Evaluation of Treatment Potential and Feasibility of Constructed Wetlands receiving Municipal Wastewater in Nova Scotia

Leslie Gray
BSc Student
Environmental Science Program
Dalhousie University

Supervisor: Dr. Rob Jamieson
Department of Process Engineering & Applied Science

Abstract

The Canadian Council of Ministers of the Environment (CCME) is proposing Canada-wide municipal wastewater effluent regulations. This would put pressure on small communities to install wastewater collection systems and treatment facilities. Artificially constructed wetlands are cost-effective wastewater treatment systems that achieve secondary effluent standards in warmer climates.

This study was conducted to assess the phosphorus and nitrogen removal of a constructed wetland during a typical Nova Scotian winter, compare the observed treatment ability to the proposed regulations, and estimate the cost-savings treatment wetlands could provide to the local community. The wetland system is located in Bible Hill and consists of a pond-marsh-pond system. The samples collected from the inlet and outlet of the system between October 2007 and February 2008 demonstrate an average phosphorus removal of 47.6% and an average nitrogen removal of 30.8%. The effluent concentrations were within the proposed regulatory limits for the parameters observed, however the CCME has proposed limits for numerous substances of concern that were not studied. The estimated cost for treatment wetlands for the village of Bible Hill over a 25-year period was $7.8 million, resulting in $6.3 million in savings over conventional facilities.

These results provide insight into the range of nutrient removal efficiencies that can be expected from surface-flow wetland systems in Nova Scotia. The regulatory review shows that more research on the fate and transport of emerging contaminants of concern is needed to better understand the feasibility of installing treatment wetland systems.

Table of Contents

List of Figures

List of Tables

Chapter One - Introduction

1.0 Introduction

As the human population grows, there are corresponding increases in the amount of anthropogenic waste generated and the extent of the environmental damage this waste causes. Increasing population densities also correspond to an increase in highly concentrated liquid and solid wastes capable of causing environmental pollution. Heightened concern over the ability of the Earth's natural systems to assimilate our waste has resulted in a movement to control and decrease the amount of waste produced and its associated pollution. The number, variety, volume and concentration of pollutants created by resource consumption and released through industrial and residential wastes today are threatening human and ecosystem health. Human ingenuity must find appropriate ways to protect the environment from these contaminants.

One major concern is the protection of water resources, especially surface and ground waters, which are often used for human consumption. Water is often used to transport and receive wastes because of its motility and dilution potential, becoming contaminated as a result. Water pollution sources include municipal wastewater effluent, industrial wastewater, agricultural wastewater and stormwater runoff. Protecting natural waters from these wastewaters will ensure our ability to provide potable water to the growing human population. It is also essential in the environmental stewardship of healthy aquatic ecosystems.

Municipal wastewater effluent, because of its sheer volume, has been the focus of the Canadian government in recent years and a Canada-wide strategy, including the establishment of municipal wastewater release guidelines, is underway (CCME, 2007). Municipal wastewater can contain organic matter, feces and urine, soaps and paper, and other chemicals or solids from residential use. It may also contain inputs from smaller industries such as photofinishing or dry cleaning (Kadlec & Knight, 1996). Synthetic chemicals and hormones used in personal care products and health medications have also been found in wastewaters and are emerging as potential concerns because of their unknown environmental and human health effects (Marbek Resource Consultants Ltd., 2006). The intent of wastewater treatment is to remove or reduce the concentration of many of these contaminants. Traditionally, municipal wastewater treatment has been voluntary and, in Canada, of particularly low quality. Treatment varies from simple screening to complete contaminant removal and disinfection through exposure to ultraviolet radiation. In coastal areas, municipal wastewater is commonly released to surface waters untreated and without appropriate screening, allowing solids and floating debris to enter the ocean. Currently, wastewater treatment falls under provincial jurisdiction, and is usually delegated to municipalities, which issue sewer-use bylaws. In Nova Scotia, municipalities control such bylaws but there are province-wide minimum standards, and permitting is required for the construction and operation of a municipal wastewater treatment facility, as well as the release of effluent to water. Substances named in the Canadian Environmental Protection Act or the Fisheries Act as toxic, deleterious or harmful fall under federal jurisdiction. The upcoming standardization of effluent-release concentrations has heightened interest in water treatment techniques for improving water quality, and led to the study of alternative and emerging treatment technologies such as membrane bioreactors, sand filtration and artificially constructed surface and subsurface wetlands, among others.

Conventional treatment systems are separated into primary, secondary, tertiary and disinfection, according to the final effluent quality they release. They typically employ natural physical, chemical and biological processes such as microbial degradation and gravity-induced settling, and augment them using energy-intensive technologies, such as aerators, pumps or grinders. Conventional systems typically have low nutrient removal abilities, leaving effluents high in nitrogen, phosphorus and carbon. At the same time, the heavy use of fertilizers and cleaning agents have caused the levels of phosphorus and nitrogen in wastewaters to rise over the years, resulting in an increased threat of eutrophication. Tertiary treatment aims at removing these nutrients to protect surface waters from the effects of fertilization. Naturally-based systems, such as constructed wetlands, can effectively perform this nutrient removal and improve the quality of effluent wastewaters.

The use of constructed wetlands, also known as treatment wetlands, to cleanse and detoxify surface water is a simple concept aimed at mimicking naturally-occurring wetlands and their processes. Processes such as sedimentation, filtration, chemical precipitation, microbial interaction, plant assimilation and adsorption to soil particles give wetlands the ability to remove several nutrients, including nitrogen, carbon, sulphur, potassium, and phosphorus, and result in an increase in water quality (Kadlec & Knight, 1996). These processes are encouraged by varying water depth, flow rates, oxygen levels and planting vegetation within the systems, which increases biological productivity, and degradation and removal rates. This gives treatment wetlands an advantage over traditional septic tank systems that are generally slower to treat wastewater, and unable to reduce nutrient concentrations. Construction techniques for wetland systems are flexible and allow industry, government, or private companies to target contaminants of concern, or high loading rates.

Constructing natural systems for wastewater quality improvement has several advantages over conventional technologies. Cost-reduction is one advantage, and a reason for increased interest in treatment wetlands; many municipalities in Canada are prevented from investing in wastewater treatment technology because of its exorbitant costs. Rural municipalities with low population densities do not have the financial capital, and are simply not able to raise the public funds necessary for such an investment. Another advantage of natural systems is their low maintenance. It is difficult for small communities to attract qualified individuals with the technical expertise necessary to oversee large conventional treatment facilities. In such rural areas, alternative treatment methods such as treatment wetlands would serve to protect the environment and dramatically increase the quality of effluent released into surface waters. Some additional benefits include the provision of green space and habitat.

Although public and professional interest in natural, constructed systems has increased, treatment wetlands have not reached widespread use in Canada. Some lingering issues include a concern that they are less effective in colder climates, a lack of best management practices, and unclear cost effectiveness. Such information is needed to adequately asses the feasibility of increased implementation of treatment wetlands in Canada.

1.1 Research Needs

Treatment wetlands have the potential to provide effective, low-cost tertiary treatment to small and rural communities. This study will provide information on the feasibility of employing treatment wetlands in Nova Scotia in an effort to determine their potential for the management of rural domestic wastewater. The implementation of nation-wide regulations concerning effluent releases will force many communities to invest in treatment. Increasing the knowledge of the nutrient removal ability and efficiency of treatment wetland systems in colder climates, as well as the economic and regulatory feasibility of installing them is essential in developing a best-practice management guide.

Constructed treatment wetland systems can provide significant savings when installation costs are compared to the price of conventional systems, and they require lower long-term operation and maintenance investments. They do necessitate an initial investment of land, which is something smaller communities usually have access to. The sustainable nature of these systems, requiring little or no energy inputs, also makes them a greener strategy in an age of dependence on increasingly scarce fossil fuels. Estimated cost savings could encourage smaller communities to seriously consider these treatment options.

Although the effectiveness of treatment wetlands has been demonstrated in warmer climates such as Cuba and the Southern United States, their ability to maintain sufficient removal levels over the colder months and during periods of ice cover has been questioned. Maintenance requirements of the system may increase over the winter, to ensure continuous optimal treatment.

1.2 Objectives

The overall goal of this project is to contribute to the knowledge of the employment of treatment wetlands in Canada and further their use as a means of protecting surface water bodies from degradation caused by harmful wastewater. Demonstrating that they provide effective wastewater treatment, can meet water-quality guidelines, and are cost-effective is important in providing small communities with a reliable and economically feasible alternative for wastewater treatment. Specifically, the objectives of this study are:

1. to analyze and to quantify the removal of phosphorus and nitrogen in a treatment wetland receiving wastewater from the municipality of Bible Hill, Nova Scotia;
2. to assess the ability of treatment wetlands to meet provincial and national wastewater treatment and release guidelines and provide recommendations concerning the use of treatment wetlands in small or rural communities;
3. to estimate the financial investments, including equipment and infrastructure required for the construction of this wetland system and to assess the potential cost-savings of a rural wetland system in comparison with conventional treatment.

Chapter Two – Literature Review

2.0 Introduction

Interest in natural wastewater treatment technology increased dramatically after the United States passed the Clean Water Act in 1972. Initially, support for the idea was based on the 1960s mantra reduce, reuse, recycle, but researchers quickly realized the cost- and energy-saving potential of natural treatment systems. The use of, and research into, natural processes as a method of water quality improvement in the U.S. gained prominence as the number of land-based treatment systems rose from 400 in the early 1970s to at least 1,400 by the mid 1980s (Reed et al., 1988; Kennedy & Mayer, 2002). In Canada, the technology has been slower to reach the mainstream, with only 67 treatment wetlands identified in 1994 (Knight & Pries, 1994). However, in 2003 the Canadian Council of Ministers of the Environment proposed implementing a Canada-wide strategy for municipal wastewater effluent, which will include minimum standards for effluent released to surface waters. This may encourage communities to invest in natural wastewater treatment and increase the use of treatment wetlands. Although constructed treatment wetlands are easy-to-construct, cheap and practical, several barriers to implementation exist specifically for Canada because of a lack of performance data in colder climatic conditions.

2.1 Wetlands as Wastewater Treatment Technology

The wastes created by human activity must inevitably be released into the natural environment. These solid and liquid wastes are highly concentrated and must be assimilated by the ecosystems of the adjacent environment. When these wastes overwhelm the assimilative capacity of the environment, they can have adverse effects on natural systems. Urban and industrial development, and increasing population density have led to the production of large amounts of liquid waste within small, localized areas which increases the effect waste has on the areas. Residential, industrial, and agricultural operations are considered point-source pollution, often releasing large amounts of contaminated water, known as effluent, into nearby surface waters via outfall piping. Point-source pollution can contain high concentrations of nutrients or contaminants, as well as organic matter and chemicals. The release of this effluent into the environment without appropriate treatment may overwhelm receiving waters and widen the effects of pollution, endangering ecosystem health (Kadlec & Knight, 1996).

Human ingenuity has created a multitude of technologies capable of treating and purifying effluent. Conventional technological systems, such as sewage treatment plants, often require heavy infrastructure and rely on large inputs of expensive materials, such as concrete, fossil fuels or chemicals. The installation of these systems is expensive, the operation and maintenance costs remain high over the course of their lifespan, and upgrading or decommissioning the plants can be complicated and time-consuming. These issues have resulted in a low rate of municipal wastewater treatment in Canada, and especially in the Atlantic Provinces. In the 2007 Municipal Water Use Report, in which 71% of the Nova Scotian population was surveyed, only 30% were connected to centralized sewage collection facilities (Environment Canada, 2007). Of this population, only 30% of the sewage collected actually received treatment prior to release into the environment. According to Natural Resources Canada (2004), in almost half the province, more than 75% of the population does not have any secondary sewage treatment (Morse, 2001) (Figure A1). Concern over the environmental impacts and potential risk of ground- and surface-water contamination posed by untreated sewage, and the acknowledgment that conventional treatment costs can be prohibitive for rural areas and small communities has led to an increasing interest in less expensive treatment options. Humans have begun emulating nature's pollution prevention processes in an attempt to avoid the high costs of traditional wastewater treatment (Reed et al., 1988).

Compared to conventional treatment systems, natural treatment options such as wetlands rely on naturally-occurring physical and chemical processes. Sedimentation, filtration, chemical precipitation, microbial interaction, plant assimilation, and adsorption to soil particles are all processes that contribute to an improvement in water quality; constructed treatment wetlands employ these processes and aim to accentuate their effectiveness in order to treat wastewater (Hamilton et al., 1993; Knight & Preis, 1994). Their relatively cheap and simple construction may include ponds or slow-moving surface- or subsurface-flow areas planted with emergent, submergent, or floating vegetation. They are extremely flexible and can be designed for site-specific treatment goals focusing on the removal of specific contaminants or nutrients (Reed, 1990; Kennedy & Mayer, 2002). The inputs of a natural system include solar energy, wind, land, plant seeds or plants and microbes. In contrast, conventional treatment systems use cement, steel, electricity, and chemicals to induce and enhance most of the same processes. Costs for the two systems differ primarily in that treatment wetlands are land-use intensive, which can increase the capital costs, while treatment plants are fossil fuel intensive, which can increase operation and maintenance costs (Knight & Preis, 1994). Wetlands remain one of the least expensive treatment systems based on their annual costs, and the low fuel and chemical consumption (Kadlec & Knight, 1996).

