot disease and skin cancer (Tseng 1977). Ill health associated with well water containing 0.35 to 1.14 mg/L of arsenic, included such things as: cancers of the bladder, kidney, skin and lung and cancers of the prostate and liver in men (Health Canada 1992(a)). Reanalysis of this study examined the correlation between arsenic concentrations in drinking water in 42 villages in Southwestern Taiwan. Of these villages, 13 had median arsenic levels below 0.10mg/L, eight ranged between 0.10 to 0.29mg/L, 15 ranged between 0.30 to 0.59 mg/L, and six had levels higher than or equal to 0.60mg/L (Health Canada 2004(b)). Again, there was a significant dose-response relationship between the exposure to arsenic and mortality from cancer (Health Canada 2004(b)). Huge health problems are also developing in millions of people in Bangladesh who are drinking well water containing elevated arsenic levels (Smith 2000).

Cadmium

Cadmium is a rare element found in soil and rock, including coal, and is primarily used for metal painting and coating, machinery, photography, television phosphors, nickel-cadmium and solar batteries (Environmental Protection Agency 2004(a)). Cadmium often leaches through the soil into the groundwater and levels may increase in acidic environments.

In Canada, the MAC for cadmium in drinking water, established for health reasons, is 0.005 mg/L (Health Canada 1986). In the United States, for three years following the regulation of cadmium in 1992, the EPA required water suppliers to collect and analyze water for cadmium and to recommend that if "it is present above [0.005], the system must continue to monitor this contaminant every three months" (Environmental Protection Agency 2004(a)). The MCLG for cadmium is 5ppb, or 0.005 mg/L because "the EPA believes this level of protection would not cause any of the potential health problems…” which occur with the presence of cadmium (Environmental Protection Agency 2004(a)).

Health Canada (1986) has claimed that “[d]rinking water supplies contain low concentrations of cadmium (<0.001mg/L) when they are drawn from unpolluted water sources”. A NAQUADAT survey of 3067 samples was conducted across Canada and only four samples contained cadmium at levels higher than the MAC of 0.01 mg/L. In this study, the highest concentration found was 0.061 mg/L (National Water Quality Data Bank 1985).

According to Health Canada (1986) diet accounts for an average intake of 0.014 mg of Cadmium. Assuming a daily respiratory volume of 20 m^3, airborne cadmium in non-urban environments contributes to an average of 0.0006 mg per day, while the consumption of 1.5 L per day of drinking water contributes an average of 0.005 mg/L of cadmium per day. Daily average exposures from diet, air and water provide the average Canadian with 0.0196 mg of cadmium per day (which is roughly 0.1372 mg per week). However, as shown in Table 4, cadmium levels are much higher than recommended in the drinking water from both observation well #330 and well sample 2623. In well sample 2623, the cadmium level is 0.1 mg/L. Assuming the daily intake of water is 1.5 L, cadmium exposure from water in this well would be 0.15 mg per day. With diet contributing to an average intake of 0.014 mg and air contributing to 0.0006 mg of cadmium per day, this would then indicate that the daily exposure to cadmium is 0.1646 mg. The World Health Organization has recommended that cadmium not exceed 0.057 to 0.071 mg/day (Health Canada 1986). Experts have estimated that a “provisional tolerable weekly intake of cadmium for an adult be from 0.4 to 0.5 mg” (Health Canada 1986).

The individuals drinking 1.5 L per day of water from this well are currently exposed to 1.1522 mg of cadmium per week.

These figures however, do not take several other factors into account that may contribute to cadmium levels in the human body. Smoking twenty cigarettes for example, contributes to roughly 0.003 mg of cadmium per day (Health Canada 1986). Furthermore, 0.014 mg of cadmium from food intake per day is a mean figure. The daily intake of cadmium from food actually ranges from 0.007 to 0.034 mg per day (Health Canada 1986). So if the individuals consuming water from the well that provided sample #2623 smoked twenty cigarettes per day and are exposed to 0.034 mg of cadmium from food, their weekly levels of cadmium intake would be raised to 1.3132 mg.

Within minutes of exposure, cadmium is present in blood plasma and accumulates in the liver and kidneys (Health Canada 1986). Only twenty-four hours after exposure cadmium is bound to metallothionein in blood cells (Health Canada 1986). Metallothionein, a metal-binding protein that is rich in cadmium and thionein, is found in the liver, kidneys, duodenum, urine and blood and may be essential for the detoxification of cadmium (Health Canada 1986). When the amount of cadmium is high or when the level of metallothionein in the liver is insufficient to bind to cadmium, toxic effects may result (Health Canada 1986). Perhaps more importantly is the ability for cadmium to accumulate in the human body, as less than 10% is excreted and eliminated in urine and feces (Health Canada 1986).

"Cadmium is not believed to be an essential nutrient for animals or man" (Health Canada 1986). The EPA has determined the short-term and long-term health effects related to cadmium. According to the EPA (2004) ill health such as; "[n]ausea, vomiting, diarrhea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure" may occur when exposed to levels of cadmium above the MCL for only a short period of time. Serious damage to the kidney, liver, bones and blood may result after exposure to cadmium above the MCL for longer periods of time (Environmental Protection Agency 2004(a)).

Cadmium has also been found to damage DNA and inhibit DNA repair while contributing to high levels of mutations which may lead to cancer, reproductive problems and birth defects (Jin 2003). An NIEHS senior scientist, Michael A. Resnick claimed that, "What cadmium does in living cells is to block post-replication mismatch repair of natural errors and thus increases the mutations dramatically-as much as 2,000-fold" (Jin 2003).

Further studies have shown that cadmium exposure may be associated with bone demineralization, decreased bone density in women and height in men (Staessen 1999). Moreover, several studies on rats have shown the detrimental health effects of the accumulation of cadmium. One study by Pasky and Varga (1992) illustrates the interference of cadmium with the ovarian function of rats. Cadmium toxicity in pregnant rats has also been shown to be responsible for thyroid cell damage, reducing thyroglobulin producing cells while decreasing T4 and T3 cells (Yoshizuka M. 1991).

Iron

Iron is an element found naturally in the crust of the Earth and is used widely for such things as metallurgy, steel production, paint pigments, polishing agents and electronic materials. It is commonly found in groundwater supplies contaminated by industrial processes, acid mine drainage, the corrosion of iron-containing metals, the refining of iron ores and leaching of soluble iron salts from rock and soil (Washington State Department of Health 1996).

The MCL for iron in drinking water has been set by the Canadian Drinking Water Quality Guidelines at an Aesthetic Objective (AO) of 0.3 mg/L. In Canada, data collected from varying drinking water stations has shown that iron concentrations do not typically exceed 1 mg/L (Health Canada 1987(b)).

Table 4 shows that in observation wells #228, 330 and 312 iron levels exceed the MCL (AO) of 0.3 mg/L. The level of iron is 6.79 mg/L in observation well #228, 0.442 mg/L in observation well #330 and 7.20 mg/L in observation well #312.

