Optimization of Wastewater Treatment in Canada: An Exploration of the Regulatory Environment.

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ABSTRACT
With one-fifth of Canada's water and wastewater pipes being over fifty years old, wastewater from municipal facilities remain the leading cause of pollution to surface water in Canada (Government of Canada 2021). The release of untreated and partially treated wastewater into the environment has negative implications on public and environmental health. Among the technologies employed in wastewater treatment are conventional treatment plants such as the activated sludge, trickling filters, and rotating biological contactors, which are common in many urban areas. In rural and remote areas, passive systems like sewage lagoons and constructed wetlands are more common due to the availability of land, and low operational and maintenance skills required. Irrespective of the technology used, all wastewater treatment facilities are mandated to comply with the Wastewater Sewage Effluent Regulations (*WSER*), introduced by Environment Canada in 2012. To better understand how wastewater treatment facilities can be optimized to always meet or exceed current regulations, this paper employs literature and document reviews to examine the current state of wastewater treatment across Canada. Specifically, this paper explores the national distribution and the monitoring requirements that guide how these facilities are operated and regulated. Finally, this paper explores how wastewater treatment facilities owned by the Department of National Defence could be better situated into the overall Canadian wastewater treatment context.

RÉSUMÉ
Avec un cinquième des conduites d'eau et d'eaux usées du Canada ayant plus de cinquante ans, les eaux usées des installations municipales demeurent la principale cause de pollution des eaux de surface au Canada (Gouvernement du Canada 2021). Le rejet d'eaux usées non traitées et partiellement traitées dans l'environnement a des implications négatives sur la santé publique et environnementale. Parmi les technologies utilisées dans le traitement des eaux usées figurent les stations d'épuration conventionnelles telles que les boues activées, les filtres bactériens et les contacteurs biologiques rotatifs, qui sont courants dans de nombreuses zones urbaines. Dans les zones rurales et éloignées, les systèmes passifs tels que les lagunes d'eaux usées et les zones humides artificielles sont plus courants en raison de la disponibilité des terres et des faibles compétences opérationnelles et de maintenance requises. Quelle que soit la technologie utilisée, toutes les installations de traitement des eaux usées sont tenues de se conformer au Règlement sur les effluents des eaux usées des eaux usées (RSEE), introduit par Environnement Canada en 2012. Pour mieux comprendre comment les installations de traitement des eaux usées peuvent être optimisées pour toujours respecter ou dépasser les réglementations en vigueur, cette Le document utilise des revues de littérature et de documents pour examiner l'état actuel du traitement des eaux usées au Canada. Plus précisément, ce document explore la distribution nationale et les exigences de surveillance qui guident la façon dont ces installations sont exploitées et réglementées. Enfin, cet article explore comment les installations de traitement des eaux usées appartenant au ministère de la Défense nationale et aux Forces armées canadiennes (MDN/FAC) pourraient être mieux situées dans le contexte global du traitement des eaux usées au Canada.

Keywords: Wastewater treatment, Effluent regulations, Optimization, Department of National Defence

1 INTRODUCTION

In Canada, effluents from sewage plants account for the largest contribution by volume, about 150 billion litres, to surface water pollution (Government of Canada 2017). These effluents are released from wastewater treatment plants (WWTPs) that vary from simple systems like sewage lagoons to more sophisticated mechanical plants. Sewage lagoons are natural or engineered ponds that rely on biological interactions between algae and bacteria to stabilize wastewater. There are several types of lagoon systems including facultative, partially mixed, and aerated. Facultative lagoons are 1.2 m to 1.5 m deep. They consist of an aerobic water layer overlying an anaerobic layer, which contains the settled sludge. Aerated lagoons are typically 2 m to 6 m deep and have a mechanical aeration system, such as surface aerators or diffusers with blowers, to supply oxygen. Aerated lagoons can be followed by a facultative lagoon in which the treatment of the suspended particulate matter is further facilitated; it eventually settles and anaerobically degrades (USEPA 2011). Sewage lagoons are preferred in rural and small communities due to the low operation and maintenance costs and ability to effectively remove pathogens, nutrients, biological oxygen demand (BOD) and other contaminants from wastewater, with negligible impact to receiving waterbodies (Glonya 1976, Shammas et al. 2009).