Constructed treatment wetlands are artificial replications of their natural cousins. Naturally-occurring wetlands are highly productive, complex ecosystems lying in areas where the water table is at or above the ground surface long enough each year to maintain saturated soil conditions and the growth of related aquatic and semi-aquatic vegetation (Reed, 1990). Wetland areas can be inundated seasonally or periodically throughout the year, but it is due to the amount of water and the large fluctuations in its levels that wetlands are able to provide a wider variety of aerobic and anaerobic conditions and therefore maintain higher biological productivity than most ecosystems (Freshwater Wetlands, n.d.; Kadlec & Knight, 1996). Natural and artificial wetlands are able to improve water quality, prevent the spread of diseases, and decrease the number and concentration of toxins entering surface waters. Other ancillary wetland benefits include the provision of aesthetically pleasing environments, wildlife habitat and recreational areas (Cairns & Nederlehner, 1994; Tenenbaum, 2004). Artificially constructed treatment wetlands emulate these highly-productive natural systems in order to treat wastewater, usually removing large quantities of nutrients.

Wastewater treatment is often characterized by the final effluent released into the environment and is traditionally divided into primary, secondary and tertiary treatment (Figure 1). The quality of water released into the environment increases with each treatment level and conversely its ability to harm the natural environment receiving it reduces with increased treatment. Primary treatment normally consists of simple screening and sedimentation processes that should remove larger particulate, grit and solids. Skimming is sometimes included in primary treatment to remove floating debris and surface scum such as soap residues. Secondary treatment normally involves decreasing the oxygen demand and increasing solid removal, which are accomplished by further sedimentation, aeration, filtration, clarification and the addition of microbes (Kadlec & Knight, 1996). Biochemical oxygen demand (BOD) is the amount of oxygen required by microbes or microorganisms to break down the organic material and oxidize the inorganic matter present in the water sample. It is essential that BOD be reduced before release to surface waters in order to prevent harm to aquatic life. If the BOD is too high, microorganisms will consume the oxygen present in the water column as they degrade organic matter, creating an anoxic environment and altering the aquatic ecosystem. In the United States, secondary wastewater treatment is mandatory before release into surface waters. Tertiary treatment, also called advanced wastewater treatment, usually removes excessive nutrients such as nitrogen (N) and phosphorus (P) through nitrification, denitrification and phosphorus removal processes (Kadlec & Knight, 1996; Sierra Legal, 2004). These processes will be examined later in this paper. Advanced treatment usually involves some form of disinfection, such as the addition of chlorine compounds or exposure to UV light, which renders pathogens harmless to humans. In the 2007 Municipal Water Use Report, only Ontario, Saskatchewan and Alberta had 25% or more of the population surveyed receiving tertiary or quaternary treatment (Environment Canada, 2007).

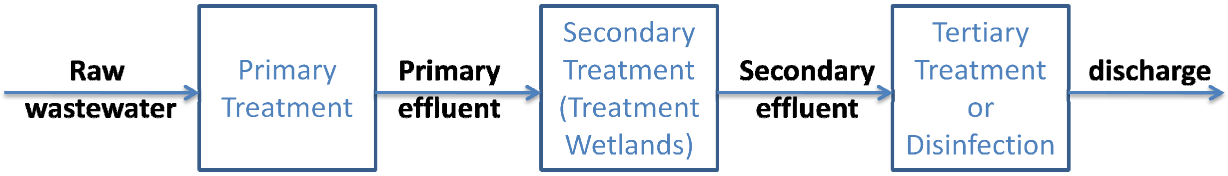


Figure 1. Wastewater Treatment Processing

Natural treatment technologies, including treatment wetlands, have a large capacity for N and P transformation and assimilation and are thus considered tertiary treatment and often used for 'polishing' previously treated water. The importance of removing excessive nutrients is relative to the receiving capacity of local surface waters. Plants require P and N for plant biomass production, and absorb and assimilate both nutrients during growth. However, both P and N are often the limiting nutrients in natural ecosystems, inhibiting plant growth by their low availability. Releasing excessive amounts of P and N to surface waters can lead to excessive plant growth, noxious algal blooms and cause eutrophication, oxygen depletion and fish kills – problems that have occurred in many Canadian waterways (Kennedy & Mayer, 2002). This makes the removal of P and N from wastewater effluent essential for the protection of natural waterways. The high capacity that treatment wetlands have for N and P removal and their flexibility during construction means they can be combined with primary or secondary treatment options, or used in place of more conventional settling ponds.

Within treatment wetland systems, N exists in various forms and compounds, and is continuously involved in chemical processes that change it from one form to another through reversible reactions. Several physical processes are involved in these transformations, including: particulate settling and resuspension, plant uptake and translocation, volatilization, sorption of soluble N onto substrates, and diffusion of dissolved forms. There are also several chemical processes that transform N. These include nitrification, denitrification, ammonification, N fixation and N assimilation. These transformations create a complex nitrogen cycle in wetland systems (Figure 2). Nitrogen gas (N_2) and dinitrous oxide (N_2O) diffuse into the water column and are fixed, or reduced to ammonia nitrogen by autotrophic and heterotrophic bacteria, as well as plant life (Kadlec & Knight, 1996). Organic nitrogen exists in living plant tissues and other organic tissue, and can undergo ammonification via breakdown of these tissues, or through excretion.

Ammonia ($NH4_+$), nitrite (NO_2-), and nitrate (NO_3-) are nitrogenous nutrients connected by oxidation and reduction reactions. Total Kjeldahl Nitrogen (TKN), a measure of organic- and ammonia-N, is often compared to total N in order to quantify the transformation of organic- and ammonia-N into inorganic NO_2- and NO_3-. The reactions responsible for these transformations involve the addition of oxygen atoms, which results in the removal of electrons during oxidation, or the removal of oxygen atoms resulting in an addition of electrons during reduction. Denitrification transforms nitrate and nitrite to nitrogen gas (N_2), dinitrous oxide or nitrous oxide, while nitrification, mediated by microorganisms, converts ammonia-N (NH_3-N) to nitrite and eventually nitrate. Denitrification occurs when oxygen is absent and bacteria are forced to use the oxygen atoms in the nitrogen compounds nitrate and nitrite as the electron acceptor in their metabolic pathways (Knight & Preis, 1994; Kadlec & Knight, 1996; Smith, 2002). This therefore requires anoxic, or oxygen poor conditions. These two processes are crucial in the effectiveness of N removal in the wetland environment as they achieve a permanent removal and transform NH_3-N into a less harmful form. However, denitrification and nitrification are temperature-dependent reactions, occurring optimally between 5° and 25° Celsius. Canada’s colder climate reduces reaction rates and thus the biological degradation of organic matter; the temperature dependence of these reactions has led to concern that treatment wetlands will not be effective in cold climates with sustained temperature below freezing (Kennedy & Mayer, 2002). A more detailed discussion of the N cycle and the processes involved is presented in Kadlec & Knight, (1996).

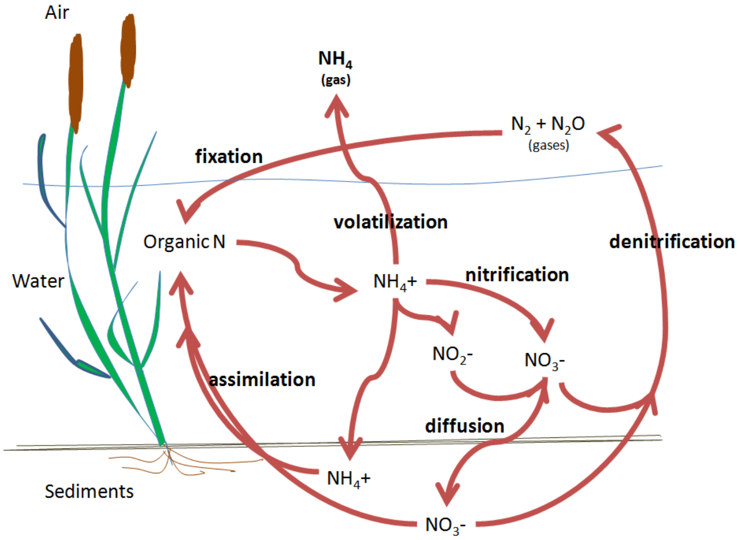


Figure 2. The Simplified Wetland Nitrogen Cycle in a Surface Flow Wetland. adapted from Knight & Preis, 1994

Phosphorus removal is of particular interest because of the magnitude of the effects even trace amounts of this element can have on receiving waters. There are frequently very high levels of P in wastewaters in the form of phosphates (XPO_4^c), and wetlands have the ability to reduce this concentration through various processes, although the land requirement for adequate P reduction is high. Phosphorus, like N, is involved in a complicated cycle of transformations and translocations within wetland systems (Figure 3). Phosphorus is taken up, and stored by living biota, although this P is released during death and decomposition. The uptake of P by plants is also highest during the growing season, leading to variable removal rates over the course of the year. Particulate, insoluble P settles out of the water column and may be removed from the system through sedimentation. Clay particles in wetland soils also have the capacity to sorb P, making it unavailable for the aquatic ecosystem. Volatilization and off-gassing of P in the form of phosphine (PH_3) has also been credited with permanent removal of P from wetland systems (Kadlec & Knight, 1996).   The only other permanent removal pathway occurs through the harvesting of wetland vegetation. If vegetation is not removed from the system, wetlands have a finite P removal capacity estimated at 15 to 20 years, after which point the soil substrate within them will need to be replaced. A more detailed examination of the phosphorus cycle and the processes involved in the removal of P in wetlands is available in Kadlec & Knight, (1996).

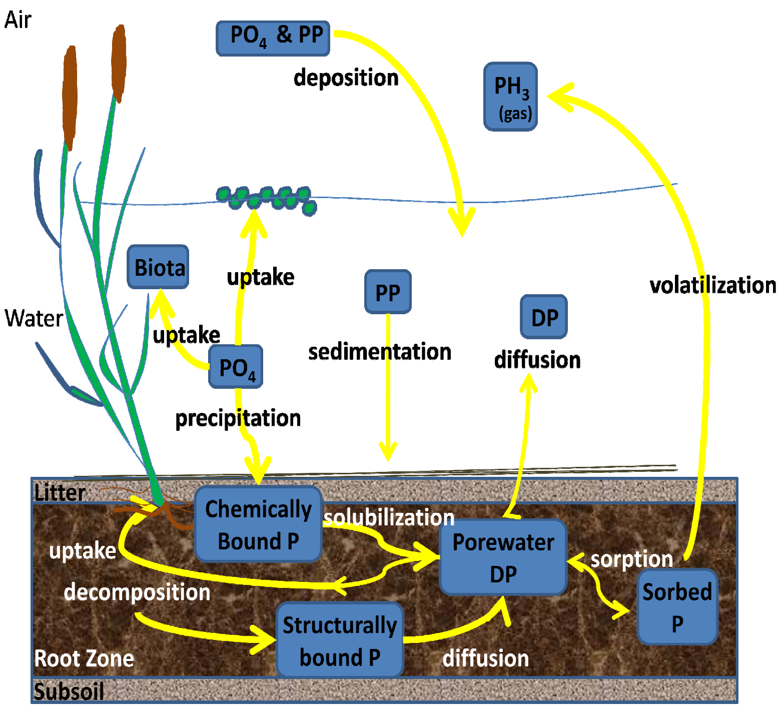


Figure 3. The simplified Wetland Phosphorus Cycle in a Surface Flow Wetland. Adapted from Kadlec & Knight, 1996

Several types of constructed wetland systems are available for the treatment of wastewaters. They are distinguished by the type of water flow present in the system, and are characterized as natural, constructed surface or constructed subsurface flow. The use of natural wetland systems to treat wastewaters has decreased dramatically with wetland protection regulations and water release guidelines. The artificially constructed variations shown in Figures 4 and 5, are more common. Surface flow wetlands maintain flood-like conditions, with high water levels that create ponds or pools on top of the exposed soil surface. Submergent, emergent and floating vegetation are typically planted in these systems. Water depth is fairly shallow, around 0.4m, although shallower areas can be combined with deeper ones (Kadlec & Knight, 1996). Subsurface flow wetlands, also called rock-plant filters, employ an impermeable soil bed or liner covered with a soil or gravel bed to create a filtration system. Rooted plants are planted in the bed media, and the depth is usually less than 0.6m. Both systems require primary treatment of wastewater to remove large particulate matter and both maintain non-turbulent flows of water. Subsurface flow systems can be prone to clogging so large gravel usually surrounds the inflow and outflow valves to prevent particulate from blocking water flow. Surface flow systems are more economical than subsurface flow systems for construction and maintenance and can treat larger volumes of water, although they have lower treatment capacities, especially for P removal (Kadlec & Knight, 1996).