According to Health Canada (1978), the average intake of iron from a typical Canadian diet is 17.6 mg and the average daily intake of iron from air is 0.036 mg (based on mean values recorded in Alberta and Ontario assuming an average respiratory volume of $20m^3$ for an adult). Assuming 0.046 mg/L is the average iron content of water and that the normal individual drinks 1.5 L of water/day, the amount of iron consumed from drinking water would be 0.07 mg (Health Canada 1987(b)). In other words, the average Canadian would receive approximately 18 mg of iron from diet, air and water sources combined. However, if the iron level in the drinking water were 7.20 mg/L (as found in observation well #312) then the iron intake from drinking water would be 10.8 mg, equaling a total daily iron intake of 28.44 mg.

The recommended nutrient intake of iron has been set by the Department of National Health and Welfare (1990) at 9.0 mg/day for men, 13 mg/day for women and 8.0 mg/day for post-menopausal women.

Iron is an essential trace element. It is vital in the transportation of oxygen and carbon dioxide and is carried in the blood mainly to the spleen, bone marrow and liver. Although not considered a health concern at levels below the aesthetic objective, iron overload, also known as haemochromatosis, causes tissue damage and the breakdown of regulatory mechanisms (Health Canada 1987(b)). Haemochromatosis may lead to chronic fatigue arthritis, heart disease, cirrhosis, cancer, diabetes, thyroid disease, impotence and sterility (Wilkes University 2004).

The ingestion of iron at toxic levels may damage the blood vessels, liver, kidney and in some cases, may result in death (Washington State Department of Health 1996). Iron overload may also result in neurodegenerative diseases, or ailments associated with the accumulation of iron in regions of the brain which are affected by Alzheimer’s disease and Parkinson’s disease (Zecca 2004). Furthermore, according to Health Canada (1978) “individuals who do develop iron overload are reported to be at greater risk of developing neoplasms”.

Lead

Lead is a widespread and naturally occurring element, however it is often released into the environment from human activities such as mining, smelting and refinement. It has been used in paints, gasoline, ceramics solder, batteries and in leaded pipes. The presence of lead in drinking water may be a result of either the dissolution from natural sources or the use of leaded pipes and solder in household plumbing systems. Several factors influence the amount of lead that may be dissolved including; the acidity, softness and standing time of the water (Health Canada 1992).

The MAC for lead in drinking water is 0.01 mg/L (10 μg/L). In the United States, the EPA has set the MCL for iron at 0.015 mg/L and at zero for the MCLG.

Table 4 shows that in the city of Nanaimo, lead is present in the drinking water at <0.0005 mg/L. However, three of the four wells tested for lead in the Regional District of Nanaimo were above both the MAC and the MCL. Observation well #330 had the highest lead concentration <0.06 mg/L (60 μg/L).

Health Canada has averaged the total daily lead intake for adults and children based on an average intake of lead from air, water, food and dust. The assumed volume of air inhaled per day is 6 m^3 for children and 20 m^3 for adults, the assumed drinking water consumption is 0.6 L/day for children and 1.5 L/day for adults (with an average lead content of 4.8 μg /L) and the assumed quantity of dirt ingested is 80 mg/day for children and 20 mg/day for adults (Health Canada 1992). From these figures, the total average daily intake of lead for children is 29.5 μg /day and 63.7 μg /day for adults (Health Canada 1992). The drinking water in observation well #330 however, contains 60 μg /L of lead, which would then make the lead intake 62.24 μg /day for children and 146.5 μg /day for adults. With drinking water lead levels at 60 μg /L, the daily intake of this toxin would be more than double the estimated average.

The World Health Organization has established a maximum weekly intake of 25 μg /kg of lead (3.5 μg /kg/day) (Health Canada 1992). If the average child, two years of age, weighs 13.6kg then the maximum allowance of lead is approximately 340 μg /week (47.6 μg/day). The lead intake for a child consuming 0.6 L/day of water with 60 μg /L of lead would be 435.68 ug/week (62.24 μg/day).

Once absorbed, lead is either taken up by the skeletal system or is distributed to the blood, liver, lungs, spleen, kidneys and/or bone marrow (Health Canada 1992). Children under the age of six are much more susceptible to the effects of lead. This is evident as roughly 40%-53% of lead ingested is absorbed in children compared to 10% absorbed in adults (Health Canada 1992). High exposure in children may cause delays in mental or physical development, mental retardation, behavioral problems, anemia, liver and kidney damage, hearing impairment, hyperactivity, brain damage and even death (Environmental Protection Agency 2004).

In adults, acute toxicity from lead usually results in restlessness, irritability, poor muscle coordination, poor attention span, headaches, hallucinations and memory loss. Symptoms of chronic toxicity include sleeplessness, nerve damage, gastrointestinal problems, hearing and vision impairment, reproductive problems, kidney damage or high blood pressure (Health Canada 1992; Environmental Protection Agency 2004). At toxic levels, lead may cause encephalopathia, anemia, seizures and mental retardation in children (Schumann 1990).

Thallium

Thallium is a metal found in natural deposits and is commonly used in electronic equipment. Although Health Canada has not specified an MAC level for thallium in drinking water, the EPA has set the MCL at 0.002 mg/L with a MCLG of 0.0005 mg/L. The EPA has established the MCL at this level for health reasons and also because “this is the lowest level to which water systems can reasonably be required to remove this contaminant should it occur in drinking water” (Environmental Protection Agency 2004).

Thallium levels were recorded in the drinking water for the City of Nanaimo and in two of the five wells located within the Regional District of Nanaimo. In both observation wells #228 and #312, thallium exceeds the MCL.

At levels above the MCL in drinking water, thallium has the potential to cause “hair loss; changes in the blood; kidney, intestine, or liver problems” (Environmental Protection Agency 2004). Gastrointestinal and nerve damage may result if individuals are exposed to thallium at levels above the MCL for short periods of time(Environmental Protection Agency 2004).

Total Coliform

“Of all contaminants in drinking water, human and/or animal feces present the greatest danger to public health” (Health Canada 2001). Bacteria (such as Shingella), viruses (such as Norwalk and Hepatitis A) and protozoa (such as Cryptosporidium) exist naturally in drinking water or may occur as a result of animal or human waste. The presence of total coliform in groundwater may be due to fecal contamination from humans or animals through unreliable septic tanks or farming.

One study, conducted in a suburban neighborhood of Montreal, examined gastrointestinal disease due to microbiological standards in drinking water. This study raised questions of drinking water quality standards, as the microbial quality was in compliance with regulations. This case-control study examined 606 households (Payment 1991). Of these households, 299 were supplied with water filters, to remove microbial and chemical contaminants, while the remaining 303 households were left with unfiltered tap water which met the drinking water standard for microbial quality (Payment 1991). The results obtained from this study concluded that gastrointestinal illnesses were higher amongst those individuals consuming unfiltered tap water (Payment 1991). Moreover, they claimed that 35% of the reported gastrointestinal illnesses found in these individuals was water-related and preventable (Payment 1991).

Water is generally tested for two types of coliform; total coliform and fecal coliform. Total coliform includes any bacteria that may live in water, soil or animals. The total bacterial coliform level in well sample #2623.01 is 668 (CFU/100ml). Canadian guidelines do not permit any amount of coliform in drinking water.

> "[B]y law in British Columbia public water systems should never have more than ten total coliform organisms in a 100 milliliter sample, and no more than ten percent of samples should have any total coliform bacteria" (Ministry of Health 1995(a)).