Sewage lagoons provide treatment to about 79% of the total population and when operated effectively, can achieve secondary treatment (Environment Canada 2010; Holeton et al. 2011). The production of variable effluent is common to sewage lagoons due to dependence of interactions on climatic and environmental. However, with proper operations and management, they are capable of producing effluent comparable to that from mechanical sewage plants. The provision of optimum conditions for the microorganisms, particularly, temperature, light and pH is the key to achieving effective treatment in sewage lagoons (USEPA 2011)

The purpose of this paper is two-fold. The first is to review the current state of wastewater treatment and management across Canada in terms of the existing regulatory framework, and the second is to situate DND/CAF sewage lagoons within the broader Canadian wastewater context.

1.1 State of Wastewater Treatment in Canada

Measuring the portion of wastewater that is treated before release into the environment provide an easy method to assess the level of treatment across a country (The Conference Board of Canada 2022). From 2013 to 2017, 86% of all Canadians had access to municipal wastewater treatment systems (Government of Canada 2020). Of the population not served by municipal systems, wastewater is achieved using septic systems or small-scale collective systems. The population density and physical geography sometimes serve as a barrier to such communities receiving municipal wastewater treatment (Government of Canada 2020). Generally, WWTPs located along the coast discharge untreated wastewater to the environment. To protect inland freshwater resources, their provinces usually treat wastewater to higher standards. For example, 70% of population in Alberta are served by WWTPs achieving tertiary treatment, whiles in Newfoundland and Labrador 33% of their wastewater is discharged into the environment untreated. Likewise, 35% of population in Nova Scotia are served by WWTPs that achieve only primary treatment; 50% primary treatment is achieved in Quebec, and 100% of WWTPs in Yukon achieve secondary treatment (Government of Canada 2020).

1.2 Wastewater Management and Regulation in Canada

Wastewater is jointly managed by all the levels of government in Canada, specifically the federal, provincial and territorial and municipal governments. These governments establish limits on contaminants and impose management on effluent treatment. In order to provide a harmonized approach to wastewater management. As well, the Council of Ministers of the Environment (CCME) developed a Canada-wide strategy for managing municipal wastewater effluents. With the two-fold aim of (a) protection of human and environmental health, and (b) provision of clarity on municipal wastewater management and regulation, the Strategy names wastewater governance, infrastructure requirements, facility performance and effluent quality and quantity, as necessary issues to be considered (CCME 2009).

The Strategy set the National Performance Standards, shown in Table 1, which are the minimum effluent quality required by all wastewater facilities across the country. The Strategy provides a timeline by which all wastewater facilities should comply based on a risk assessment. Based on the level of risk, it is expected that by 2040, all wastewater facilities would have achieved compliance with the National Performance Standards. To achieve the minimum standards, many WWTPs must upgrade their plants, which is estimated to cost about six billion dollars (James and Leffler 2013). Sewage plants could also optimize existing infrastructure or introduce processes that yield improved effluent without the need for new infrastructure, which comes with high financial implications (Holeton et al. 2011). Furthermore, jurisdictions are required through Environmental Risk Assessment, to establish Effluent Discharge Objectives, for locations where specific substances such as metals, nutrients, and pathogens may pose a threat to the receiving environments or human health (CCME 2014).

As a follow up to the Strategy and with a view to providing a one window approach to governance, in 2012, Environment Canada instituted the Wastewater Systems Effluent Regulations (*WSER*), under the Fisheries Act, as the legal instrument to regulate the release of deleterious substances into waterbodies. The law stipulates the minimum mandatory national standards for wastewater systems (shown in Table 1) with average daily influent volume of $100m^3$ or more; or systems whose effluents is discharged into waterbodies associated with fish life (Government of Canada 2015). Nunavut, northern parts of Quebec and the Northwest territories are currently exempt from the *WSER* due to the climatic conditions which makes achieving the minimum effluent standard difficult. Specifically, the *WSER* only establishes the barest minimum quality for four specific deleterious substances which are carbonaceous biochemical oxygen demanding matter (CBOD), suspended solids (SS), unionized ammonia, and total residual chlorine (TRC). A further inclusion is that the effluent should not have acute toxicity, which is determined by a 96-hour toxicity test for rainbow trout (Government of Canada 2012). The concentrations of the four deleterious substances stipulated in the *WSER* can be achieved through secondary treatment.