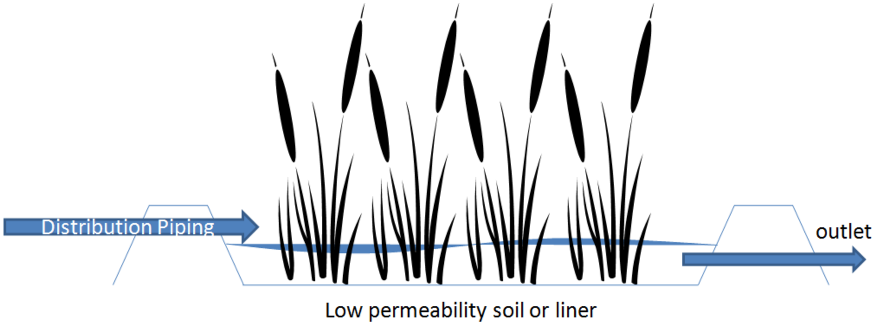


Figure 4. Surface Flow Constructed Wetland System.
adapted from Kadlec & Knight, 1996

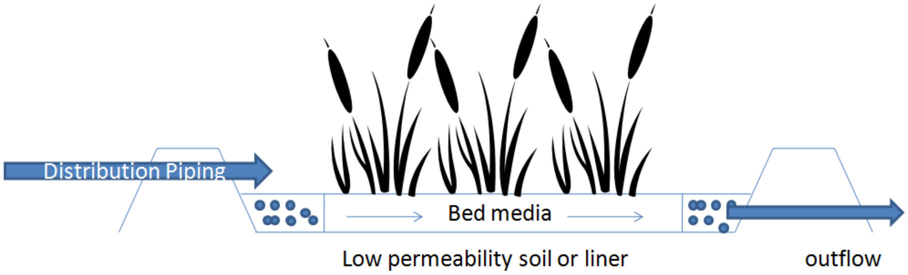


Figure 5. Subsurface Flow Constructed Wetland System.
adapted from Kadlec & Knight, 1996

2.2 Wetland Research and Use in Canada

Laboratory work on treatment wetland technology began in 1954 in the German Max Planck Institute with a study of the Root-Zone uptake system. Since then countless studies, including pilot-scale treatment wetlands, laboratory analyses, and natural wetland monitoring studies have been initiated worldwide (Reed et. al., 1988; Kennedy & Mayer, 2002). However, even in the research stage Canada continues to lag behind, with the first known Canadian study conducted in 1980 on pilot-scale wetlands in Listowel, Ontario (Knight & Preis, 1994). In a 2002 overview of natural and constructed wetlands in Canada, Kennedy and Mayer cited 67 as the number of wastewater treatment wetlands in operation, based on Preis's 1994 data. Although there are several organizations promoting the conservation of natural wetland ecosystems (including the North American Wetlands Conservation Council and the Canadian Wetlands Inventory) there is no national database of constructed treatment wetland use and a general lack of information-sharing regarding their wastewater treatment potential in Canada.

Interest in treatment wetlands increased in the United States after the Clean Water Act was passed in 1972. This Act introduced stringent regulations regarding the quality of water released into surface waters, including zero-pollution discharge requirements (Reed, 1990). Enforcing the treatment of municipal wastewater effluent quickly made it clear that the costs of traditional energy-intensive mechanical equipment could be prohibitive for many communities. Municipalities in the United States are required by law to treat wastewater to a minimum standard of secondary treatment, which led to a widening of research into the effectiveness of natural treatment processes (Kadlec & Knight, 1996).

In contrast, Canada only began developing a national policy regarding municipal wastewater effluent quality in 2003. This policy is still in the draft stage, with the Canadian Council of Ministers of the Environment currently considering comments received from the public over the course of the 2008 winter. Currently wastewater regulations fall under provincial jurisdiction and the provinces may delegate the responsibility for municipal wastewater treatment to municipalities; legislation and effluent guidelines vary significantly across Canada (Table A1). Many municipalities in Canada, particularly coastal cities, continue to release effluent with no treatment, or very minimal screening while a large proportion of the population still relies on septic systems (Sierra Legal, 2004). Nova Scotia does currently use guidelines issued by Environment Canada for the Atlantic region concerning sanitary sewage disposal, these guidelines govern newly constructed treatment facilities (Environment Canada Atlantic Region, n.d.). The introduction of regulations that apply to all effluent discharges will require small and rural communities to update their wastewater collection and treatment strategies.

Globally, major research efforts have concentrated on the use of constructed wetlands for the treatment of municipal wastewater and acid-mine drainage. This research has provided background information on the effectiveness of treatment wetlands in warmer regions (Mainguy et al., 2000). Constructed wetlands have been proven to improve municipal wastewater quality according to five main parameters: Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Ammonium Nitrate (NH_4-N), Total Nitrogen (TN), and Total Phosphorus (TP) (Reed et al., 1988; Kadlec & Knight, 1996; Mainguy et al., 2000).

In recent years the number of Canadian studies has increased, making significant contributions to the literature on wetlands in Canada. Several studies have focused specifically on the ability of wetlands to treat agricultural or livestock wastes (Smith, 2002; Jamieson et al, 2007). Other studies have focused more generally on the potential for wetlands to remove nutrients, including N and P

(Smith, 2002; LaFlamme, 2005). Other assessments have examined constructed wetlands as wildlife habitat (Rodruigues, 1997). These studies have highlighted some of the major challenges facing the use of wetlands in a cold climate as well as some of their benefits.

Rodrigues (1997) examined the estimated costs of constructing wetlands for the purpose of municipal wastewater treatment and assembled data comparing those costs with conventional treatment (Table 1). These comparisons, from six different municipalities, demonstrate the enormous cost-saving potential of treatment wetlands. Although based on costs incurred in the 1990s, the comparisons still hold today. Natural Systems International, a company operating out of New Mexico in the United States estimated the installation costs for systems achieving secondary treatment standards: $2,400,000 for a surface flow constructed wetland and $5,000,000 for a conventional activated-sludge system (Natural Systems International, 2008). These system estimates were based on 3,000,000-litre flows, or a population of 13,000 people using approximately 225 litres per person per day and the 2006 US dollar. Kadlec and Knight (1996) also estimated the costs of construction for the treatment of 3,786,000 litres of wastewater at $3,664,000 for lagoon-wetland system, and $4,112,000 for an activated sludge system both reaching treatment levels of 10mg/L BOD and TSS. This estimate was based on the 1994 US dollar. Although construction costs can be high because of the extensive groundwork that is needed to install these systems, the operation and maintenance costs are significantly lower and amount to larger savings. Kadlec and Knight (1996) estimated the operation and maintenance costs for the above systems at $156,000 and $45,000 per year for the activated sludge and natural systems, respectively. These examples simply show the cost-reduction that can be achieved by employing natural systems. Construction, maintenance and operation cost estimates for systems in operation in Canada are generally lacking.

Table 1. Construction Costs Comparison for Conventional Sewage Treatment Systems and Constructed Wetland Systems

Community	Population	Year Installed	Conventional Cost	Constructed Wetland Cost
Benton, Kentucky	4700	1985	\$3-4 million	\$300,000
Platteville, Colorado	---	---	> \$450,000	\$150,000
Union, Mississippi	<2000	late 1980s	\$1.2 million	\$450,000
Picayune, Mississippi	---	1992	\$4-8 million	\$300,000
Monterey, Virginia	---	1989	\$1-200,000	\$40,000
Gainsville, Florida*	100,000	---	\$1 million	\$340,000

*This system treats sewage waste only during part of the year
Sources: Dawson, 1989; Reed, 1991; Gillette, 1992 Shireman, 1993; after Rodrigues, 1997

Several recent studies focused on treatment wetlands receiving agricultural and feedstock wastewater, highlighting the unique challenge presented when using these systems in colder climates. Jamieson et al., (2007) found that the removal rates for N were lower than similar studies in warmer areas, while P removal was comparable. Smith (2002) examined common water quality parameters and found that average removal efficiencies for two wetland systems were 98-99% for BOD over a 17 month sampling period, not accounting for dilution from precipitation and variations in flow. Smith also found that TSS concentrations observed at the outlet of the wetland system were higher during the colder months, although the average removal efficiency was still 94-97%. When measuring TP, this study found high removal rates, nearing 90%, which Smith attributed to the vigorous plant growth that occurred in the recently-planted wetlands. The Total Kjeldahl Nitrogen (TKN) was also quantified. Removal rates were high, between 93 and 97%, which was also attributed to higher plant growth rates. In a study looking more specifically at a mature wetland, Laflamme (2005) found that there was a 42% removal of TP during the peak growing season of the summer months and a nitrate (NO_3^-) removal rate of only 20-25%. LaFlamme (2005) does not document removal rates over the winter months.

Low temperatures present unique challenges for the use of treatment wetlands in colder climates however, there are several measures that can help reduce the effects of temperature. Several plant species have been identified for wetland use in northern climates which include several reed species (*Typha spp.*) and floating plants (*Lemna spp.*), commonly known as cattails and duckweed respectively (Reed et al., 1988). These species occur naturally in Canada and can adapt to treatment wetland conditions. It is also possible to use the detritus from reed species, such as cattails, to act as an insulating layer and help maintain slightly higher temperatures (Knight & Preis, 1994; Smith, 2002).

Allowing an ice layer to build up on the water surface and subsequently dropping the water level can create an ice-air insulation layer and reduce the drop in temperature over the winter (Kennedy & Mayer, 2002. Smith (2002), found that this air-snow-ice insulation layer prevented the total freeze-up of a wetland of less than 1m depth, while the twin wetland without the insulation layer did experience total freeze-up. Such freezing could cause the hydraulic failure of a treatment wetland system, a problem usually avoided in subsurface flow wetlands where water flow below the surface is insulated. In their study of wastewater stabilization ponds, Rockne and Brezonik (2006) used the technique of emptying the ponds prior to freeze-up and allowing them to fill without outflow over the course of the winter, beginning water releases again in the spring with icemelt. This increases the removal of nitrogen prior to release in the spring because it facilitates the off-gassing of ammonia-N after the ice has melted. With appropriate care and maintenance over the winter season, treatment wetlands have demonstrated adequate nutrient removal for wastewater.

Chapter 3 – Methods

3.0 Introduction

The field investigations aimed to examine the treatment performance of a constructed treatment wetland during the cold season in Nova Scotia. The field study focused on the nutrient treatment potential of the system. The costs for the system were also used as an estimate of the investment required for this type of wetland and the treatment it provided. This site-specific information provided a basis for comparison to conventional treatment system costs and nutrient removal capacities, as well as insight into the ability of treatment wetland systems to meet or exceed the regulation guidelines proposed by the Canadian Council of Ministers of the Environment (CCME).

3.1 Wetland Description

The analysis of nutrient removal in this study evaluated a pilot-scale, experimental, surface flow treatment wetland system. It is located at the Nova Scotia Agricultural College (NSAC) Bio-Environmental Engineering Centre (BEEC) in Truro, Nova Scotia (45°40’N, 62°50’W). The average annual precipitation for the area includes 991 mm of rainfall and 229 cm of snowfall, and ice formation can be complete by late November with breakup beginning in April or early May (Environment Canada, 2004). The wetland system consists of two twin wetlands sitting in parallel, each 5m wide and 20m long with a 1.2m wide berm between them (Figures B1 & B2). A polyethylene liner prevents any wastewater from leaching into the substrate, which is sandy loam with high hydraulic conductivity (Smith, 2002).

Although the area has been landscaped to minimize runoff, the wetland identified as #1 is within 3m of a small hill (Figures B3 & B4). Each wetland has a pond-marsh-pond design; there are two ponds of 1m depth with a marsh 0.2m deep in between. Each wetland was planted in July of 2007 with cattails (*Typha latifolia)* which dominate the shallow marsh zone while duckweed (*Lemna, spp.)* floats on the water surface in both shallow and deep areas. Construction of the treatment wetlands was completed in the summer of 2007, and flow into the wetlands began in August.

The wetlands were designed to receive a flow of $1.25m^3$ d^{-1} and aimed at achieving concentrations of 15mg L^{-1} for both TSS and BOD, and 1 mg L^{-1} total phosphorus (TP) and 5mg L^{-1} total nitrogen (TN). The retention time used to design for these effluent targets was almost 25 days (Boutilier, 2007).

3.2 Sampling Approach

The wetlands have receive primary municipal wastewater effluent at approximate loading of 1400 Ld^{-1} since August, 2007. Municipal wastewater from Bible Hill is pumped from a flowing sewer line, up into a large, deep holding tank. This wastewater flows from the holding tank into a septic tank where receives primary treatment, before moving into the first deep zone via an inflow pipe approximately 60cm below the water surface. After flowing through the shallow wetland area, the wastewater moves into the second deep zone and finally leaves the system through an outflow pipe. Heated sampling huts are located at the inflow and outflow to facilitate sample collection. The treated wastewater is then piped back into the municipal sewage collection system.

Samples were collected monthly, beginning on October 1st, 2007, from the inlet and outlet huts. Samples collected from the inlet hut indicate the initial concentrations of contaminants in the wastewater, before it has entered either wetland. As they sit in parallel, wetland 1 and wetland 2 receive the same quality water from the septic tank. Samples collected from the outlet hut are collected separately for wetland 1 and 2 as these samples demonstrate the different treatment abilities of each wetland. These samples were sent to the Nova Scotia Agricultural College (NSAC) for processing. They were analyzed for common wastewater parameters including biochemical oxygen demand (BOD), total suspended solids (TSS), total coliform, and Escherichia *coli* bacteria (E. *coli*), pH, total kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), total phosphorus (TP), and soluble reactive phosphorus. The analyses were performed at the NSAC Soil and Water Quality Laboratory.

Samples were collected monthly between November and February in standard 250 mL #2 high-density polyethylene plastic containers. These samples were collected from within the shallow region on the inside edge of each wetland, at approximately 8m and 16m lengthwise (Figures B1 – B4).

Samples of approximately 250 mL were collected using a pole sampler, reaching into the wetland approximately 45cm. Most samples were left unpreserved and processed within 7 days of collection. One set of samples was preserved using dilute sulphuric acid and processed within 28 days, after neutralization with 5N NaOH. Sampling occurred on randomly selected dates irrespective of weather, and at random times. These samples were analyzed for total nitrogen (TN) and total phosphorus (TP) at the Dalhousie University Environmental Hydrology Laboratory. Total Nitrogen was analyzed using HACH Method 10071 using a standard persulfate digestion method, and a Hach DR 5000 spectrophotometer (Hach Company, Loveland, CO). According to this method, all forms of nitrogen within a sample are converted to nitrate through an alkaline persulfate digestion, using a Hach DRB 200 (Digital Reactor Block). Absorbance measurements are taken at 410nm after the nitrate reacts with chromotropic acid, forming a yellow colour. In wetland systems TN measurements indicate the sum of TKN nitrate and nitrite concentrations. Total phosphorus was measured according to HACH Method 8190, which uses the molybdovanadate method with acid persulfate digestion. This method converts organic and condensed inorganic forms of phosphate to reactive orthophosphate via acid treatment and heat digestion, and treatment with persulfate for the organic phosphates. In acidic media, orthophosphate complexes with molybdate, which reacts to ascorbic acid creating a blue colour that can be measured at 880nm.

