

Characterization and Environmental Risk Assessment Associated with a Sewage Lagoon Managed by the Canadian Armed Forces

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ABSTRACT

The use of lagoons is one of the most cost-effective wastewater treatment (WWT) options for rural communities in Canada. This type of wastewater treatment is also used at several military bases of the Canadian Armed Forces. Lagoons are low-maintenance systems that use natural and energy-efficient processes. This paper presents an investigation of a two-stage facultative lagoon system at a military base in Central Canada, originally constructed in 1988. The methodology employed includes a source to effluent approach to examine the lagoon system with the intent of assessing the effectiveness of the treatment and the potential of contaminants influencing the source water and migrating off-site. In this regard, numerical modelling, a field study, and stakeholder consultations were conducted and are summarized in this paper. The proposed solutions outlined in this paper aims to improve the lagoon's treatment performance and reliability whilst producing an economical effluent of quality that meets or surpasses the regulatory framework.

RÉSUMÉ

L'utilisation de lagunes est parmi les méthodes les moins dispendieuses pour le traitement des eaux usées pour les communautés rurales au Canada. Ce type de traitement des eaux usées est aussi employé à plusieurs bases militaires des Forces armées canadiennes. Les lagunes utilisent des processus naturel, écoénergétique et ainsi nécessite peu d'entretien. Cet article présente une investigation d'un system de lagune à deux étang facultatif utilisé a une base militaire situé dans la région central du Canada, originalement construis en 1988. La méthodologie employer inclue une approche de source à effluent pour l'étude du system avec l'intention d'évaluer efficacité du traitement ainsi que le risque d'infiltration de contaminant dans l'eau de source et leur mobilisation or-site. À cet effet, de la modélisation numérique, une étude sur le terrain et des consultations avec les parties d'itérais a été réalisé et est résumé dans cet article. Les propositions souligné vise a amélioré la performance et la fiabilité de la lagune ainsi que produire un effluent économique surpassant les exigences réglementaire.

1 INTRODUCTION

The use of lagoons is one of the most simplistic and cost-effective wastewater treatment options for rural communities in Canada. According to (Statistics Canada and Infrastructure Canada 2016a), 49.7% (1244 facilities) of treatment facilities are lagoon systems. Lagoons are particularly favoured in the Prairie Provinces with Manitoba, Saskatchewan, and Alberta at 89.9% (179 facilities), 79% (124 facilities), and 81% (313 facilities) respectively. This type of wastewater treatment is also used at several military bases of the Canadian Armed Forces (CAF). As wastewater treatment (WWT) lagoons rely on providing optimal conditions for naturally occurring processes to stabilize the wastewater, they do not require the complex infrastructure and chemical additives of typical wastewater treatment plants. This simplicity results in low-energy and low-maintenance requirements for the treatment of wastewater. Despite their mechanical simplicity, there are complex chemical, biological, and physical processes taking place in lagoons that can be further burdened by site-specific factors including hydrogeological parameters and inflow volume.

The two (2) main forms of biological reactions taking place in WWT lagoons are aerobic stabilization and anaerobic fermentation and are produced via algae and bacterial activity. Aerobic stabilization occurs in the upper

layer of the facultative lagoons and throughout the water column in aerobic lagoons. Oxygen is introduced to the wastewater via algae photosynthesis and surface reaeration. In contrast, anaerobic fermentation occurs in zones where dissolved oxygen (DO) is absent from the wastewater. In this environment, bacterial acid creation and methane fermentation provide effective treatment (Federation of Canadian Municipalities and National Research Council 2004, USEPA 2011, Metcalf & Eddy 2013). Due to the higher reaction rate of aerobic stabilization and the objectionable odour emissions from anaerobic fermentation, facultative and aerobic lagoons are more frequently used for the treatment of municipal wastewater.