To reach the outcome of clarity about the governance and management of wastewater effluent, the Strategy advocated for the one – window approach to governance. The Effluent Regulatory Reporting Information System provides the one window information manager where all sewage facilities can submit their monitoring and other reports and requirements of the *WSER*. This harmonized one-widow platform saves the facility operators from duplication of reports to the different jurisdictions.

Table 1. Minimum *WSER* Effluent Standard (Government of Canada 2015)

Effluent Parameter	Regulated concentration
CBOD	25 mg/L
Suspended Solids	25 mg/L
Total Residual Chlorine (TRC)	0.02 mg/L
Un-ionized Ammonia (NH_3-N)	1.25 mg/L

In addition to the Strategy, jurisdictions have the power to impose stricter requirements for wastewater operators under them. As a result, there are variations in the effluent quality and practices in municipal wastewater treatment across the nation although it should be emphasized that the *WSER* supersedes all provincial, territorial and municipal regulations. The various provincial governments are responsible for the issuance of licences to WWTP owners which may include the siting, design, construction, monitoring and decommissioning guidelines for the facilities.

The provincial government of Saskatchewan released the Water and Sewage Works Regulations in 2015 under the Environmental Management and Protection Act, 2010, wherein many features of the *WSER* and CCME Strategy were adopted. Specifically, effluents from municipal plants in the province, the majority of which are sewage lagoons, must meet the National Performance Standards and *WSER* as well as a limit of 30 mg/L for total BOD (Canadian Water Network 2018, Government of Saskatchewan 2015).

In Manitoba, sewage plants including sewage lagoons are licensed by the Manitoba Conservation and Water Stewardship under the Environment Act. Another legislative instrument in that province is the Water Protection Act, which also has the Water Quality Standards, Objectives and Guidelines imposes stricter effluent requirements (Table 2) than the federal *WSER*. Furthermore, the province sometimes includes stricter limits for additional compounds to individual sewage facilities (CCME 2014)

Table 2. Effluent Regulations in Manitoba (Manitoba, 2017)

Effluent Parameter	Regulation
CBOD	25 mg/L
BOD	25 mg/L
Total Suspended Solids	25 mg/L
Un-ionized Ammonia (NH_3-N)	1.25 mg/L(site specific)
Total Phosphorus	1.00 mg/L
Total Nitrogen	15.00 mg/L
Chlorine	0.02 mg/L
Fecal coliforms	200 fecal coliforms/100ml
Best practical technology	

1.3 Monitoring Requirements of Wastewater Treatment Plants

Monitoring of WWTPs is done for two reasons. The first type of monitoring is for process control and assists the operators in assessing the performance and condition of their system. Table 3 shows some operations and maintenance monitoring activities at sewage lagoons. Such monitoring allows the detection of early signs of system failure. The second type of monitoring is stipulated in the operating license or certificate of approval issued by the regulatory government. The specific requirements of such compliance monitoring are based on factors such as the size of the plant, location of facility and sensitivity of receiving environment. For example, stricter monitoring may be required of WWTPs that discharge into fish spawning sites. Additionally, in the case of long detention sewage lagoons, monitoring for regulatory compliance may only be required immediately before and during effluent discharge. However, best management practices require that different aspects of WWTPs are monitored on daily, weekly, monthly, or quarterly basis. For example, daily monitoring of flow, temperature and pH are common with all types of treatment systems. The installation of automated systems such as the supervisory control and data acquisition (SCADA) make it easy for operators to monitor the performance of their systems and troubleshoot if the need arises (Armstrong 2019)

Table 3. Common Operations and Maintenance Activities at Sewage Lagoons

Operation Activities	Maintenance Activities
Control of wastewater levels	Berms and liner checks
Record keeping	Inlet and outlet structure checks
Removal of macrophytes from surface	Odour, weed and pest control
Wastewater quality monitoring (sampling and water colour checking)	Sludge management