3.3 Wetland Costs

A list of construction costs and the initial investment required for the construction of the treatment wetland system were compiled. Total costs for the system were estimated based on the preliminary information available, excluding the costs of sampling and laboratory analysis. This information was used to provide insight into a cost estimation for the municipality of Bible Hill for the construction of a natural treatment wetland system.

3.4 Limitations

The longevity and complexity of wetland systems makes them ideal for long-term study. The temporal limitations of this study severely limit the significance of the data collected. Although four months of nutrient removal ability will provide insight into the treatment potential of this wetland, it is not representative of the overall treatment capacity for the wetland lifespan of 15 to 25 years. Wetlands are unsteady-state systems with seasonal and annual variation, which would be considered in a longer monitoring period.

Chapter Four – Results & Discussion

4.0 Introduction

The field investigations conducted during the cold season highlight the ability of treatment wetlands to perform adequately in Nova Scotia's climate; the nutrient treatment potential of the system falls within the proposed guidelines outlined by the CCME for municipal wastewater effluents for the parameters examined. These preliminary effluent limits are currently under review, with a potential release date of December 2009. The cost estimates for a natural treatment system for the municipality of Bible Hill also identified potential savings of almost $7 million over the course of a 25-year treatment period, when compared with cost estimates for conventional systems. However, the regulatory review identified some potential problems arising from the increasing number of emerging contaminants that are contained in wastewater, which indicates that treatment wetlands may not be an adequate form of treatment on their own.

4.1 Treatment Potential

Results for the water quality analysis (mg L^{-1}) and removal rates (%) for each wetland for the monitoring period demonstrate a removal ability comparable to conventional secondary treatment for several common wastewater parameters (Table 2). Only the main nutrient parameters, including TP, TN, TKN, NO_3^--N, and NH_3-N will be discussed further in this study. Since soluble and insoluble organic nitrogen dominated in this wetland, TKN is assumed to be approximately equal to TN. Wetlands are not steady-state systems and as this study period was quite short, these data may not be representative of the overall treatment capacity for this system. Precipitation events were neither measured, nor considered when examining the concentration data.

Table 2. Average concentrations (mg/L) and percent (%) removal rates over the October to January sampling period.

Parameter	[inlet] (mg/L)	[outlet] WL #1 (mg/L)	[outlet] WL #2 (mg/L)	% Removal WL#1	% Removal WL #2
Total Coliform (CFU/ 100mL)	≥7,500,000	≥123,300	≥101,300	98.4	98.7
E. Coli (CFU/100mL)	≥4,750,000	≥94,167	≥87,582	98.0	98.2
TSS (mg/L)	51.6	13.3	16.8	74.3	67.5
BOD (mg/L)	165.8	53.7	49.7	67.6	70.0
TKN (mg/L)	43.1	26.5	23.1	38.4	46.4
NH_3-N (mg/L)	13.1	6.7	7.6	48.4	42.1
NO_3- N (mg/L)	0.14	≤0.16	≤0.10	-13.1	24.4
Total-P (mg/L)	4.1	2.4	1.9	41.3	53.9
pH	7.1	6.9	7.0	-	-

4.1.1 Total Phosphorus

Excess P is often present in wastewater, so much so that the nutrient balance in the wetland ecosystem is disturbed and the phosphorus, normally the limiting nutrient, overwhelms the system and cannot be assimilated (Kadlec & Knight, 1996). Phosphorus is present in wetlands in several forms, including orthophosphate (PO_4), which can be taken up by plants and microbiota, particulate phosphate, dissolved phosphate, and phosphine (PH_3), a form that can off-gas. The principal compounds acting as P sinks in wetlands systems are dissolved inorganic P (phosphates), solid mineral P (precipitates with calcium, iron, or aluminum), and solid organic P (in tissues). Organic P and phosphates are measured in wastewater as total P.

The average inlet concentration of total phosphorus was 4.1 mg L^{-1} which is within the range of 4 to 8 mg L^{-1} outlined by Kadlec and Knight (1996) for secondary effluent and well below the 12 mg L^{-1} concentration estimated by Marbek Resource Consultants Limited (2006) for untreated domestic wastewater. Although it is low for septic tank effluent, it is within the averages outlined in the CCME review of effluent substance concentrations, which identified a range of 0.19 mg L^{-1} to 6.9 mg L^{-1} (Hydromantics Ltd., 2005). Average outlet concentrations were 2.4mg L^{-1}, and 1.9mg L^{-1} for wetland 1 and 2 respectively, which demonstrates some removal capacity and are comparable to results reported by Smith (2002) in her assessment of agricultural waste treatment using wetlands. It is also below the average of 4 mg L^{-1} for typical secondary effluent from conventional systems (Kadlec & Knight, 1996). It is similar to removal rates found by Rockne and Brezonik (2006) who reported an average removal of 55% over a twelve month study period. Removal efficiency nearing 45% is comparable to secondary activated sludge treatment used in conventional systems (Tchobanoglous *et al.*, 2003).

Phosphorus removal is generally expected to be low in treatment wetlands and occurs principally via sedimentation and precipitation processes. These processes are usually higher in newer wetlands as assimilation capacity is at its maximum and phosphorus is able to flood into available porewater spaces and sorb to soil substrate. Wetlands 1 and 2 removed 74% and 62% of the TP in the system respectively (Figure 4). These rates may be attributable in part to the growth of the vegetation and in part to the high availability of adsorption sites within the new system. Phosphorus reduction is also generally higher in the growing period of the summer months as biota can contain up to 40% P in percent dry weight (Rejmánková, 2005). The average TP removal for Wetland 1 and 2 over the course of the sampling period were 41% and 54% respectively. The higher average removal rate in Wetland 2 may be due in part to the thicker growth of cattails in the shallow zone.

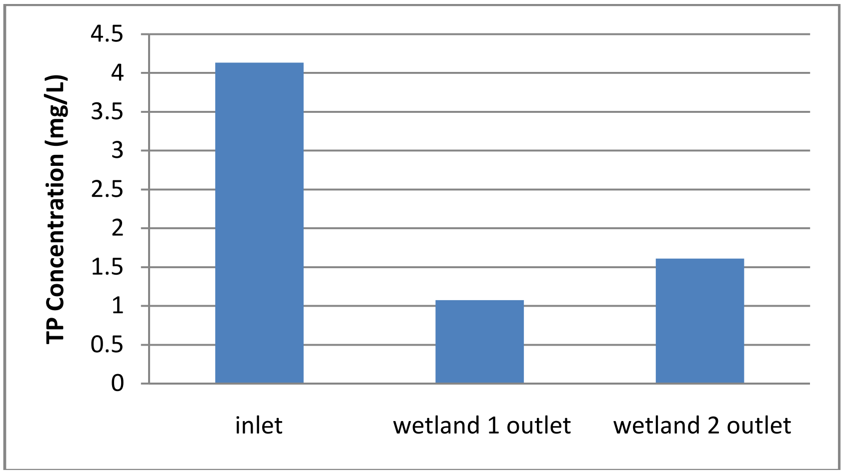


Figure 6. Average Total Phosphorus concentration (mg/L) for October, 2007.

If the plants are left unharvested however, this stored P is usually returned to the system as the biota decomposes over the course of the winter months (Kadlec & Knight, 1996). The return of solid organic P to the water column may be a factor in the low average removal documented for this system. In a study of nutrient resorption in wetland species, Rejmánková (2005) found that *Typha* spp. had a live and senescent P tissue concentration of 1.2 mg g^{-1} and 0.4 mg g^{-1} respectively, indicating a large transfer from plant tissue into the system. The shallow zone data for TP in both wetlands visibly demonstrate an increase in the TP concentrations within the shallow regions where cattails were planted, possibly indicating P release from the plants (Figure 7 & 8). The decrease in TP observed before 8m and between 16m and the outlet highlight the importance of deep-zone sedimentation (Figure 9).

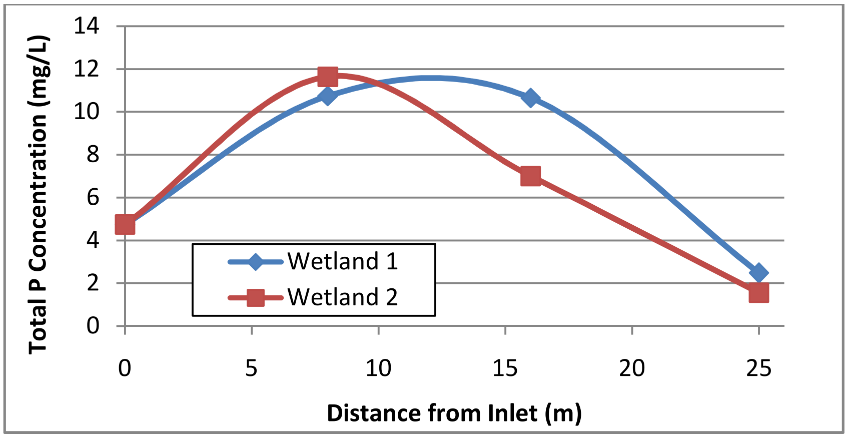


Figure 7. November Total Phosphorus Concentrations

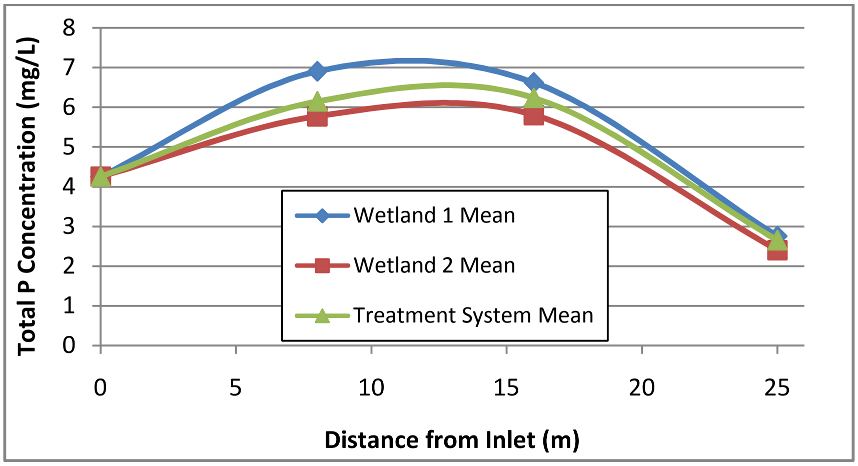


Figure 8. Mean Total Phosphorus Concentrations

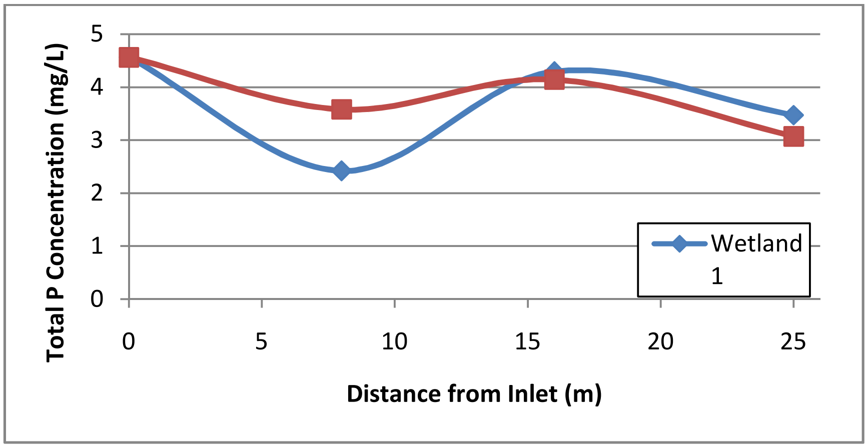


Figure 9. Total Phosphorus reduction zones for January

In a bench-scale wetland model Weng *et al* (2006) found that harvesting cattails soon after the end of growing season removed approximately 40% of the P mass input into the system. Harvesting is normally considered impractical as it is labour intensive, however harvesting both the reed species such as cattails, and the floating aquatic plants, such as duckweed, could remove upwards of 20% of the total phosphorus in a treatment wetland (Kadlec & Knight, 1996). The maximum P concentration is reached by cattails after 50-60 days of growth, which could mean double harvesting is possible in longer growing seasons (Weng et al, 2006). Cattails can store enough nutrients in the lower portions of the plant to support regrowth in the spring, which means harvesting in early fall would also maintain wetland capacity for P uptake by biota the following year. Harvesting could feasibly occur in August and October in Nova Scotia. Although harvesting would incur costs and use resources, there is potential the organic material could be used in compost and serve as fertilizer after processing.

Other methods for increasing P removal include adding lime, aluminum or iron (Fe) compounds to increase precipitation of phosphorus in insoluble complexes with these ions, depending on the pH of the wetland. Smith (2002) noted that a wetland with a higher Fe concentration also had higher P % mass reduction.

4.1.2 Total Nitrogen

For all sampling dates, the inlet concentrations of nitrogen-containing compounds were greater than the oulet concentrations for both wetlands (Figure 10). Inlet concentrations of TKN ranged from 36 mg L^{-1} to 51 mg L^{-1} with an average inlet concentration of 43 mg L^{-1}, while outlet concentrations ranged from 17 to 35 mg L^{-1} and 5 to 42 mg L^{-1} for wetland 1 and wetland 2 respectively, with outlet averages of 27 mg L^{-1} and 23 mg L^{-1}. The highest outlet concentrations for both wetlands were observed in January. Nitrogen removal rates were lower than those reported by Rocke and Brezonik (2006), who found an average removal of 80% over a 12 month sampling period. The results found in this study are comparable to the 10-20% removal expected from conventional secondary treatment, although 70-95% removal can be achieved through the specific nitrification and denitrification treatments performed in some activated sludge treatment methods (Tchobanoglous et al., 2003).