The presence of total coliforms in private wells would indicate either an inadequacy in treatment or re-growth of the pathogen. It may also indicate that the well is prone to infiltration, in which case fecal materials may be entering the water supply (Health Canada 2004). If total coliforms are detected in the water supply, a boil water advisory should be implemented immediately (Health Canada 2004).

There are several ill health effects of ingesting water contaminated with coliform. The health threat of total coliform is dependent on whether a potentially harmful bacteria is present in the water supply. If present, certain pathogens and parasites may cause potentially seriously adverse health effects. Some pathogens affect only the gastrointestinal tract while others may infect the kidneys, lungs central nervous system or other organs. Gastrointestinal problems such as, nausea, vomiting and diarrhea are the most common ailments associated with short-term exposure to coliform in drinking water. However, chronic health problems and even fatal ailments may arise with the presence of certain organisms. E. coli is one coliform that is typically found in human and animal feces and, if ingested, may cause serious intestinal diseases.

One study showed the relationship between the bacteria Helicobacter pylori in well water, to stomach ulcers and cancers (Author unknown 1999). Several bacteria cause acute diarrhea and/or constipation. Mycobacterium is one pathogen that has been found to cause systemic bacterial infections and pulmonary diseases (Health Canada 2001). Children, the elderly and those with depressed immune systems may be at extra risk to bacterial contamination in drinking water.

Conclusions

Contaminants in water may adversely affect health depending on the dose or exposure to the contaminant, the duration of the exposure and the biological, environmental, lifestyle and behavior of the individuals ingesting the water. It is also, important to consider the significance of the concurrent exposure to several different contaminants at the same time.

Lead, cadmium, mercury, antimony and aluminum are toxic heavy metals that are of particular concern to the health of children. Each of these metals acts as a neurotoxin and, in combination, may cause more significant health problems. Lead exposure in children may result in intelligence quotient (IQ) deficits, mental retardation, irritability, behavioral problems and hyperactivity (Health Canada 1992; Environmental Protection Agency 2004). Cadmium and mercury are both neurotoxins, which may cause mental retardation (Buttram 2003). Antimony has also been attributed to poor neurological health. In his report Jon Pangbora researched abnormally high levels of antimony in children with autism (Buttram 2003). Aluminum has been linked to Alzheimer's disease and when in conjunction with lead, "Elevated hair aluminum in children…has been found to cause decreased visual motor performance" (Buttram 2003).

Aluminum and cadmium are both antagonists to copper and the balance between magnesium, aluminum and copper are important for thyroid health. In conjunction other metals such as lead, mercury, cadmium and arsenic deplete antioxidants in cells causing "oxidative stress"(Ercal 2001; Fowler 2004). In a study by Loyke (2002), high blood pressure was linked to the combination and interaction between several metals including; zinc, copper, iron, lead, mercury, cadmium, barium, arsenic and thallium. In addition, the combination of arsenic and cadmium in rats has been shown to have toxic effects on the heart (Y'a~nez L. 1991). This study showed that rats treated with a combination of arsenic and cadmium had more arsenic accumulate in the tissue of the heart than in rats treated with arsenic alone. In another study, reduced weight gain and a reduction in hemoglobin and hematocrit occurred only when rats were administered a combination of lead, cadmium and arsenic (Mahaffey 1981). This study proved that the concurrent exposure and "interaction between common toxic elements do occur and are characterized by alterations in both tissue and trace metal levels and toxicity" (Mahaffey 1981).

As expected, the analysis of well water samples in South Wellington have uncovered high levels of total dissolved solids and total coliform, aluminum, antimony, arsenic, cadmium, iron, lead, selenium, sodium and thallium. As each of these elements have been linked to diseases and disorders, it seems predictable that these high levels may contribute to ill health amongst the community in South Wellington.

CHAPTER SIX: SURVEY RESULTS

Introduction

The following chapter will present the results of the questionnaire data and will attempt to explain variations in health between South Wellington and Cinnabar. Descriptive statistics were employed to test the hypothesis that the quality of drinking water in South Wellington may be associated with ill health. To achieve this, data from the survey questionnaire were analyzed, primarily using Chi-square analyses. Analyses included examining the health differences between the two communities, comparing the socio-economic and population characteristics and further examining risk factors on ill health, including water quality.

Results of Statistical Analyses

Table 3 compares the percentage and the frequency of diseases present in South Wellington and Cinnabar. This table clearly shows that more diseases are associated with more individuals in South Wellington than in Cinnabar including; diseases and disorders of the bowel, blood, ear and sinus, endocrine and musculoskeletal system, liver, nervous system, respiratory system, high blood pressure, cardiovascular disease, cancer, mental and behavioral diseases and disorders and organ failure.

Table 4 shows the percentage and frequency of diseases and disorders by category and the significance of disease and disorder occurrence in both communities. These analyses show that disease and/or disorder occurrences are higher in South Wellington than in Cinnabar. Statistically, disease and disorder occurrences, with the exception of cancer and cardiovascular diseases and disorders, are significantly higher in South Wellington.

Table 3: Frequencies of diseases/disorders in South Wellington and Cinnabar

Disease/Disorder	South Wellington (n=185)				Cinnabar (n=198)			
	Yes	%	No	%	Yes	%	No	%
Bowel	17	9.2%	168	90.8%	7	3.5%	191	96.5%
Blood	5	2.7%	180	97.3%	0	0.0%	198	100.0%
Cancer	14	7.6%	171	92.4%	10	5.1%	188	94.9%
Ear/Sinus	3	1.6%	182	98.4%	1	0.5%	197	99.5%
Endocrine	14	7.6%	171	92.4%	3	1.5%	195	98.5%
High Blood Pressure	16	8.6%	169	91.4%	4	2.0%	194	98.0%
Cardiovascular	22	11.9%	163	88.1%	16	8.1%	182	91.9%
Liver	6	3.2%	179	96.8%	2	1.0%	196	99.0%
Mental and behavioral	6	3.2%	179	96.8%	0	0.0%	198	100.0%
Musculoskeletal system	17	9.2%	168	90.8%	8	4.0%	190	96.0%
Nervous System	3	1.6%	182	98.4%	1	0.5%	197	99.5%
Organ Failure	6	3.2%	179	96.8%	0	0.0%	198	100.0%
Respiratory System	22	11.90	163	88.1%	11	5.6%	187	94.4%

Diseases and disorders affect 75 of the 185 residents (40.5%) in South Wellington and 46 of the 198 residents (23.2%) in Cinnabar. The odds of developing a disease or disorder is 2.25 times higher for individuals living in South Wellington drinking well water compared to individuals living in Cinnabar drinking city water.

Diseases and disorders of the bowel and liver affect 22 individuals living in South Wellington (11.9%) and only 8 individuals (4.0%) in Cinnabar. When comparing individuals living in South Wellington drinking well water to individuals living in Cinnabar drinking city water, the odds of developing diseases and disorders of the bowel and liver is 3.2 times higher for those living in South Wellington.

Although not statistically significant, both cardiovascular disease and cancer are higher in South Wellington than Cinnabar. The odds of developing these diseases is 1.5 times higher for individuals living in South Wellington and consuming well water.