1.4 Research Context

The Department of National Defence (DND), a federal government organization, is the owner of the largest land, over 20,000 square kilometers and infrastructure spread across all of Canada (Government of Canada 2019). Among its infrastructure are sewer lines, sewage lagoons, mechanical wastewater plants, drinking water systems, hangars and tank maintenance facilities whose use could produce waste that pose dire environmental consequences if released into the environment. As such, the DND mandates the highest environmental stewardship at its bases, wings and installments, scattered throughout Canada and abroad.

Although the Department is required to adhere only to federal government regulations, in its effort to be a responsible organization, DND goes above and beyond by complying to provincial and territorial regulations and guidelines. Furthermore, DND has also instituted Department-specific directives, policies and strategies, developed through sound science, all geared at prevention or abatement of environmental impact of previous and present activities.

The RMC Green Team, a research group within the Civil Engineering Department of the Royal Military College, has been involved in providing support to the DND/CAF through employing a research-based approach to sustainable infrastructure and environmental management. The research group, through sound science, offers expert advice and has developed relevant programs such as the Quality Management Program for Water & Wastewater Treatment Facilities for DND facilities and the Environmental Management Systems Program for DND/CAF facilities. Using a modification of the Composite Correction Program (CCP) developed by the USEPA (Skordaki et al. 2017; Skordaki and Vlachopoulos 2018; USEPA 1998), the RMC Green Team has successfully assisted most water /wastewater treatment plants and water distribution systems operated by DND/CAF to optimize their operations. The CCP Program consists of the Comprehensive Performance Evaluation and Comprehensive Technical Assistance components. This current paper highlights one of the current projects geared at assisting sewage lagoon systems optimize their operations. This has become necessary in the wake of more stringent regulations such as the *WSER* being in force. Additionally, the current mandate to "green" the federal government and reduce its carbon footprint requires that the DND/CAF facilities, including its sewage lagoons, are evaluated and assessed for both sustainability and compliant effluent quality.

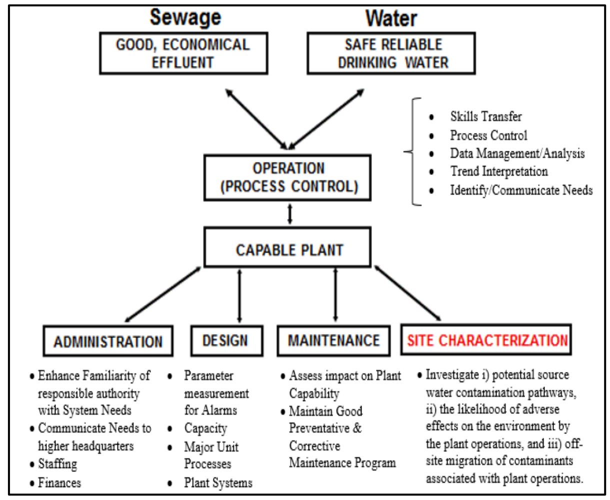

Figure 1. Diagram of components of a CCP Program (Skordaki and RMC Green Team 2017)

2 METHODOLOGY

The methodology for this paper consisted of a literature review, document review, and historical effluent data review. Documents reviewed included federal, provincial and DND/CAF regulations, standards and guidelines.

2.1 Study Area

Facility A and B[1] are sewage lagoons located in the Canadian prairies and experience cold temperate climate. Facility A (Figure 1), located in Saskatchewan serves a population of 250 but with seasonal increase to about 500 in the summer. Mean monthly temperatures range from -18°C in February to 19.4°C in July. The wastewater treatment system at Facility A consists of a series of two lagoon cells constructed in 1988 preceded by preliminary treatment in septic tanks. The first cell serves as the main treatment lagoon while the second serves as the storage cell. The lagoons are operated as a long detention lagoon with seasonal discharge in the spring into a small creek. The effluent in the cells is sampled and analyzed prior to discharge, while the effluents being discharged are sampled and analyzed daily during the discharge period lasting about two weeks. The age of the lagoons poses a threat to their integrity of producing consistent compliant effluents. Additionally, the lagoons are located within proximity to drinking water wells, thus any contamination from the lagoons may critically impact the drinking water source.