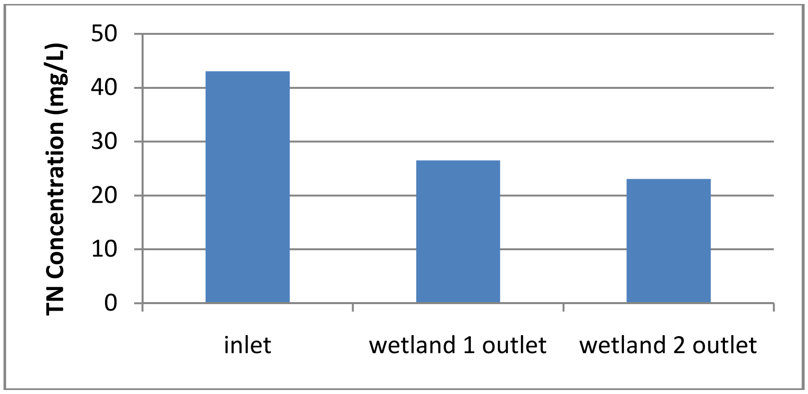


Figure 10. Average Total Nitrogen Concentrations (mg/L) for the sampling period

Typically, assimilation of nutrients within treatment wetland systems is high during the first one to two years because of vigorous plant growth and the expansion of stand areas (Kadlec & Knight, 1996). The wetlands studied were planted in July of 2007, and although this is after the flowering period for the common cattail (*Typha latifolia)*, seeds are capable of germination immediately when shed in favourable conditions. Cattails respond well to planting in summer and spread rapidly via rhizome networks in the soil. The rapid growth phase lasts for the duration of the growing season, which extends into early October in Nova Scotia. Nitrogen storage in plant tissues can be significant, ranging from 100 – 500 kg ha^{-1}, although it varies between systems (Kadlec & Knight, 1996). This is temporary storage however and once senescence occurs, N is generally released back into the water column as detritus decays. In a study of nutrient resorption in wetland species, Rejmánková (2005) found that *Typha* spp. had a live and senescent N tissue concentration of 14.7 mg g^{-1} and 7.1 mg g^{-1} respectively, indicating a large release of N into the water column post growing-season. The main processes responsible for longer-term N sinks in wetland systems are volatilization and sedimentation.

In the winter during ice cover, algal growth is presumed to stop as the ice cuts off atmospheric air exchanges and reduces light penetration. Anaerobic conditions are created as plant root systems cease to add dissolved oxygen to the water column. The decomposition of organic matter and algae (equation 4,1) under anaerobic conditions lowers pH in the system as H^+ ions are released back into the water column. With pH values below 8, the equilibrium between the nitrogen forms NH_3 and NH_4+ is destabilized and the reaction favours the ionized form of ammonia (4,2).

$$C_{106}H_{263}O_{110}N_{16}P_1 + 138O_2\ (algae) = \qquad (4,1)$$

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 18H^+ + (trace\ elements, \text{energy})$$

$$NH_3 + H_2O = NH_4^+ + OH^- \qquad (4,2)$$

The ionized form of ammonia, also known as the ammonium ion (NH_4^+), is the predominant form of ammonia in most wetland systems, especially over the winter months. When in this form, little volatilization occurs and the concentration of total N in the system increases. Rockne and Brezonik (2006) reported that the primary removal of N from their wetland system occurred via the volatilization of un-ionized ammonia. Once ice-melt occurred, algal growth resumed, increasing the dissolved oxygen levels in the water column, and subsequently raising pH. This reaction sequence shifts the equilibrium of reaction 4,2 back to the more volatile neutral form resulting in off-gassing of NH_3. They reported a 70% removal rate during the winter-spring monitoring period for nitrogen, though only half of this occurred during ice cover. Volatilization maximums were recorded 45-75 days after ice melt in the spring for that study. This highlights the increased N removal possible if wastewater releases can be postponed until after ice cover has melted, allowing increasing volatilization to remove further N from the effluent discharged into surface waters. However, because the N lost in this form is a reactive species and readily dissolves into water, this is not the ideal mechanism for removal. Although the removal of N from effluent in an effort to protect receiving waters from eutrophication is one goal, in a broader environmental context, the amount of NH_3 volatilized must be examined and the effects of its deposition elsewhere considered.

For their study, Rockne and Brezonik (2006) controlled all discharges, allowing their stabilization ponds to fill over the four-month ice cover period, and beginning releases again in the spring. Although this prevents effluent releases high in nutrients, it is often impractical because of the large storage areas required for the wastewater flows of large populations. Ammonia reduction should be a key component of wetland design because of the importance of keeping ammonia out of receiving waters.

The preferred removal of N from wetland systems is via the nitrification and denitrification pathway, which leads to the release of inactive N_2 (Rockne & Brezonik, 2006). However, these processes are highly temperature dependent and virtually cease once the temperature drops below 5°C (Smith, 2002; Ouellet-Plamondon et al., 2006). Nitrification requires the presence of dissolved oxygen in the water column, which is limited by ice cover during the winter months. Once nitrification decreases, denitrification slows and the concentration of ammonia in the water column increases, usually corresponding to decreasing temperatures (Figure 10). Aeration of the water column is one measure that can increase the nitrification process. To ensure the water temperature is maintained above 5°C , it is essential that some form of insulation is used. This could involve creating a snow-ice-air insulation layer by raising the water level before ice forms, and subsequently lowering it. It could also involved using harvested organic matter for insulation of the ice layer. These data highlights that mitigative measures must be taken in the Nova Scotia climate to ensure optimal reaction processes occur in treatment wetland systems.

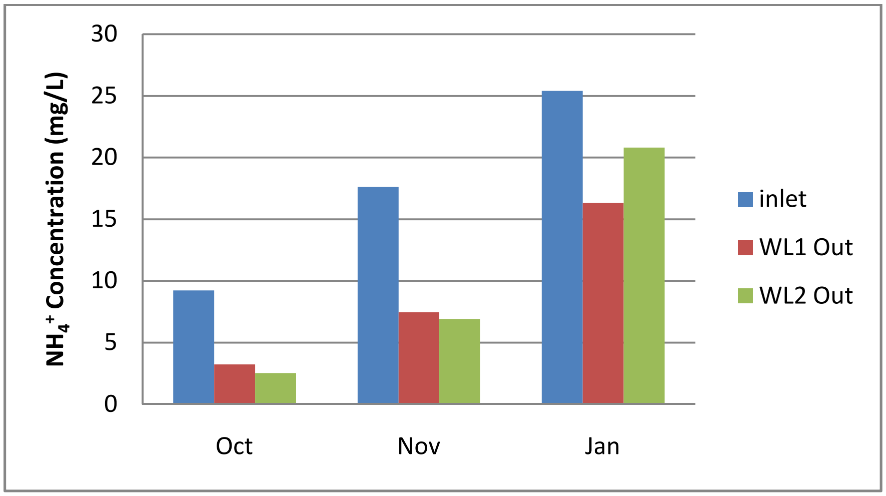


Figure 11. Cold Season Water Column Ammonia-N Concentrations

Algae and plant uptake is also an important N sink, however it too must be harvested to prevent the N being released back into the water column. Harvesting algae can be simpler than harvesting emergent vegetation as it can simply be skimmed off the surface of the water, yet it remains labour intensive. Aerobic conditions are also important for algae growth, which in turn contributes to reductions in BOD. Ouellet-Plamondon et al. (2006), found that the aeration of planted sub-surface flow wetland units increased the removal of TKN. The reduction of N removal due to low oxygen availability and lower temperatures of winter months could be partially offset using this method.

4.2 Regulation Review

To date, the majority of Canadian municipalities have approached the management of municipal wastewater effluents using both technology-based standards for effluent releases and site-specific considerations for the protection of receiving waters. More commonly employed are generic effluent limits for the most common conventional wastewater parameters including BOD, TSS and Fecal Coliforms (Minnow Environmental Inc., 2005). There is no standardization across treatment facilities or geographic areas, and further effluent restrictions can be imposed at the discretion of the regulatory bodies within the provinces.

In Nova Scotia, effluent discharge is regulated by the province through operating an approval system under the Water Activities Designation Regulations under the Nova Scotia Environment Act (1995). In 1992 the province adopted the Nova Scotia Standards and Guidelines Manual for the Collection, Treatment and Disposal of Sanitary Sewage, which was updated in 2003 when the criteria for approval were aligned with Environment Canada standards. However, these regulations only apply to newly-constructed facilities. Facilities permitted before 2003 have to meet older standards, which use generic objectives based on the receiving waters. These guidelines include a 30 mg L^{-1} target for TSS and BOD discharged to the open ocean, which decreases to 10 mg L^{-1} and 5 mg L^{-1} for rivers and lakes respectively (Table 4). There are currently no governing standards for P, ammonia, or nitrates although nutrient removal may be requested by the regulatory authority (Atlantic Canada, 2005). According to 2003 regulations, the effluent release limits are governed by the assimilative capacity of the receiving water, which is assessed. As noted by Minnow Environmental Inc. (2005), some large coastal cities continue to discharge untreated sewage, the cause for which they cite as the high costs of providing collection and treatment. Treatment facilities are operated by municipalities.

Table 3. Nova Scotia Wastewater Effluent Requirements

	2000			2006		
Parameter measured ->	**BOD (mg/L)**	**SS (mg/L)**	**Fecal Coliform (#/100mL)**	**CBOD (mg/L)**	**SS (mg/L)**	**Fecal Coliform (MPN/100mL)**
Discharge location						
Fresh water with limited dilution	5	5	200	0	20	200
Fresh water with dilution	10	10	200	0	20	200
Brackish water or restricted Bays	20	20	1000	20	20	200
Open coastline	30	30	5000	25	25	200

source: Environment Canada Atlantic Region, 2000; Environment Canada, 2006; Minnow Environmental Inc., 2005

According to these standards, the treatment wetlands in operation in Bible Hill were not able to meet the fecal coliform guidelines as the effluent contained a high concentration of E. *coli* and total coliforms. The treatment wetlands do meet the standards for suspended solids, averaging 11 mg L^{-1} at the outlet between October and December, which are below the 20 mg L^{-1} guideline. In terms of biological oxygen demand, the wetlands were able to maintain outlet concentrations below the guidelines in October, but these increased as algal growth declined in colder temperatures. Because treatment wetlands are not steady-state systems, it is difficult to guarantee their performance will meet strict effluent guidelines. In order to ensure compliance with regulations, other treatment options would have to be incorporated into a wetland design.

The regulations currently used under the 2006 Atlantic Canada Wastewater Guidelines Manual for Collection, Treatment, and Disposal are also subject to change within 2-3 years. The CCME has released a draft of the Canada-wide strategy for the Management of Municipal Wastewater Effluent, which indicates the proposed limits for effluent concentrations for several common wastewater parameters (Table 4). The proposed guidelines will indicate limits for 41 core substances deemed harmful. In comparison to the concentrations found in raw wastewater, the proposed concentration limits appear conservative, and the Bible Hill treatment wetland system is able to comply with the regulations.

Table 4. Bible Hill Wetland Effluent Concentrations, CCME effluent Guidelines and Raw Wastewater Concentrations

Parameter	Range of Effluent from Bible Hill TW	CCME Regulation Requirements (mg/L)	Raw Wastewater (mg/L)
BOD	7.7 - 111	300	≤600
TSS	8 - 31	300	≤600
TP	0.3 – 3.5	12	≤150
TN/TKN	5.3 – 41	70	≤150
Ammonia-N	2.5 – 20.8	24	≤50
pH	6.7 – 7.3	6-11.5	3-12

Source: Kadlec & Knight, 1996; Marbek Resource Consultants, Ltd. (2006)

Although the Bible Hill treatment wetlands have the capacity to meet the upcoming regulations, there are 41 substances named on the CCME Core Substances List, which include metals such as arsenic, and industrial compounds such as hexachlorobenzene and methylene chloride. Furthermore, the proposed CCME guidelines also contain a Long List of Substances, a Master List of Substances (120 named), and a List of Substances for Discussion by the Development Committee. All of these lists contain compounds which may be identified as: (i) having human health effects, (ii) being known or possible carcinogens, (iii) being toxic, (iv) being bioaccumulative, (v) being persistent, (vi) threatening the effluent collection or processing system, (vii) threatening the health of employees of the aforementioned systems, (viii) threatening the receiving environment of the effluent, or (ix) threatening the biosolids quality (Marbek, 2006). The CCME has also identified that there are emerging compounds of concern, which include natural and synthetic estrogens, pharmaceuticals, personal care products, surfactants, anti-convulsants, anti-depressants, and flame-retardants. Should these substances come under regulation in the future, further information on the ability of treatment wetlands to deal with them would be necessary.

4.3 Cost Assessment

The costs associated with natural treatment systems are usually significantly lower than conventional treatment options. The life span for conventional systems ranges from 20-50 years although concrete and steel equipment frequently need replacing or repairing (Kadlec & Knight, 1996). Because treatment wetland systems are a fairly new treatment option, there are few examples of long operation periods; the stabilization ponds studied by Rockne and Brezonik (2006) were adequately treating wastewater after more than 24 years in operation. As discussed earlier, wetlands are land-intensive systems while conventional treatment is traditionally fossil-fuel intensive, which could lead to considerable operation and maintenance costs in a time of fossil fuel scarcity. The estimates for conventional and wetland treatment systems indicate a potential cost saving of over $6 million for a 25 year life span.