As the stabilization of wastewater within lagoons is conducted via biological processes, the rate and efficiency of the treatment will vary in accordance to three (3) main factors: light, temperature, and pH (Tilsworth and Smith 1984, USEPA 2011, Metcalf & Eddy 2013). These factors are further influenced by the total suspended solids (TSS) levels, loading rate (i.e. BOD₅ and CBOD₅), and wind action. A schematic representation of the wastewater stabilization within a WWT lagoon is presented in Figure 1. To assess the performance of a WWT lagoon, all the factors presented above need to be determined.

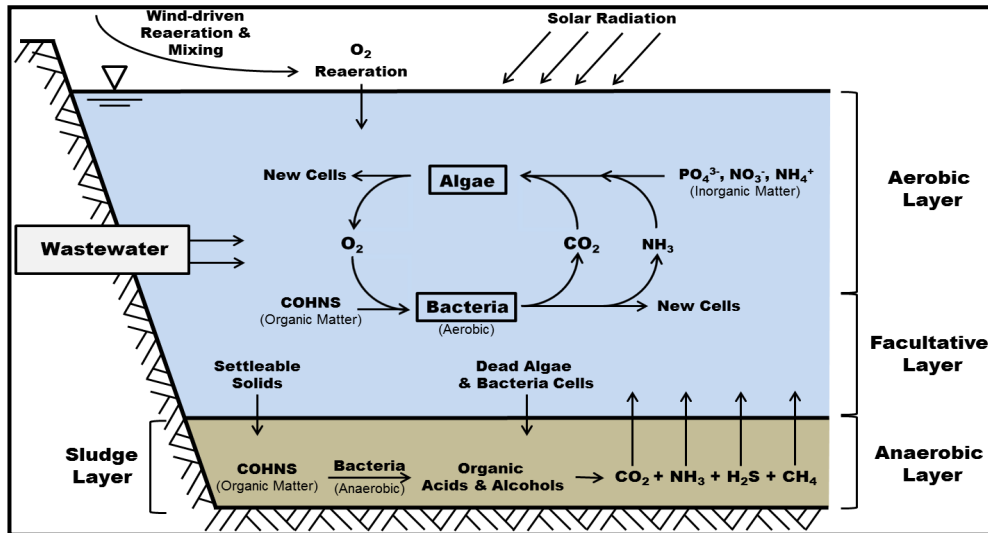


Figure 1. Schematic of the stabilization of wastewater in lagoon systems (Adapted from Tchobanoglous & Schoeder, 1985)

WWT lagoons located on CAF bases are under federal jurisdiction and thus must follow the effluent quality standards stipulated by the Government of Canada (2016). These regulations are intended for the protection of the receiving ecosystem and as such regulate the concentration of biochemical oxygen demand (BOD), carbonaceous biochemical oxygen demand (CBOD), total suspended solids (TSS), nutrients (such as ammonia and nitrate), and residual chlorine which are known to have deleterious effects.

2 OBJECTIVES

The aim of this research project is to quantify and assess the effectiveness of the treatment and operational performance of a particular WWT lagoon with a source to effluent approach with a view to applying these insights nation-wide. To achieve this aim, several objectives were determined and included: characterizing the WWT lagoon system, evaluating the effectiveness of the treatment, determining the environmental effect on the WWT lagoon's surroundings, and assessing the risk of continued lagoon operations to the base's drinking water supply. This paper focuses on the methodology employed for the characterization and assessment of a WWT lagoon and presents selected results and recommendations.

The methodology was developed to address both the WWT lagoon system's treatment performance as well as its ability to effectively contain the wastewater. This methodology was determined based on the possible failure mechanisms of a WWT lagoon system. These failure mechanisms can be divided into two (2) main categories: containment failure and treatment failure.

2.1 Failure to Contain the Wastewater

Containment failure is defined as the involuntary discharge of wastewater in sufficiently large quantities to have deleterious effects on the surrounding environment.

As the majority of the treatment is undertaken in two (2) cut-and-fill reservoirs, the primary focus is placed on the support structure (i.e. berms) and the lining system of the lagoons. The berms and the lining system are the two (2) principal elements that compose the structural health of the WWT lagoon. In addition, containment failure may be caused by human actions (operation problems) such as excessive hydraulic loading, improper maintenance cleaning, or even vandalism. This failure mechanism was obtained from the USEPA's municipal wastewater stabilization pond design manual (USEPA 1983).