[1] Within the context of this paper, the facilities have been anonymized and referred to as Facility A and Facility B

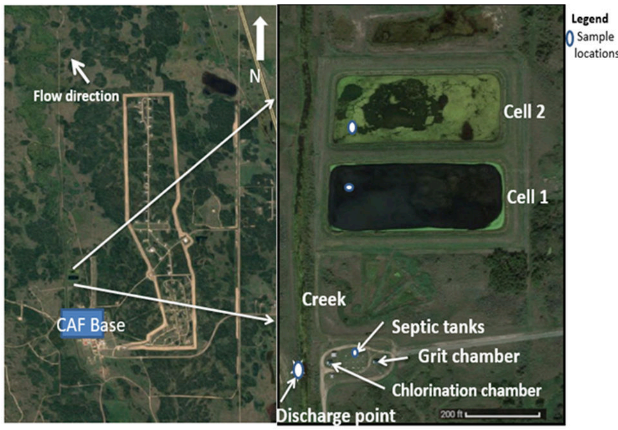

Figure 1. Map of Facility A showing sampling locations used in study

Facility B (Figure 2) consists of three sewage lagoon cells (one primary and two secondary) in sequence which were constructed in 1997. The lagoons are operated as long detention and discharged annually for about 4-14 days into a river. Facility B is located in Manitoba with a mean temperature ranging from -16.5°C in January and 19.2°C in July (Environment Canada 2022). The facility serves a base with population of 2400 people.

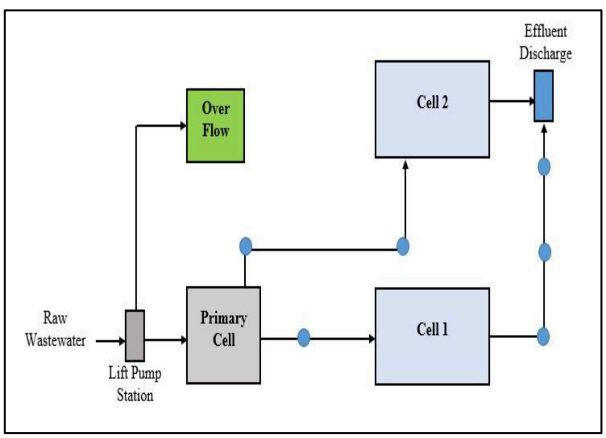

Figure 1. Schematic drawing of Facility B

2.2 Data Collection

Grab samples were taken daily from the effluent discharge pipe at Facility A during the 2019 and 2021 discharge periods respectively and sent to a commercial laboratory for the analytical results. For 2019, the effluent had been in the storage cell from the summer of 2018, while for 2021, the effluent had been in storage since the summer of 2019 because the facility missed the 2020 discharge season.

Grab samples were also taken from effluent discharge pipe of Facility B during the 2020 discharge season in the fall.

3 RESULTS AND DISCUSSION

3.1. Effluent Quality

As shown in Table 4, the pH of the effluent released from Facility A was between 8.79 and 9.62 in 2019 and 8.55 and 9.11 in 2021. The BOD in effluent were also well below the *WSER* requirement of 25mg/L. In 2019 the effluent BOD ranged from 2 to 5, and in 2021 it ranged from 4.9 to 12.3 mg/L. For the years studied, TSS and Ammonia were also below the stipulated minimum requirement of 25mg/L and 1.25mg/L for *WSER* respectively. In 2019 total phosphorus ranged from 0.48 to 0.72 mg/L. However, throughout the 2021 discharge period total effluent was above the provincial guidelines of 1.25mg/L in Saskatchewan for Facility A.