4.3.1 Treatment Wetlands

Capital cost for the treatment wetlands in Bible Hill, Nova Scotia was approximately $30,000 (Table C1). This cost represents infrastructure and earthwork only, as there were no land purchasing fees associated with the construction of these experimental wetlands. The operation and maintenance of these wetlands was also extremely low as it is situated on institutional land with employees available for consultation and labour. Each wetland was designed to receive a total of 1400L day^{-1} with a hydraulic retention time of almost 25 days. Each wetland could service one household of 3 to 5 people.

The village of Bible Hill has an estimated population of 6000 people (2001). A conservative water-use estimate of 300 L per person per day would result in wastewater flows of 1,800,000 L or $1800m^3\ d^{-1}$. This would indicate that almost 1300 times the capacity is required for the treatment of Bible Hill's municipal wastewater effluent using small scale treatment wetlands. A decentralized system with treatment wetlands occurring at converging sewer drains for small sections of the municipality would be required. However, the effluent also requires discharge, which is normally released into flowing surface waters. The likelihood of one larger scale system is more probable.

The treatment requirements could be met in one collective system, although the land area needed would increase. Land used for natural systems for flows below $5{,}000m^3\ day^{-1}$ ranged from 9ha to 54 ha (Kadlec & Knight, 1996). The area required depends on the hydraulic retention time sought, and although retention time could be varied, longer retention times contribute to better quality effluent and longer lifespans for treatment wetlands. Average undeveloped land values of $500-$6,000 per hectare (ha) translates into a large initial capital investment for land acquisition, estimated at $240,000 for approximately 40ha. Using the capital investment estimate from the treatment wetland in this study, the initial system set up costs should reach $3,900,000. Using an average of the operation and maintenance costs estimated by the Wastewater Treatment Costing Templates for stabilization ponds and aerated lagoons, of approximately $146,000 the total estimated wetland costs are $7.8 million over the course of 25 years.

Treatment wetlands, and their use in the treatment of wastewater, can provide ancillary benefits that are difficult to quantify, such as educational, recreational and wildlife benefits. As outdoor facilities they create green-space and vegetated park-like land. Although treatment wetlands should be fenced to prevent public access, they can provide recreational walking trails outside the immediate wetland zone if the land area is large enough. The wide variety of habitat created by inundated areas and emergent vegetation can encourage a wider diversity of insect, bird and fish species to occupy the area. There are also educational opportunities in terms of community engagement in the wastewater treatment processes. Awareness is a key factor in preventing the disposal of harmful materials such as paints or oils, into the municipal wastewater collection system. In some instances, the harvesting of wetland vegetation such as duckweed could provide fodder for nearby agricultural operations, or compost for community garden projects. These activities may in turn have economic benefits when contrasted against conventional treatment systems, as there would be a reduction in the transportation and processing of sewage sludge. As with any system there are several concerns associated with the use of treatment wetlands such as increased mosquito breeding habitat, (*Culiseta, spp.),* and unpleasant odours.

4.3.2 Conventional Treatment Costs

The costs for various forms of conventional treatment systems were estimated using the Wastewater Treatment Costing Templates (Appendix C). The treatment wetlands studied release effluent similar to that seen after secondary treatment, offering a good basis for cost comparisons. Conventional secondary treatment options range in cost from $1.45 to $12.82 million. The annual operation and maintenance minimums and maximums were $65,000 and $356,000 respectively. Recirculation sand filters have the lowest estimated capital investment and operation and maintenance inputs required, at $1.45 million, but are normally employed with another treatment option. The highest capital cost was associated aerated lagoon systems, likely related to the high cost of earthwork and land required for these systems. Overall, the average estimated costs for common conventional systems aimed at reducing ammonia concentrations was $7.21 million with an average operation and maintenance cost of $276,000. This included estimates for conventional activated sludge, rotating biological contactors, trickling sand filters, and sequencing batch reactors. Over a 25-year period, the total costs would be approximately $14.1 million.

Conclusions and Recommendations

Conclusion

The introduction of Canada-wide regulations concerning municipal wastewater effluent will place a certain amount of pressure on small communities. They will need to install wastewater collection systems and treatment facilities in order to meet the proposed guidelines. The information gathered in this study indicates that it is feasible and financially beneficial for small communities to install natural treatment systems. The effluent concentrations observed at the Bible Hill Treatment Wetland Facility were below the limits proposed by the Canadian Council of Ministers of the Environment for the parameters observed, while the estimated cost savings were $6.3 million over a 25-year period.

The intent of wastewater treatment is to protect surface- and groundwater systems from the stress that municipal wastewater effluent can cause. Because wastewater contains an increasing number of compounds in increasing concentrations, it is essential that these are removed or reduced before the wastewater is released. Information on the ability of natural systems to adequately treat these emerging contaminants is required before widespread implementation of natural systems can be recommended. When faced with regulations, municipalities will be reluctant to invest in a technology that cannot guarantee appropriate treatment, preferring to use a preventive approach and design treatment systems to meet future standards. Although the information gathered by this study indicates that it is possible to use treatment wetlands during the winter months in Nova Scotia, it does not ensure optimal environmental protection.

Recommendations for Implementation

Given that wetland systems are not steady state and cannot guarantee a certain level of treatment, they should be combined with other treatment options to increase the standardization of effluent releases. The combination of several treatment technologies, often called treatment trains, can maximize the treatment capacity of small spaces. For example, a treatment train could employ a preliminary settling tank, a treatment wetland, a recirculating sand filter, and finally a UV or chlorine disinfection unit (Figure D1) (NSI, 2008). The flexibility of outdoor systems means they can be modified as regulations change, ensuring adequate treatment in the long term. Treatment trains would also allow the least-costly version of a treatment process to be utilized. Wetlands could also be combined with stabilization ponds in order to store the wastewater over the winter months, recommencing effluent releases in the spring when wetland treatment performance increases.

Subsurface flow wetland systems have the ability to insulate the water column from colder air temperatures, which can increase their removal performance over the winter months. Treatment trains employing both surface- and subsurface flow wetlands, could ensure optimal treatment, especially concerning P removal, while handling large volumes of wastewater. This could provide municipalities with a more standardized effluent.

As a stand-alone treatment technology, wetlands have limited use in Nova Scotia. They could reasonably be employed in campgrounds, national parks or recreation areas, or in cottage developments that are primarily inhabited during the summer months. In these areas, the substantial nutrient uptake that occurs over the summer months would provide adequate protection for nearby surface waters. However, in view of the large number of emerging contaminants identified by the CCME, using treatment wetlands even seasonally without any other form of wastewater treatment could endanger the local environmental quality by allowing compounds such as natural and synthetic hormones or chemicals from personal care products and medications to be released. Further investigation into the effectiveness of treatment wetlands with respect to these compounds is needed.

Future Research Recommendations

The field investigations of this study were performed over a four-month period, a relatively short time with respect to the lifespan of a typical wetland. Monitoring over a longer period of time would provide further insight into the treatment capacities of the wetland system. This system was also recently constructed which affects its removal ability. Future research should assess older wetland systems and aim for several years of performance data.

It would also be worthwhile to investigate the affects of aerating a treatment wetland system over the cold season. Aerating the first deep zone would prevent ice cover, introduce dissolved oxygen into the water column and could encourage nitrification. Maintaining higher levels of ammonia conversion via nitrification and the release of nitrogen gas to the atmosphere would decrease the N concentrations in effluent in an environmentally sound manner.

The effectiveness of P and N removal from wetland systems by harvesting floating aquatic plants and emergent vegetation requires further investigation, which should include labour estimates. Municipalities with available labour would be encouraged to employ these strategies if backed by scientific evidence. The harvested vegetation should be assessed for elevated levels of contaminants to determine if they are safe for compost and subsequent use.

Most constructed wetlands in Canada appear to be experimental and are therefore funded by research grants or the federal government. This does not necessarily encourage accurate record-keeping or total-cost accounting. Detailed costs assessments for the construction of natural treatment systems would provide municipalities with evidence of the cost-saving potential. A national or provincial database for natural treatment systems would facilitate knowledge-sharing and cost comparisons.

The results of these studies would inform Canadian decision-makers of the option to use treatment wetlands as secondary or tertiary wastewater treatment, and how best to do so.

References

Boutilier, Leah. (2007). Personal Communication. October 2007, Halifax, Nova Scotia.

Cairns, J., Niederlehner, B.R. (1994). Comments and Reviews: Estimating the Effects of Toxicants on Ecosystem Services. *Environmental Health Perspectives,* 102.11: 936-939.

Canadian Council of Ministers of the Environment (CCME). (2006). *User Guidance for the Wastewater Treatment and Collection System Templates.* Retreived March 20th, 2008 from: http://www.ccme.ca/assets/pdf/cost_template_user_guide_e.pdf

Canadian Council of Ministers of the Environment (CCME). (2007). *Canada-wide Strategy for the Management of Municipal Wastewater Effluent Draft*. Retrieved March 12th, 2008 from: http://www.ccme.ca/assets/pdf/mwwe_cda_wide_strategy_consultation_e.pdf

Dawson, B. (1989). High Hopes for Cattails. *Civil Engineering,* 59.5: 48-50.

Environment Canada Atlantic Region. (2000). *Atlantic Canada Standards and Guidelines Manual for the Collection, Treatment and Disposal of Sanitary Sewage.* Retrieved Nov 2nd, 2007 from: http://www.gov.ns.ca/enla/water/docs/AtlCanStdGuideSewage.pdf

Environment Canada. (2004). *Canadian Climate Normals 1971 to 2000*. Retrieved March 22, 2008 from: http://climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=ALL&StationName=Truro&SearchType=BeginsWith&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=6491&&autofwd=1

Environment Canada. (2006) *Atlantic Canada Wastewater Guidelines Manual for collection, Treatment, and Disposal*. Retrieved March 28th, 2008 from: https://www.gov.ns.ca/enla/water/docs/AtlCanStdGuideSewage.pdf

Environment Canada. (2007) *The 2007 Municipal Water Use Report.* Minister of Public Works and Goverment Services Canada. Cat. No. En11-2/2004E-PDF. ISBN 978-0-662-45852-4. Retrieved February 24th, 2008 from: http://www.ec.gc.ca/Water/en/info/pubs/sss/e_mun2004.pdf

Freshwater Wetlands. (n.d.) The Province of Nova Scotia: Nova Scotia Museum of Natural History – Natural Hisotry of Nova Scotia Volume One, Topic T8.3. (n.d.). Retrieved October 19, 2006 from: http://museum.gov.ns.ca/mnh/nature/nhns/t8/t8-2.htm

Gillette, B. (1992). The Green Revolution in Wastewater Treatment. *Biocycle, 33.12*: 44-48.

Hamilton, H., Nix, P.G., & Sobolewski, A. (1993). An Overview of Constructed Wetlands as Alternatives to Conventional Waste Treatment Systems. *Water Pollution Research Journal Canada*, 28.3: 529-548.

Hydromantis Ltd. (2005). *Review of the State of Knowledge of Municipal Effluent Science and Research: Review of Effluent Substances*, Final Report prepared for the Development Committee for the MWWE Canada-Wide Strategy for the Canadian Council of Ministers of the Environment. Retrieved March 2, 2008 from: http://www.ccme.ca/assets/pdf/csr_rev_emerge_tech_bmp.pdf

Jamieson, R., Gordon, R., Wheeler, N., Smith, E., Stratton, G., & Madani, A. (2007). Determination of First order Rate Constants for wetlands treating livestock wastewater in cold climates. *Journal of Environmental Engineering and Science,* 6.1: 65-72.

Kadlec, Robert H., Knight, Robert L. (1996). *Treatment Wetlands*. Boca Raton, Fl., Lewis Publishers.

Kennedy, Gavin, Mayer, Tatiana. (2002). Natural and Constructed Wetlands in Canada: An Overview. *Water Quality Research Journal*, 37.2: 295-325.

Knight, Robert L., Pries, John. (1994). *Nova Scotia Department of Agriculture and Marketing: Workshop on Constructed Wetlands for wastewater and Stormwater Treatment*. CH2M Hill Engineering Ltd.

LaFlamme, Christina. (2005) *Nutrient Removal using a Constructed Wetland in Southern Quebec*. Masters Thesis. McGill University.

Mainguy, Sarah K., Pries, John, & Chinniah, Karu. (2000). *Guidelines for the Approval and Design of Natural and Constructed Treatment Wetlands for Water Quality Improvement*. Retrieved on October 16th, 2007 from: www.gov.ab.ca/env/protenf/publications/guidelinesfornaturalandconstructedtreatmentwetlandsmar00.pdf

Marbek Resource Consultants Ltd. (2006). *Model Sewer Use Bylaw Development Report* – Final Report, prepared for the Canadian Council of Ministers of the Environment. Retrieved February 19th, 2008 from: http://www.ccme.ca/assets/pdf/mwwe_source_control_rpts_e.pdf

Minnow Environmental Inc. (2005). *Environmental Risk-Based Approached for Managing Municipal Wastewater Effluent* (MWWE) Final Report prepared for the Canadian Council of Ministers of the Environment. Retrieved March 22nd, 2008 from: http://www.ccme.ca/assets/pdf/mwwe_es_ermm_consrpt_e.pdf

Morse, David. (2001) Province of Nova Scotia, Minister of Environment and Labour – *News Release march 30th, 2001.* Retrieved February 25th, 2008 from: http://www.gov.ns.ca/news/details.asp?id=20010330002

Natural Resources Canada. (2004). *The Atlas of Canada – Sewage Treatment*. Retrieved November 10th, 2007 from: http://atlas.nrcan.gc.ca/site/english/maps/environment/ecology/threats/sewagetreatment

Natural Systems International (NSI). (2008) *Capital Costs Comparisons of Four Treatment Systems in 2006 Dollars*. Retrieved March 6th, 2008 from: http://www.natsys-inc.com/about/cost-comparisons/

Ouellet-Plamondon, Claudiane, Chazarenc, Florent, Comeau, Yves, and Brisson, Jacques. (2006). Artificial Aeration to increase pollutant removal efficiency in constructed wetlands in cold climates. *Ecological Engineering* 27.3: 258-264

Reed, Sherwood C. (1990). *Manual of Practice FD-16: Natural Systems for Wastewater Treatment.* Alexandria, VA. Water Pollution Control Federation.