Table 4: Frequencies of disease/disorder groups in South Wellington and Cinnabar

Disease/Disorder	South Wellington (n=185)				Cinnabar (n=198)				Sig.	Odds Ratio
	Yes	%	No	%	Yes	%	No	%		
Presence of a disease/disorder	75	40.5%	110	59.5%	46	23.2%	152	76.8%	0.000	2.25
Bowel/Liver	22	11.9%	163	88.1%	8	4.0%	190	96.0%	0.004	3.20
Cardiovascular/Cancer	33	17.8%	152	82.2%	25	12.6%	173	87.4%	0.100	1.50
Endocrine/ Musculoskeletal	28	15.1%	157	84.9%	11	5.6%	187	94.4%	0.002	3.03
Respiratory System/ Ear/Sinus	24	13.0%	161	87%	12	6.1%	186	93.9%	0.016	2.31
Other disease/disorders	33	17.8%	152	82.2%	5	2.5%	193	97.5%	0.000	8.38

In South Wellington, these diseases affect 33 individuals, 17.8% of the population. In Cinnabar, these diseases affect only 25 individuals, 12.6% of the population.

Endocrine and musculoskeletal diseases are significantly higher in South Wellington, and affect 28 individuals, or 15.1% of the population. In Cinnabar, only 11 individuals, or 5.6% of the population, have either of these diseases. Individuals are 3.03 times more likely to develop either or both of these diseases if they live in South Wellington compared to Cinnabar.

Respiratory diseases, including ear and sinus disorders, are also significantly higher in South Wellington compared to Cinnabar. Of the population studied in South Wellington, 24 individuals claimed to have some form of respiratory disease (13% of the population), in comparison to only 12 individuals (6.1% of the population) in Cinnabar. Moreover, the odds of developing respiratory disease are 2.31 times more likely in South Wellington.

Diseases and disorders in the category “other” affect 33 individuals or 17.8% of the population in South Wellington compared to 5 individuals or 2.5% of the population in Cinnabar. Statistically, these diseases are significantly higher in South Wellington and the odds of developing a disease or disorder classified in this category is 8.38 times higher for individuals living in South Wellington.

As shown in Table 5, cross-tabulations and Chi-square analyses were used in an attempt to understand the social and demographic variations between South Wellington and Cinnabar. This analysis shows that there is very little variation between the two communities.

The distribution of population characteristics, age and gender, were similar in South Wellington and Cinnabar. This analysis shows that neither age nor gender are significant factors in distinguishing differences in population or demographic characteristics between the two areas. The distribution of age in both communities is fairly even and no specific group appears to dominate in either area. Although not statistically significant, there are slightly more females than males in both areas. In South Wellington 88 individuals are male and 97 are female, and in Cinnabar, 97 are male and 101 are female. Females constitute 49.0% of the population in South Wellington and 57.0% of the population in Cinnabar, whereas males constitute 47.6% of the population in South Wellington and 52.4% of the population in Cinnabar.

Behavioral characteristics also appear to be similar in both areas. Participation in exercise for example, is similar in both South Wellington and Cinnabar. The majority of individuals in this study claim to participate in exercise three or more times per week. In South Wellington 30 individuals (14.70%) participate in exercise 0-2 times per

Table 5: Residential Characteristics: Comparison of Risk Factors for disease/disorder in South Wellington and Cinnabar

Characteristics	South Wellington (n=185)		Cinnabar (n=198)		Sig.
	N	%	N	%	
Age					
0-18	41	22.7%	53	27.6%	0.360
19-39	46	25.4%	37	19.3%	
40-53	46	25.4%	56	29.2%	
54+	48	26.5%	46	24.0%	
Gender					
Male	88	47.6%	97	52.4%	0.430
Female	97	49.0%	101	57.0%	
Homeownership					
Rent	20	10.8%	16	8.1%	0.230
Own	165	89.2%	182	91.9%	
Daily Consumption of water from a well					
0%	55	29.7%	198	100.0%	0.000
1%-25%	19	10.3%	0	0.0%	
26%-50%	24	13.0%	0	0.0%	
51%-75%	22	11.9%	0	0.0%	
76%-100%	65	35.1%	0	0.0%	
Days per week exercising					
0-2 times per week	30	27.0%	26	28.0%	0.503
3 or more times per week	81	73.0%	67	72.0%	
Fruit consumed per day					
Once per day or less	65	59.0%	64	31.4%	0.118
More than once per day	45	41.0%	30	14.7%	
Juice consumed per day					
Less than once per day	54	48.6%	43	45.7%	0.392
Once per day or more	57	51.4%	51	54.3%	
Smoke tobacco					
Yes	48	43.2%	49	52.7%	0.114
No	63	56.8%	44	47.3%	
Consume Alcohol					
Yes	77	69.4%	64	68.1%	0.481
No	34	30.6%	30	31.9%	

week and 81 individuals (39.70%) participate in exercise three or more times per week. In comparison, 26 individuals (12.70%) in Cinnabar participate in exercise 0-2 times per week and 67 (32.80%) participate in exercise three or more time per week.

There is also no significant difference between the population of South Wellington or Cinnabar and the consumption of either fruit or juice. Residents in both communities appear to share similar nutritional habits. Neither community, for the majority, consumes much fruit or juice. In both areas, the majority of individuals consume fruit or juice once per day or less. In South Wellington 65 individuals (59.0%) consume fruit once per day or less, compared to 64 (31.40%) in Cinnabar. And in South Wellington 45 individuals (41.0%), compared to 30 (14.70%) individuals in Cinnabar, consume fruit once per day or more.

Neither alcohol consumption nor smoking habits seem to be more prominent, or statistically significant, in either area and both habits have afflicted less than half of the population in each area. In South Wellington 48 individuals or 23.50% of the population has smoked tobacco, in comparison to 49 individuals or 31.20% of the population in Cinnabar. And in South Wellington 77 individuals or 37.60% have consumed alcohol, compared to 64 (31.20%) in Cinnabar.

In this analysis habitat characteristics included homeownership and daily consumption of well water. South Wellington and Cinnabar are similar in terms of homeownership as there are no significant differences in the number of individuals renting accommodations versus owning property. In South Wellington 165 (43.10%) individuals are homeowners compared to 182 (47.50%) in Cinnabar. And 20 individuals (5.20%) in South Wellington rent their accommodation compared to 16 (4.20%)

individuals in Cinnabar. Income was not analyzed in this analysis, due to the high number of missing cases (*n=127*). However, data from the Canadian Census showed the mean average household monthly income of South Wellington was $3241.53 in comparison to $3691.73 in Cinnabar (Statistics Canada 2001). A mean difference of $450.20.

The only significant difference between the two populations is the consumption of water. The consumption of well water is geographical, as Cinnabar derives its water from the City of Nanaimo and residents in South Wellington derive water from private wells. In South Wellington 65 individuals, or 35.1% of the population, claim that 100% of their daily consumption of water comes from a private well. Although only supplied with well water, not every individual in South Wellington consumes water from their well. Several households use varying water filtration systems or obtain water from various sources including bottled water. Nonetheless, this difference in water consumption is the only variable that is statistically significant when comparing the two populations. Aside from well water consumption, there is no significant variation between the demographic and population characteristics examined in the two communities.

Table 6 shows the relationship between the risk factors and disease occurrence for the entire population sampled (*n=383)*. As expected, these results show that disease is more prominent and more statistically significant in South Wellington.