2.2 Failure to Provide Sufficient Treatment

Treatment failure is defined by the voluntary release of water that has not met the regulatory quality standards. Additionally, treatment failure can occur if objectionable odours are impacting the neighbours of a lagoon facilities. The treatment failure mechanisms that were considered in this monitoring programme are listed in Table 1. The WWT lagoon's emissions were not compared with the Canadian Ambient Air Quality Standards as part of this particular portion of the research project.

Table 1. Principal behaviour leading to treatment failure of WWT lagoons (Tilsworth and Smith 1984, USEPA 2011, Metcalf & Eddy 2013, Barlet 2017)

Treatment Problems	Odour & Emissions Problems
Insufficient in cell light	Overloading of cells
Insufficient DO	Excessive accumulation of surface scum
Water temperature too low	
Excessive nutrient concentration	Uncontrolled aquatic and embankment vegetation
Excessive SS concentration	

2.3 Scope Limitation

The investigation of the WWT lagoon excluded an assessment of the infrastructural appurtenances (e.g. septic tank access housing, pump house, and chlorination chamber housing). In addition, the state of the electrical and mechanical equipment was also not included in the investigation.

3 METHODOLOGY

In order to conduct this research study, a methodology, which emulates the procedure of a typical field investigation, was developed. The steps of this procedure can be seen in Figure 2

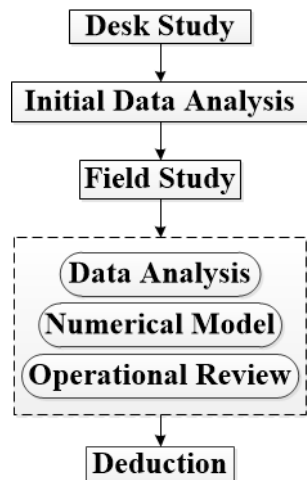


Figure 2. Research procedure

The first step in the research project was to conduct a desk study in order to collect and analyse all available information regarding the base and its WWT lagoon from previous projects and to establish connections with the owners and operators. The majority of the information utilized during this project was collected during a two (2) day preliminary site visit which was conducted on 15–16 Feb 2018. The successful completion of the desk study directed the remainder of the research project.

The second step in the research that was undertaken was to conduct an initial analysis on all the available data; both publicly available and data obtained during multiple site visits. This step provided an understanding of what data was produced from past studies and what data is regularly being monitored and recorded by the WWT operators. This initial data analysis along with the desk study further refined the objectives of this research project, based on the site conditions, data availability, and limitations imposed on the project.

A field study was developed and executed to compliment ongoing, related activities as well as available data, in order to accomplish the aim and objectives of this research project. The field study also provided a detailed understanding of the site condition and the operational environment at the WWT lagoon's infrastructure. The field study consisted of a series of site visits spaced out

throughout the active portions of the 2018–2019 treatment period. Three (3) visits were conducted during: 13–16 Aug 2018, 09–12 Oct 2018, and 16–19 Apr 2019. Three (3) tasks were undertaken during the field visits which included: conducting an assessment of the WWT lagoon system's operations, conducting an assessment of the infrastructure's condition, and conducting a water and wastewater sampling programme.

With the information and data collected during the field study, a series of follow-on tasks were also conducted simultaneously. The primary tasks consisted of data analysis, development of a numerical model, and performing an operational review. With the completion of these tasks, deductions and recommendations regarding the design, operation, and maintenance of the WWT lagoon system could be made.

4 SITE DESCRIPTION

The site of interest is located in central Canada and more specifically, within the Canadian Prairies. The daily average temperature for the warm months (June to August) is below 20°C and cold months (November to March) are below the freezing point (0°C). On average, the site receives an annual rainfall of 263.8 mm and snowfall of 76.6 mm. The yearly cumulative hours of sunshine are approximately 2268 hr in accordance to the historical climate data available online through the Government of Canada (Government of Canada, 2018). The meteorological data for the site was estimated based on the closest weather station for which historical climate data was available through the Government of Canada (Government of Canada, 2018). This weather station is located approximately 40 km north of the site of the WWT lagoon.