Reed, Sherwood C. (1991). Constructed Wetlands for Wastewater Treatment. *Biocycle,* 32.1: 44-49.

Reed, Sherwood C., Middlebrooks, E. Joe., Crites, Ronald W. (1988). *Natural Systems for Waste Management and Treatment*. New York, NY. McGraw-Hill, Inc.

Rejmánková, Eliška. (2005) Nutrient resorption in wetland macrophystes: comparison across several regions of different nutrient status. *New Phytologist* 167: 471-482.

Rockne, Karl J., & Brezonik, Patrick L. (2006) Nutrient Removal in a Cold-Region Wastewater Stabilization Pond: Importance of Ammonia Volatilization. *ASCE Journal of Environmental Engineering:* 132.4: 451-459.

Rodrigues, Vanessa. (1997). *Constructed Wetlands as Tertiary Sewage Treatment and Wildlife Habitat in Nova Scotia*. Masters Thesis. Dalhousie University School for Resource and Environmental Studies, Halifax, NS.

Sierra Legal Defense Fund. (2004) *The National Sewage Report Card III: Grading Sewage Treatment of 22 Canadian Cities*. Retrieved November 15, 2005 from: http://www.ecojustice.ca/reports/sewage_report_card_III.pdf

Smith, Erin L. (2002). *Evaluation of Agricultural Constructed Wetlands in Cold Climates*. MSc Thesis. Nova Scotia Agricultural College and Dalhousie University, Truro and Halifax, NS.

Shireman, J. (1993). Constructed Wetlands Treat Batch Loads. *Water Environment and Technology* 5.12: 25-26.

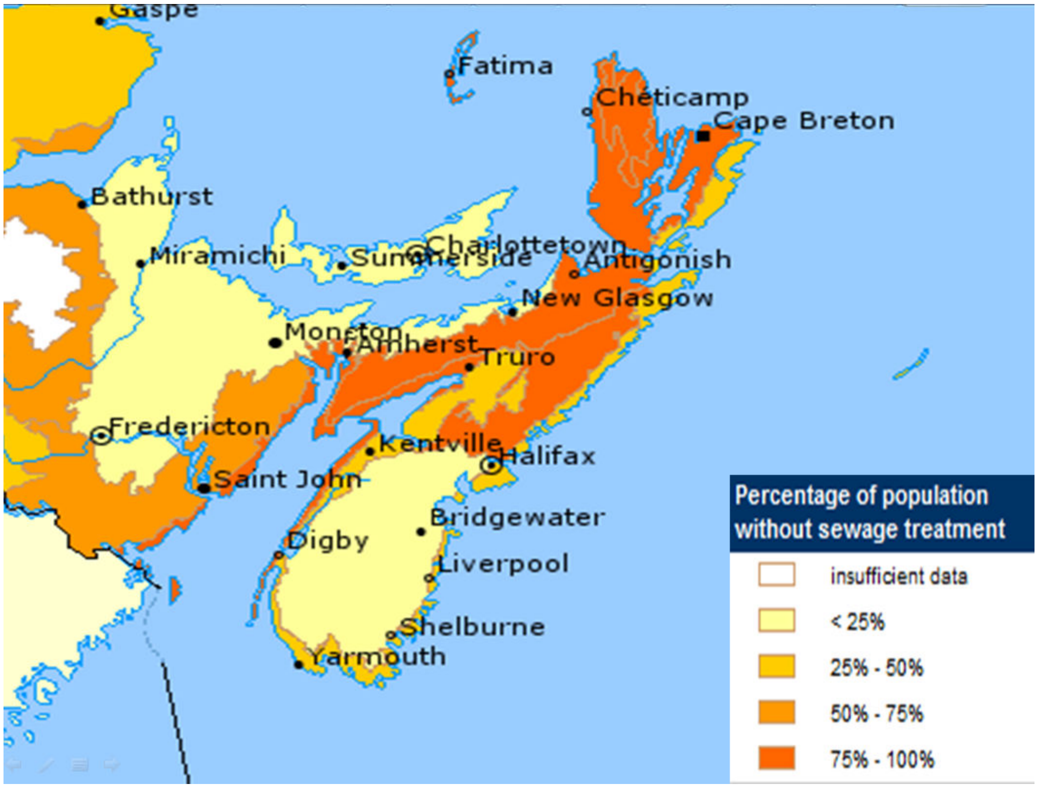
Tchobanoglous, George., Burton, Franklin L., and Stensel, David H. (2003). Metcalf and Eddy, Inc., *Wastewater Engineering: treatment and reuse*, McGraw-Hill, New York.

Tenenbaum, David J. (2004) Innovations: Constructed Wetlands – Borrowing a Concept from Nature. *Environmental Health Perspectives,* 112.1: A44-A48.

Weng, S. Putz, G., & Kells, J.A. (2006). Phosphorus Uptake by cattail plants in a laboratory-scale experiment related to constructed treatment wetlands. *Journal of Environmental Engineering and Science:* 5.4; 295-308.

Appendices

Appendix A – Municipal Wastewater Effluent treatment in Canada



Source: Natural Resources Canada, 2004

Figure A 1. Percentage of Nova Scotia's Population without Sewage Treatment

Table A 1. Municipal Wastewater Effluent limits in cities across Canada

Parameter	Canadian City					Nova Scotia model-use bylaw
	Halifax	Fredericton	Regina	Victoria	Whitehorse	
BOD (mg/L)	300	600	-	500	300	300
TSS (mg/L)	300	500	-	350	300	350
Ammonia (mg/L)	Inoffensive odor	Inoffensive odor	-	-	-	Inoffensive odor
TKN (mg/L)	100	-	-	-	-	-
TP (mg/L)	10	100	-	-	10	30
pH	5.5-9.5	6.0-10.5	5.5-9.0	5.5-11	5.5-10.5	5.5-9.5

Source: adapted from Marbek, 2006

Appendix B – Bible Hill Treatment Wetland Site

Figure B 1. Spatial arrangement of case study treatment wetlands #1 (right) and #2 (left) at the Bio-Environmental Engineering Facility of the Nova Scotia Agricultural College in Truro, Nova Scotia

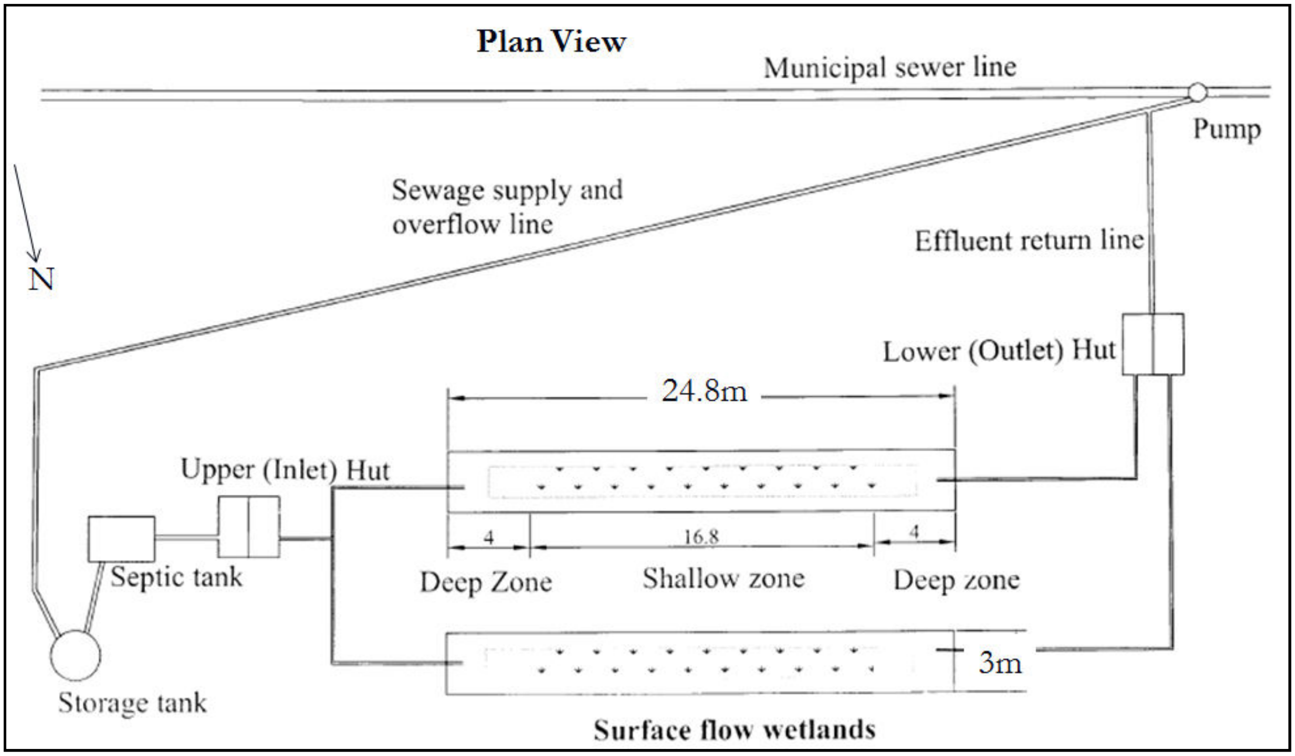


Figure B 2. Plan View of Bible Hill Domestic Wastewater Treatment Wetland system

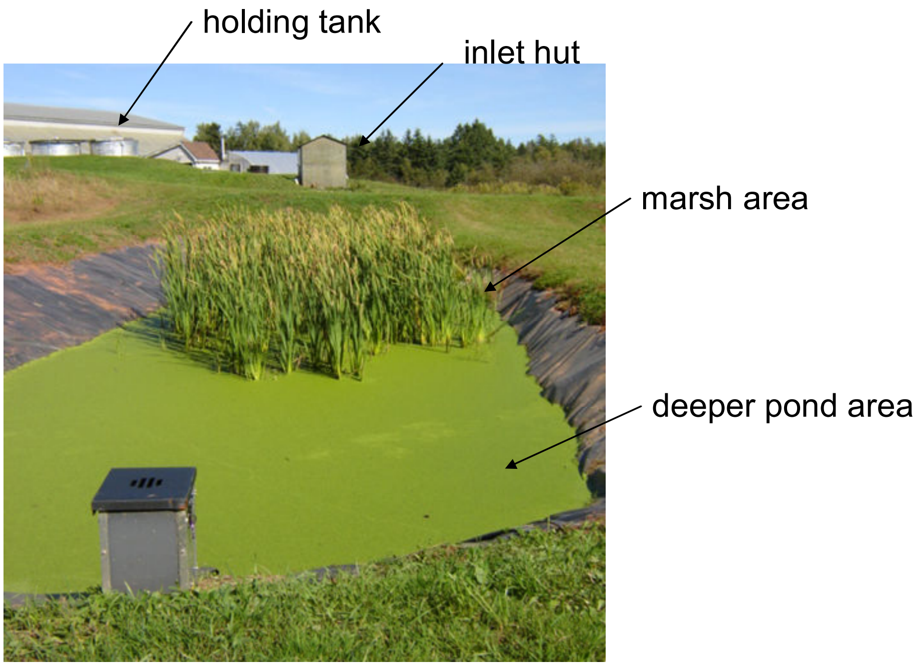


Figure B 3. Profile view of Wetland #1: visible are the holding tank, inlet hut, deep and shallow zones, Cattail (*Typha latifolia)* growth and Duckweed (*Lemna spp.)* cover.

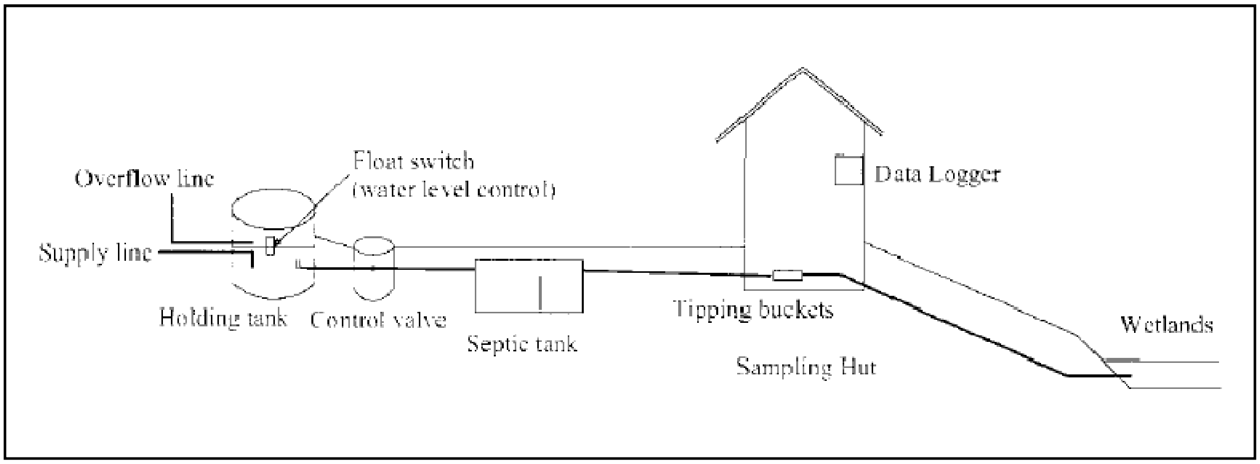


Figure B 4. Water Flow Pattern within the Bible Hill Domestic Wastewater Treatment Wetland system

Appendix C – Cost Estimates

Case Study Wetland Costs

Table C 1. Bible Hill Domestic Wastewater Treatment Wetland system Construction Costs

Component	Total Price
4"x4' Inline Water level control structure	$1,500
Liner - 45 mm	$6,500
Piping - 4"	$1,000
piping - 2"	$1,000
Miscellaneous: fittings, etc.	$1,500
Pump	$1,500
Electrical tech cable	$3,500
Excavation and gravel	$7,500
1- 1000 gallon septic tank	$1,500
Access port, valves, unions, filters	$2,000
Total Construction Costs	**$27,500**

System Costing Estimates

The price estimates for various types of conventional wastewater treatment systems are based on the Wastewater Treatment Costing Templates (Table B.2). These templates were created by CBCL Limited Consulting Engineers, and modified by the CCME. The template is contained within an Excel spreadsheet and is offered free on the CCME website. It is proposed as a tool for the comparison of various levels of treatment and their associated costs. Items that are common to all projects such as access roads, pumping stations, or biosolids disposal have been omitted, as have site specific considerations (CCME, 2006). A copy of the template is provided in Figure B1.