These results show that age, residential area, length of residency (new, short-term or long-term residents) and the consumption of well water are significantly associated with the frequency of disease occurrence. There is little evidence of statistically significant correlations between the occurrence of disease and moving patterns, homeownership or gender.

Table 6: Risk factors associated with diseases/disorders in both South Wellington and Cinnabar

Risk Factors for Disease	Diseased		Not Diseased		Sig.
	N	%	N	%	
Age					
0-18	7	5.9%	87	34.3%	0.000
19-39	17	14.3%	66	26.0%	
40-53	38	31.9%	64	25.2%	
54+	57	47.9%	37	14.6%	
Residential Area					
South Wellington	75	62.0%	110	42.0%	0.000
Cinnabar	46	38.0%	152	58.0%	
Resident Moving Pattern					
No Moves	19	17.9%	41	16.5%	0.923
Short Distance Movers	49	46.2%	120	48.2%	
Long Distance Movers	38	35.8%	88	35.3%	
Residential Pattern					
New Residents	16	13.3%	73	27.9%	0.000
Short-term Residents	22	18.3%	76	29.0%	
Long-term Residents	82	68.3%	113	43.1%	
Daily consumption of water from a well					
0%	57	47.1%	196	74.8%	0.000
1-25%	0	0.0%	19	7.3%	
26-50%	12	9.9%	12	4.6%	
51-75%	10	8.3%	12	4.6%	
76-100%	42	34.7%	23	8.8%	
Homeownership					
Rent	16	13.2%	20	7.6%	0.063
Own	105	86.8%	242	92.4%	
Gender					
Male	59	48.8%	126	48.1%	0.495
Female	62	51.2%	136	51.9%	

As age increases, so does the frequency of disease. Disease occurrence is most prominent amongst individuals 54 years of age and older. Disease affects 57 (47.9%) of the individuals in this age category, compared to 7 (5.9%) in the age category 0-18 years.

More disease affects individuals in South Wellington than in Cinnabar, and those who are long-term residents. A total of 121 (32%) of the individuals in this study have diseases: 75 (62%) of the residents in South Wellington and 46 (38%) of the residents in Cinnabar. Disease also affects long-term residents more frequently than short-term or new residents. Of the population affected with disease, 68.3% are long-term residents. In comparison, the diseased population constitutes only 18.3% of the short-term residents and 13.3% of the new residents.

The frequency of disease also increases with the consumption of well water. The relationship between well water consumption and disease are strongly significant, and the frequency of disease increases with the consumption of well water. Of the population affected with disease (*n=121*), 42 (34.7%) of these individuals consume 76-100% of their drinking water from a domestic well.

Results from this analysis conclude that disease is more prominent and more significant amongst individuals in South Wellington. Age, well water consumption and length of residency are all significant factors associated with disease. The following analysis examined only individuals affected with disease, in both South Wellington and Cinnabar. Isolating individuals with disease in both communities revealed that disease is associated with moving patterns and well water consumption.

Age, homeownership, average household monthly income, length of residency, smoking habits, participation in exercise per week, fruit, alcohol and juice consumption appear to not be associated with the presence of disease (see Table 7).

Age is a significant factor in the presence of disease, however when comparing the diseased populations of South Wellington and Cinnabar, it is not a significant risk

Table 7: Risk factors: Diseased individuals in South Wellington and Cinnabar

Characteristics	South Wellington		Cinnabar		Sig.
	N	%	n	%	
Age					0.218
0-18	3	4.1%	4	8.7%	
19-39	14	19.2%	3	6.5%	
40-53	22	30.1%	6	34.8%	
54+	34	46.6%	23	50.0%	
Average household monthly income					0.516
$0-2749	19	42.2%	8	26.7%	
$2750-3749	12	26.7%	12	40.0%	
$3750-4999	9	20.0%	6	20.0%	
$5000+	5	11.1%	4	13.3%	
Alcohol Consumption					0.089
Yes	53	71.6%	26	57.8%	
No	21	28.4%	19	42.4%	
Exercise					1.710
0-2 times per week	22	29.7%	18	40.0%	
3 or more times per week	52	70.3%	27	60.0%	
Fruit consumption					0.099
Once per day or less	42	57.5%	32	71.1%	
More than once per day	31	42.5%	13	28.9%	
***Well water consumption**					0.000
None	11	14.7%	46	100.0%	
26-50%	12	16.0%	0	0.0%	
51-75%	10	13.3%	0	0.0%	
76-100%	42	56.0%	0	0.0%	
Homeownership					0.380
Rent	11	14.7%	5	10.9%	
Own	64	85.3%	41	89.1%	
Juice Consumption					0.341
Less than once per day	32	43.2%	22	48.9%	
Once per day or more	42	56.8%	23	51.1%	
***Moving Patterns**					0.011
No moves	7	10.4%	12	30.8%	
Short-distance moves	37	55.2%	12	30.8%	
Long-distance moves	23	34.3%	15	38.5%	
***Residential Pattern**					0.057
New Residents	11	14.9%	5	10.9%	
Short-term residents	18	24.3%	4	8.7%	
Long-term residents	45	60.8%	37	80.4%	
Gender					0.511
Male	37	49.3%	22	47.8%	
Female	38	50.7%	24	52.2%	
Smoking habits					0.051
Yes	30	40.5%	26	57.8%	
No	44	59.5%	19	42.2%	

factor associated with ill health. Likewise, gender is similar in both areas and does not appear to be a risk factor associated with ill health. Disease is more prominent amongst long-term residents of both areas, constituting approximately 60% of the population in South Wellington and 80% in Cinnabar. However, this risk factor is not significantly correlated with the presence of disease.

None of the behavioral risk factors examined are significantly associated with the diseased population. Amongst the diseased population in South Wellington, 53 individuals (71.6%) have consumed or presently consume alcohol, in comparison to 26 individuals (57.8%) in Cinnabar. However of the diseased population who do not consume alcohol 21 individuals (28.4%) reside in South Wellington, and 19 (42.2%) reside in Cinnabar. Although there are slight differences in the consumption of alcohol in both areas, it is not a statistically significant risk factor in the prediction of disease in either area (*sig=0.089*).

Neither exercise, the consumption of fruit or juice, nor smoking habits are significant risk factors for the diseased population of either South Wellington or Cinnabar. Of the population in South Wellington with a disease or disorder, approximately 70% claim to exercise 3 or more times per week, in comparison to 60% of the diseased population in Cinnabar. Neither fruit nor juice consumption have significance on the distribution of disease. In both areas, the majority of the diseased population consumes fruit less than once per day and juice more than once per day.

Although not a statistically significant risk factor for disease, 40.5% of the diseased population in South Wellington have smoked tobacco, in comparison to 57.8% of the diseased population in Cinnabar.

In terms of habitat risk factors, homeownership is not a significant factor amongst the diseased populations of either South Wellington or Cinnabar, although disease occurrence is more frequent amongst households earning less than $2749 per month. In South Wellington, the diseased population constitutes 19 individuals (42.2%) whose average household monthly income is less than $2749. And in South Wellington diseased individuals account for merely 5 individuals (11.1%) with household monthly income greater than $5,000. In Cinnabar, disease affects 8 individuals (26.7%) whose monthly income is less than $2749 and 4 individuals (13.3%) whose average household monthly income is greater than $5,000. Although disease is more prevalent amongst the lower income population, it is not a significant risk factor associated with disease in South Wellington and Cinnabar.