Table 4. Effluent Quality for Facility A

Parameter	2019 Range (average)	2021 Range (average)	Compliance Criteria
pH	8.79-9.62 (9.33)	8.55-9.11 (8.96)	6-9
BOD (mg/L)	2-5 (3.2)	4.9-12.3 (9.788)	30
TSS (mg/L)	5.1-18.8 (14.68)	20-81.1 (35.644)	30
Ammonia (mg/L)	0.069-0.368 (0.174)	0.0303-0.372 (0.0771)	1.24
Total P (mg/L)	0.48-0.72 (0.574)	1.41-12.3 (2.098)	-
Fecal coliform (MPN/100ml)	1-4 (2.8)	3-135 (21.5)	200

Table 5. Effluent Quality for Facility B

Parameter	2020 Average	Compliance Criteria
pH	8.82	6-9
BOD (mg/L)	2.1	25
TSS (mg/L)	6.9	25
Ammonia (mg/L)	0.028	1.25
Total P (mg/L)	0.87	1
Fecal coliform (CFU/100ml)	30	200

The effluent quality is within the typical value recorded in other studies. The 2019 average effluent quality was compliant to both the federal and provincial effluent standards in all but one parameter (ie pH) while effluent from 2021 was only compliant to four out of six parameters in the effluent standards. A comparison of the effluent quality of Facility A shows that 2019 produced a better effluent quality than 2021. These results seem to deviate from the literature and best practice which state that longer retention times produce effluent of higher quality. High TSS values in lagoons are attributed to algal blooms common in the summer and as the algae decompose, they also release nutrients like phosphorus back into the lagoons thus also affecting the total phosphorus concentration in effluents. At Facility A, the higher TSS and TP could also be from the effects of the Covid-19 pandemic on the whole facility. With the stay-at-home mandate in many parts of Canada, the lagoons may not have received the necessary operations and adequate maintenance practices that would have ensured the improved effluent quality for that year.

The effluent quality monitoring parameters measured at Facility B, shown in Table 5 were below the effluent standard for all parameters of the provincial and federal standards. This improved effluent quality could be because of the additional number of treatment units the wastewater goes through before being discharged

3.2 Wastewater Treatment and Sustainability

The requirement for consistently achieving compliant effluent in wastewater treatment cannot ignore the environmental impact of associated operations and management practices, as well as the need for sustainable practices. As DND actively seeks solutions to reduce its carbon footprint, one of the biggest challenges to sewage lagoons is their requirement for large areas of land. Further, one aspect that highly impacts the energy demand in lagoons are the frequency of discharge which can either be continuous, seasonal (i.e., discharge over weeks or months during specific times of the year) or annual (i.e., discharge over a limited time, once a year) (USEPA 2002). While this may not be feasible in many instances, there are several operations and management energy consuming activities which, if not controlled, can further contribute to high energy use at sewage lagoons. These include (a) pumping sewage from lift station to lagoons and between lagoon cells; (b) cutting of grass around the lagoon; (c) chemical use in phosphorus removal; (d) algae removal without resource recovery, and (e) the use of aerators in aerated lagoons. Improvements in lagoon operations would potentially increase plant capacity, improve effluent quality to meet more stringent permit requirements, reduce energy and chemical consumption and its associated costs, and reduce odour emissions (USEPA 2002).

4 SUMMARY AND CONCLUSION

From the literature reviewed and facilities studied in this paper, it is evident that effluent from wastewater treatment facilities, especially sewage lagoons, can meet regulatory requirements. This can be achieved if they are managed effectively in all of the components that constitute the CCP, i.e. administration, design, operation, maintenance, as well as the environmental impact (Skordaki and RMC Green Team 2017). From this study Facility B generally produced better effluent quality in comparison to Facility A. Facility B has more lagoon cells which could account for the improved treatment. However, Facility B also serves a larger population than Facility A suggesting that other operations and management factors could also contribute to the improved effluent quality.

The RMC Green Team has identified several best practices in their nation-wide quality management program in terms of guiding wastewater treatment facilities to optimize their routines in a sustainable way (Addai et al. 2019; Armstrong et al. 2019). These recommended practices include: adequate facility performance data record keeping, continual information-sharing between relevant stakeholders within a military installation and local authorities, ongoing operators' training and proper certification. The next phase of the study would thus investigate the how the experiences and activities of staff contribute to overall sewage lagoon performance.

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