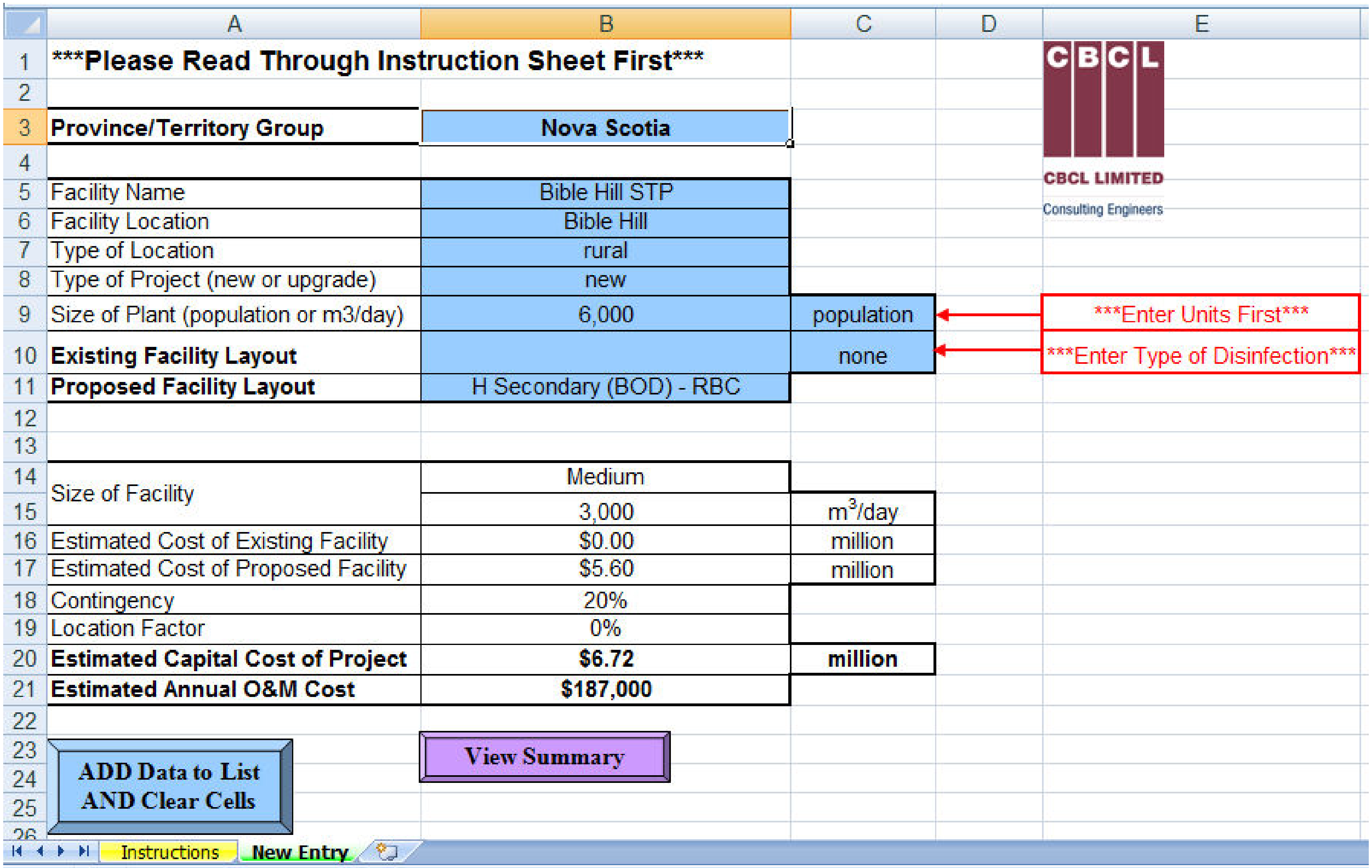
This template was used to estimate the costs for various treatment systems for the village of Bible Hill, Nova Scotia. The input parameters included the population estimate of 6,000, which corresponds to a total daily flow of 3,000m^3. It was identified as a rural location with a medium sized treatment facility. All models were run as if the facility was new, and no type of disinfection was requested. The Collection System Costing Templates were not used as these estimates would be the same for conventional and natural treatment systems.

Table C 2. Estimated costs for available process options

Process Option	Cost Estimate (millions)	Operation and Maintenance Estimate
Enhanced Primary	$6.04	$310,000
Secondary (BOD) Stabilization Ponds	$7.78	$102,000
2° (BOD) Lagoon	$12.82	$190,000
2° (BOD) Nitrifying Sequencing Batch Reactor	$6.84	$318,000
2° (BOD) Conventional Activated Sludge	$6.92	$286,000
2° (BOD) Rotating Biological Contactor	$6.72	$187,000
2° (BOD) Trickling Filter	$6.58	$203,000
2° (NH_3) Sequencing Batch Reactor	$6.92	$356,000
2° (NH_3) Conventional Activated Sludge	$6.99	$307,000
2° (NH_3) Rotating Biological Contactors	$7.25	$206,000
2° (NH_3) Trickling Filters	$7.68	$235,000
2° (NH_3) Recirculating Sand Filters	$1.45	$65,000
Tertiary (BOD & SS) Sequencing Batch Reactor	$7.92	$341,000
3° (BOD & SS) Conventional Activated Sludge	$8.00	$308,000
3° (BOD, SS, NH_3) Conventional Activated Sludge	$8.07	$330,000
3° (BNR*) Conventional Activated Sludge	$8.26	$395,000
3° (BOD, SS, BNR) Conventional Activated Sludge	$9.36	$418,000

* BNR = Biological Nutrient Removal

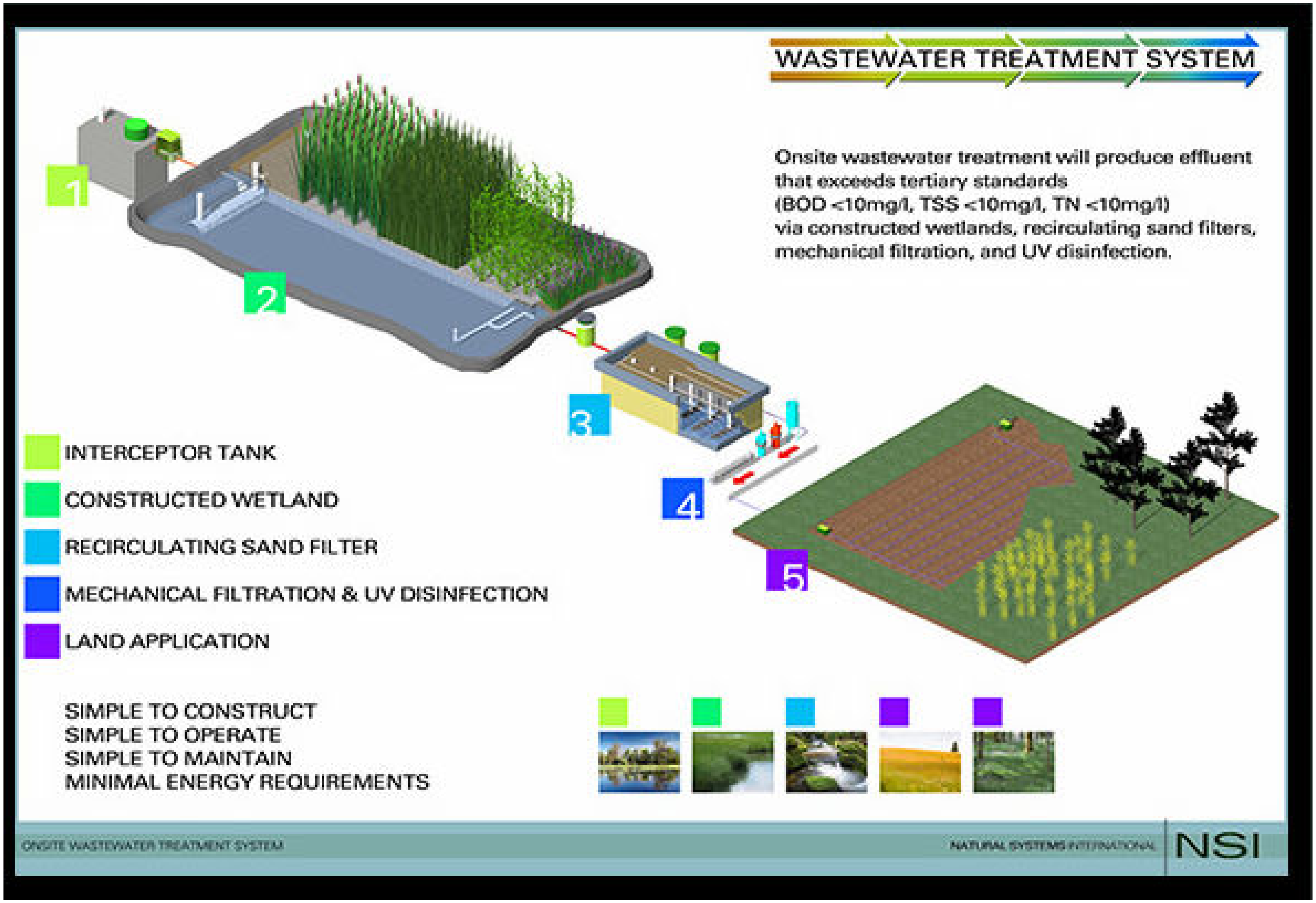
** a 20% Contingency fund is added to the total estimated capital costs



	A	B	C	D	E
1	*****Please Read Through Instruction Sheet First*****				
2					
3	**Province/Territory Group**	**Nova Scotia**			
4					
5	Facility Name	Bible Hill STP			
6	Facility Location	Bible Hill			
7	Type of Location	rural			
8	Type of Project (new or upgrade)	new			
9	Size of Plant (population or m3/day)	6,000	population		***Enter Units First***
10	**Existing Facility Layout**		none		***Enter Type of Disinfection***
11	**Proposed Facility Layout**	H Secondary (BOD) - RBC			
12					
13					
14	Size of Facility	Medium			
15		3,000	m^3/day		
16	Estimated Cost of Existing Facility	$0.00	million		
17	Estimated Cost of Proposed Facility	$5.60	million		
18	Contingency	20%			
19	Location Factor	0%			
20	**Estimated Capital Cost of Project**	**$6.72**	**million**		
21	**Estimated Annual O&M Cost**	**$187,000**			

Figure C 1. Template for Wastewater Treatment Costing (CCME, 2006)

Appendix D – Natural Treatment System Trains



Onsite wastewater treatment will produce effluent that exceeds tertiary standards (BOD <10mg/l, TSS <10mg/l, TN <10mg/l) via constructed wetlands, recirculating sand filters, mechanical filtration, and UV disinfection.

- INTERCEPTOR TANK
- CONSTRUCTED WETLAND
- RECIRCULATING SAND FILTER
- MECHANICAL FILTRATION & UV DISINFECTION
- LAND APPLICATION

SIMPLE TO CONSTRUCT
SIMPLE TO OPERATE
SIMPLE TO MAINTAIN
MINIMAL ENERGY REQUIREMENTS

Figure D 1. A municipal wastewater effluent Treatment Train as advertised by NSI (2008)

Appendix E – Raw Data

Table E 1. Total Phosphorus Raw Data

Sample Date	Wetland	Sample Location (m)	Trial #	Concentration (mg/L)	Sdev	median	mean
November	1	8	1	11.27	0.70	10.68	10.61
			2	9.88			
			3	10.68			
		16	1	10.86	1.48	10.86	10.65
			2	9.08			
			3	12.01			
	2	8	1	12.18	2.49	12.18	13.04
			2	11.09			
			3	15.85			
		16	1	7.17	0.15	6.96	7.00
			2	6.96			
			3	6.88			
December	1	8	1	10.93	3.04	7.52	7.77
			2	7.52			
			3	4.87			
		16	1	2.28	2.11	4.24	4.34
			2	6.49			
			3	4.24			
	2	8	1	2.09	0.15	2.23	2.23
			2	2.23			
			3	2.38			
		16	1	7.44	2.68	7.44	6.28
			2	8.18			
			3	3.22			
January	1	8	1	2.15	0.26	2.45	2.42
			2	2.45			
			3	2.66			
		16	1	3.82	0.56	4.17	4.30
			2	4.91			
			3	4.17			
	2	8	1	3.5	0.11	3.53	3.58
			2	3.71			
			3	3.53			
		16	1	4.12	0.06	4.12	4.15
			2	4.1			
			3	4.22			

Table E 2. Ammonia Nitrogen Concentrations

Sample location	**Sample Date**		
	Oct	Nov	Jan
inlet	9.22	17.6	25.4
WL1 Out	3.21	7.46	16.3
WL2 Out	2.52	6.9	20.8