Moving patterns and well water consumption however, are statistically significant amongst the diseased populations of South Wellington and Cinnabar. In both areas, more diseased individuals constitute the population of long-distance movers. The consumption of well water is not significant amongst the population living with disease in Cinnabar, as drinking water is derived from the City of Nanaimo. However, the majority of the population living with disease in South Wellington consumes more than 76% of their drinking water from a private well.

SURVEY RESULTS: CONCLUSIONS

The analysis of questionnaire data has shown by default the amount of well water consumed has been a significant risk factor affecting the health of residents of South Wellington. All diseases occur more frequently in South Wellington than in Cinnabar. More importantly all diseases, with the exception of cancer and cardiovascular disease significantly affect South Wellington more than Cinnabar. Analysis of population, habitat and behavioral characteristics revealed that the consumption of well water is the only difference between the two communities.

Habitat and population risk factors contributing to disease amongst the entire population sampled (n=383) include age, the consumption of well water, the geographical area of residence and the length of residence. As expected, results from binary logistic regression show that as age increases so does the frequency of disease. More disease affects individuals in South Wellington than in Cinnabar, and those individuals who are long-term residents. And, as the consumption of well water increases, so does the frequency of disease. Amongst the population living with disease, risk factors significant to ill health include well water consumption and moving patterns.

These risk factors alone however, do not explain why disease is more frequent in South Wellington as age, length of residence and moving patterns are not significantly different amongst the two populations. This study indicates that the only significantly different population characteristic found between South Wellington and Cinnabar is the water source.

It could be assumed that the significance of the association between the consumption of well water on disease occurrence would indicate the difference in the geographical area of residence. However, this factor was associated with disease for individuals in South Wellington alone. The consumption of well water is one of the key differences between the population in South Wellington and Cinnabar and one of the most significant risk factors associated with the population living with disease in South Wellington.

CHAPTER SEVEN-RECOMMENDATIONS AND CONCLUSIONS

The water quality analysis of the drinking water in South Wellington contained high levels of total dissolved solids and total coliform, aluminum, antimony, arsenic, cadmium, iron, lead, selenium, sodium and thallium. Geographically, disease and ill health is more common in South Wellington as opposed to Cinnabar. Throughout the analysis that was undertaken of South Wellington residents revealed the consumption of well water to be the most significant factor associated with disease. These results support the case that the water source in South Wellington is a contributing factor to the ill health observed in that area.

Previous research on the impacts of abandoned coal mines on the quality of groundwater and, through it on health, are limited (National Research Council 1980(b)). By 2000, the budget of the Ministry of Energy and Mines was reduced and, as a result its branch in Nanaimo was closed. Although the Ministry of Health has been involved in studies relating to polluted groundwater and residential health in South Wellington, research has been limited and often incomplete as a result of inadequate funding (Walsh 2003).

Statistics from 1981 have shown that, in British Columbia, “22% (600,000 persons) of the province’s population depend upon groundwater for water supplies” (MWLAP 2001). Thus, humans may be exposed to several substances in the environment through their drinking water. It has been estimated that there is roughly 37L of water in the body of an average adult, or 75% of the brain and 83% of blood (Health Canada 2003 (a)). Both exposure and dose must be considered when describing the health effects of substances in water. Exposure refers to the amount of a substance present in the water, and the dose is the actual amount of the substance that an individual receives.

In Canada, safe drinking water is either a provincial or territorial jurisdiction. “Little attention is given, however, to sites in rural areas with low population densities where natural, geogenic sources of contamination might also occur” (Peplow 2004).

> “Single-family residences with single connections to wells or surface waters located on their private property are not covered by provincial or territorial drinking water legislation. These households are responsible for ensuring that their water is potable by having it tested regularly and treating it if necessary” (Health Canada 2003, 1 (b)).

Amendments to the Drinking Water Protection Act became effective November 1, 2004. These new measures were put in place to improve the drinking water quality and to protect the health of British Columbians, including the well water of 750,000 rural residents (MWLAP 2001; CBC 2004). According to Mike Wei, BC’s senior groundwater specialist, “there have been problems [with groundwater in BC] over the years with fertilizers, septic systems and bacteria from sewage” (CBC 2004). Under the legislation, twenty new drinking-water officers, have been appointed by regional health authorities throughout BC, to ensure the safety of drinking water. The new drinking water legislation enforces the certification and registration of qualified well drillers and pump installers.

Ground water protection regulations include the identification of wells, flood proofing of wells and surface sealing of wells, which will prevent contaminants from entering either the well or any aquifer penetrated by the well. These regulations also require homeowners to ensure protection of the wellhead, to cap and cover their wells and to deactivate or close a well that is not used for five years, or is a threat to property or public safety or if there is a threat of a contaminant entering the well.

Although these new regulations are a step forward in the management of groundwater quality, they were only recently put in place and there have already been numerous groundwater issues in various locations throughout British Columbia. Many of these problems and potential safety hazards have originated from improper land-use over susceptible aquifers, and not properly capping or filling in old wells, test wells or foundation test holes (MWLAP 2001).

Pollution is becoming increasingly recognized as a threat to public health. Economic constraints appear to be one of the main barriers to progress in this area of research (Mastio 2000). When the Britannia copper mines closed, the public was left to deal with the aftermath. For years residents of Britannia were exposed to highly acidic waters and soil (National Film Board of Canada 2001). One resident even exclaimed that he needed to purchase new footwear each year as, ‘the soles of [his] boots would be eaten away by the groundwater’ (National Film Board of Canada 2001). For this community however, the cost of an environmental clean up was a financial barrier they felt did not belong to them. With little funding put into research and clean up, the community seemingly ignored their environmental quandary. A similar generalization could be made about South Wellington.

South Wellington is situated outside the city limits of Nanaimo in the Regional District of Nanaimo. Although not far from the city, the urban water pipeline does not extend into this area. In the past, residents enquired about the extension of the pipeline into this area. A majority of the residents in South Wellington would rather be drinking water from the City of Nanaimo than well water. It would be interesting to evaluate the cost for the City of Nanaimo to extend the pipeline to South Wellington. This figure should be compared against the very high additional healthcare costs associated with the disease burden in South Wellington that appears to be associated with the very poor quality of the available drinking water.

Adams, Francis (1849). The Genuine Works of Hippocrates. London, Sydenham Society.

Arbuckle et al. (1988). "Water Nitrates and CNS Birth Defects: A Population-Based Case-Control Study." Archives of Environmental Health 43(2).

Authour unknown (1999). "Bacteria in Drinking Water Linked Directly to Stomach Ulcers." Journal of Environmental Health **62**(5).

Barrie, W.B., and C.H. Carr (1988). Water Use in the Coal Mining Industry and its Influence on Ground Water in Western Canada. Ottawa, National Hydrology Research Institute.

Bickford, Gweneth (2003). Personal Interview. K. Biagioni. Victoria.

Board on Environmetal Studies and Toxicology (2001). Arsenic in Drinking Water. Washington, National Academy Press.

Boda, Carolyn and Alison Marczak (1998). Watershed Management: Protecting our Groundwater, Groundwater Pollution Primer. **2004**.

Brown, P.J., and Melvin Konner (1998). An Anthropological Perspective on Obesity. Understanding and Applying Medical Anthropology. California, Mayfield Publishing**:** 401-413.

Buttram, Harold E., and Piccola (2003). Our Toxic World.

CBC (2004). New Rules for Rural Wells. Vancouver, CBC News British Columbia.

Ceneto, Jose A. et al (2002). "Pathology Related to Chronic Arsenic Exposure." Environmental Health Perspectives Supplements **110**(5).

Centeno, Jose (2002). "Pathology Related to Chronic Arsenic Exposure." Environmental Health Perspectives Supplements **110**(5).

Center for Disease Control (2005). Center for Disease Control. **2004**.

City of Nanaimo (2001). Electoral Area "A" Official Community Bylaw No. 1240. Nanaimo, City of Nanaimo.

City of Nanaimo (2001(a)). Greater Nanaimo Water District, City of Nanaimo. **2003**.

Commission on Energy and the Environment (1981). Coal and the Environment. London.

Committee on Toxicology (1999). Arsenic in Drinking Water: 2001 Update. Washington, National Academy Press**:** 226.

Conboy, M.J. and M.J. Goss (1999). "Contamination of Rural Drinking Water Wells by Fecal Origin Bacteria - Survey Findings." Water Quality Research Journal of Canada **34**(2): 281-303.

Copes, Ed (2003). Personal Interview. K. Biagioni. Victoria.

Davis, Jack (1986). Coal in British Columbia. Victoria, ministry of Energy, Mines and Petroleum Resources.

Dillman, Don A. and Priscilla Salant (1994). How to Conduct your Own Survey. New York, John Wiley & Sons, Inc.

Environmental Protection Agency (2001). Technical Fact Sheet: Final Rule for Arsenic in Drinking Water, Environmental Protection Agency. **2005**.

Environmental Protection Agency (2002). Implementation Guidance for the Arsenic Rule: Drinking Water Regulations for Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring, Environmental Protection Agency. **2005**.

Environmental Protection Agency (2004). Consumer Factsheet on: Thallium, Environmental Protection Agency. **2005**.

Environmental Protection Agency (2004). Lead and Human Health, Environmental Protection Agency. **2004**.

Environmental Protection Agency (2004). List of Drinking Water Contaminants and MCLs, Environmental Protection Agency. **2005**.

Environmental Protection Agency (2004(a)). Consumer Factsheet on: Cadmium, Environmental Protection Agency. **2005**.

Environmental Protection Agency (2005). Drinking Water Contaminants-Antimony. **2005**.

Epstein, Murray (1997). "Alcohols Impact on Kidney Function." Alcohol Health and Research World **21**(1).

Ercal, N. et al. (2001). "Toxic metals and oxidative stress part I: mechanisms involved in metal-induced oxidative damage." Current Topics in Medical Chemistry **1**(6): 529-539.

Foster, Harold D. (2002, 2004). "Why the preeminent risk factor in sporadic Alzheimer's disease cannot be genetic." Medical Hypotheses **59**(1): 57-61.

Fowler, B.A. et al. (2004). "Oxidative stress induced by lead, cadmium and arsenic mixtures: 30-day, 90-day, and 80-day drinking water studies in rats: An overview." Biometals **17**: 567-568.

Freedman, Michael D. et al. (2000). "A Case-Control Study of nitrate in Drinking Water and Non-Hodgkin's Lymphoma in Minnesota." Archives of Environmental Health **55**(5): 326-329.

Gardner, S.L. (1999). Coal Resources and Coal Mining on Vancouver Island. Campbell River, Gardner Exploration Consultants.

George, M et al (2001). "Incidence and geographical distribution of sudden infant death syndrome in relation to content of nitrate in drinking water and groundwater levels." European Journal of Clinical Investigation **31**: 1083-1094.

Greater Nanaimo Regional District (2003). Liquid Waste: Septic Systems. **2004**.

Harte, John et al. (1991). Toxics A-Z: A Guide to Everyday Pollution Hazards. Berkeley, University of California Press.

Health Canada (1986). Guidelines for Canadian Drinking Water Quality Supporting Documents: Cadmium, Health Canada. **2005**.

Health Canada (1987(a)). Guidelines for Canadian Drinking Water Quality-Supporting Documents: Sulphide (as H2S), Health Canada. **2003**.

Health Canada (1987(b)). Guidelines for Canadian Drinking Water Quality-Supporting Documents: Iron, Health Canada. **2003**.

Health Canada (1992). Guidelines for Canadian Drinking Water Quality-Supporting Documents: Lead, Health Canada. **2005**.

Health Canada (1992(a)). Drinking Water Quality Guidelines Supporting Documents: Arsenic, Health Canada**:** 1-6.

Health Canada (1995). Its Your Health: Aluminum in Drinking Water and Human Health, Health Canada. **2003:** 1-7.

Health Canada (1999). Guidelines for Canadian Drinking Water Quality Supporting Documents: Antimony, Health Canada**:** 1-7.

Health Canada (2001). Guidelines for Drinking Water Quality Supporting Documents: Bacteriological Quality, Health Canada. **2004**.

Health Canada (2001(b)). Arsenic in Drinking Water, Health Canada. **2004**.

Health Canada (2003 (a)). Water-Facts and Tips, Health Canada. **2005**.

Health Canada (2003 (b)). Public Health Initiatives Related to Drinking Water Quality in Canada, Health Canada**:** 1-23.

Health Canada (2004). Microbiological Quality of Drinking Water: Total Coliforms, Health Canada**:** 1-30.

Health Canada (2004(b)). Arsenic in Drinking Water: Document for Public Comment, Health Canada**:** 1-30.

Hecht, Jeff (2001). "Wells of Misery." New Scientist **172**(2317): 16.

Ihrig, M.M. et al. (1998). "A hospital-based case-control study of stillbirths and environmental exposure to arsenic using an atmospheric dispersion model linked to a geographical information system." Epidemiology **9**(3): 290-294.

Jian'an, Tan et al. (1990). Medical Geography. Recent Developments of Geographical Science in China. Beijing, Science Press**:** 259-279.

Jin, Yong Hwan (2003). "Cadmium studies suggest new pathway to human cancer." Cancer Weekly: 77-78.

Johnson, Barrie et al (2002). "The Microbiology of acid mine drainage: genesis and biotreatment." South African Journal of Science **98**: 249-256.

Karagas, Margaret R. (1998). "Design of an Epidemiologic Study of Drinking Water Arsenic Exposure and Skin and Bladder Cancer Risk in a U.S. Population." Environmental Health Perspectives Supplements **106**(4): 1047-1050.

Koblinsky, M., Timan, J. et al, (1993). The health of women in global perspective. Boulder, CO, Westview Press.

Landers, Jay (2002). "Arizona town votes to remove 25,000 septic tanks." Civil Engineering **72**(2).

Lawson, A.B and F.Williams (2001). An Introductory Guide to Disease Mapping. New York, John Willey & Sons.

Leduc, Marie (2004). Nanaimo's Historical Development, City of Nanaimo. **2004**.

Light, R (1944). "The Progress of Medical Geography." Geographical Perspectives **34**(4): 636-641.

M. J. Goss, D. A. J. Barry and D. L. Rudolph (1998). "Contamination in Ontario farmstead domestic wells and its association with agriculture." Journal of Contaminant Hydrology **32**(3-4): 267-293.

MacFarlane, David (2003). K. Biagioni. Victoria.

Mackin, Jeanne (1992). "Contaminants found in large numbers of wells." Human Ecology **20**(2).

Mahaffey, K.R., et al., (1981). "Concurrent exposure to lead, cadmium, and arsenic. Effects on toxicity and tissue metal concentration in the rat." Journal of Laboratory Clinical Medicine **98**(4): 463-481.

Mastio, David (2000). AutomakersThrive Under EPA Rules: Early Predictions of Economic Damage never Materialized, Environmental Protection Agency. **2003**.

May, J.M (1961). The Ecology of Human Disease. New York, MD Publications.

McGlashan (1972). Medical Geography. London, Methuen.

Meade, M and R. Earikson (2000). Medical Geography. New York, Guildford Publications.

Meadows and Carpenter (1997). Acid Mine Drainage and Groundwater Pollution, Groundwater Pollution Primer. **2003**.

Michaud DS et al. (2004). "Arsenic concentrations in prediagnostic toenails and the risk of bladder cancer in a cohort study of male smokers." American Journal of Epidemiology **160**(9): 853-9.

Ministry of Energy and Mines (1999). Production Report: Douglas Seam Mines. Victoria, Ministry of Energy and Mines**:** 25.

Ministry of Health (1995). Should I Get My Well Water Tested. British Columbia, Ministry of Health.

Ministry of Health (1995(a)). Safe Water Supply Vital to your Health. British Columbia, Ministry of Health.

Ministry of Health (2000). Nitrate Contamination in Well Water, Government of British Columbia. **2003**.

Ministry of Water, Land and Air Protection (1998). British Columbia Approved Water Quality Guidelines (Criteria), Government of British Columbia: Water Protection Branch. **2003**.

Ministry of Water, Land and Air Protection Analytical Services. Submitted by: Liboiron, Russ (2002). Analytical Report (Form 50072372), Ministry of Water, Land and Air Protection.

Moerman, David R. Briggins and Dennis E. (1995). "Pesticides, Nitrate-N and Bacteria in Farm Wells of Kings County, Nova Scotia." Water Quality Research Journal of Canada **30**(3): 429-442.

Murray, Keith (1986). Map of Coal mine and Exploration Data, and Gas Shows. Vancouver Island, Vancouver Island Gas company.

MWLAP, Air and Climate Change Branch (2001). Ground Water Issues in British Columbia, Ministry of Water, Land and Air Protection. **2005**.

National Film Board of Canada (2001). Britannia a Company Town.

National Research Council (1980(b)). Drinking Water and Health. Washington, D.C., National Academy Press.

National Research Council (1999). Arsenic in Drinking Water. Washington, National Academy Press.

National Research Council (NRC) (1980(a)). Trace-Element Geochemisty of Coal Resource Development. Washington, National Academy Press.

National Water Quality Data Bank (1985). Ottawa, Water Quality Branch, Inland Waters Directorate, Environment Canada.

Office of Environmental Health Assessments (2003). Fact Sheet: Hydrogen Sulphide. Washington.

Orem, William H et. al. (2003). "The Effects of Toxic Organic Compounds From Coal: From Romania to Powder River Basin, Wyoming." Medical Geology Newsletter: IUGS Special Initiative on Medical Geography **7**: 3-10.

Parr, Hester (2003). "Medical Geography: care and caring." Progress in Human Geography **27**(2): 212-221.

Payment, Piere et al (1991). "A Randomized Trial to Evaluate the Gastrointestinal Disease due to Consumption of Drinking Water Meeting Curent Microbial Standards." American Journal of Public Health **81**(6): 703-708.

Peplow, D., and R. Edmonds, (2004). "Health risks associated with contamination of groundwater by abandoned mines near Twisp in Okanogan County, Washington, USA." Environmental Geochemistry and Health **26**(1): 69-79.

Ritter Len et al. (2002). "Sources, Pathways, and Relative Risks of Contamination in Surface Water and Groundwater: A Perspective Prepared for the Walkerton Inquiry." Journal of Toxicology and Environmental Health **Part A**(65): 1-142.

Santini, Joanne (2004). "Arsenic-Eating Bacteria May Clean Mines and Save Lives." Journal of Environmental Health **66**(6): 67-68.

Schroeder, H.A. (1970). "A sensible look at air pollution by metals." Arch.Envionmental Health **21**: 789-806.

Schumann, K. (1990). "The toxicological estimation of the heavy metal content (CD, Hg, Pb) in food for infants and small children." Z Ernahrungswiss **29**(1): 54-73.

Sherlock, Shelia (1995). "Alcoholic Liver Disease." Lancet **345**(8944): 227-230.

Sherwood, Julia M. and Paul Younger (1997). "Modelling Groundwater Rebound after Coalfield Closure." Groundwater in the Urban Environment **1**: 165-170.

Smith, Allan et al. (2000). Contamination of drinking water by arsenic in Bangledesh: a public health emergency. WHO Bulletin, World Health Organization**:** 78.

Soliman, M. Mostafa et al. (1998). Environmental Hydrology, Lewis Publishers.

Staessen, JA., and H.A. Roels et al., (1999). "Environmental exposure to cadmium, forearm bone density, and risk of prospective population study. Public health and environmental exposure to cadmium (PheeCad) study group." Lancet **353**(9159): 1140-1144.

Statistics Canada (2001). Census, Government of Canada. **2004**.

Tseng, W.P. (1977). "Effects of dose-response relationship of skin cancer and blackfoot disease with arsenic." Environmental Health Perspectives **19**(109).

Varner, et al. (2003). Drinking Water: Sulfates and Hydrogen Sulfide.

Walsh (2003). K. Biagioni. Nanaimo.

Washington State Department of Health (1996). Iron Fact Sheet, Environmental Health Promotion Programs: Office of Environmental Health and Safety. **2004**.

Weir, Erica (2002). "Arsenic in Drinking Water." Canadian Medical Association Journal **166**(1).

Wilkes University (2004). Iron and Manganese in Drinking Water, Center for Environmental Quality: GeoEnvironmental Sciences and Engineering Department. **2005**.

World Coal Institute (1991). Coal in the Environment. London.

World Health Organization (1992). Health Research Methodology: A Guide for Training in Research Methods. Manila, World Health Organization.

World Health Organization (2003). Antimony in Drinking-water: Background document of WHO *Guidelines for Drinking-water Quality*, World Health Organization**:** 1-10.

Y'a~nez L., et al. (1991). "Arsenic-cadmium interaction in rats: toxic effects in the heart and tissue metal." Toxicology **67**(2): 227-234.

Yoshizuka M., and N. Mori et al. (1991). "Cadmium toxicity in the thyroid gland of pregnant rats." Exp Mol Pathol **55**(1): 97-104.

Zecca, L (2004). "Iron, brain ageing and neurodegenerative disorders." Nat Rev Neuroscience **5**(11): 863-873.