The WWT lagoon (Figure 3) is located approximately 900 m away from the closest production well that supplies the base's drinking water. The soil at the base consists of silty sand with an average hydraulic conductivity ranging from $5e^{-5}$ to $3.9e^{-4}$ cm/s. The groundwater at the site is considered to be under the direct influence of surface water and is located 6.5 m to 9.5 m below grade. The proximity of the WWT lagoon to the production wells along with the surface water's influence on the groundwater leaves the base's drinking water source vulnerable to possible leaks or breaches of the WWT lagoon system.

The only major surface water body in the vicinity of the WWT lagoon is a creek which serves as the effluent's receiving ecosystem. This creek was realigned and straightened in 1941 and is 30–50 m away from the Western border of the WWT lagoon. The flow rate of the creek was estimated to vary between 0 m³/s and 1.1 m³/s base on Water Survey of Canada (2019)'s online historical databank. The effluent travels approximately 71 km along the creek before reaching the northern boundary of the base and entering provincial jurisdiction.

A series of nine (9) monitoring wells (MW)s surrounds the WWT lagoon and were installed prior to 2002 as part of the base's groundwater monitoring programme as seen in Figure 3.



Figure 3. Site layout. The nomenclature SL# is used to identify the monitoring wells located near the WWT lagoon (Imagery Microsoft Corporation 2018).

4.1 Infrastructure Description

The WWT lagoon is managed by the Real Property Operations (RP Ops) detachment of the base. The RP Ops section is responsible for the management of all buildings and utilities located on the base. The WWT lagoon is normally operated by three (3) operators, which include one (1) supervisor, and two (2) apprentice operators. For a period of approximately six (6) months, the WWT lagoon was operated by only the two (2) apprentices due to a turnover. The same operators are also responsible for the operation of the base's water treatment plant and conducting the daily water quality control sampling across the base.

The WWT lagoon was originally constructed in 1988 and currently serves a population of 150–230 people with a seasonal surge of 450 people. A record surge of 1500 people was reported in the past. These surges are due to increase in military training exercises that take place in the mid-summer to autumn period. These surges result in significant increase in loading rates to the WWT lagoon. This significant variation in loading rate is unlike all WWT lagoon system of typical municipalities of similar sizes.

The WWT lagoon system consists of two (2) facultative cells, 1.5 m and 2.1 m deep for Cell #1 and Cell #2 respectively. Each cell holds approximately 22,000 m³ of wastewater (Table 2). The wastewater is contained in the cells using a high-density polyethylene (HDPE) liner superimposed with 600 mm of compacted

imported clay till on the berms and 150 mm of native sand in the beds. The HDPE liner is anchored at the top of the berms using the trench cut and backfill method. The HDPE liner has not been replaced and is now over 30 years old.

Table 2. Basic properties of the WWT lagoon's cells (all values correspond to the maximum operating water quantity based on the original construction drawing).

Cell #	Water Column (m)	Cell Surface Area (m ²)	Cell Volume (m ³)
1	1.5	21,896.20	30,212.69
2	2.1	22,120.85	41,059.12

The influent is pre-treated in a 45 m³ grit chamber and five (5) two (2) celled septic tanks operating in parallel in order to settle out large solids prior to entering cell #1. Discharge is controlled and occurs once annually (mid to late May) for a period of approximately 8–15 days. Prior to its discharge (discharge point indicated on Figure 3), the effluent flows through a chlorination chamber. However, chlorination has been discontinued several years ago. The grit chamber, septic tanks, and chlorination chamber were part of the base's original wastewater treatment system built in 1941.

5 SAMPLING PROGRAMME

Whilst the current monitoring practice meets the requirements as dictated by the Wastewater Systems Effluent Regulations (Government of Canada, 2016), the data collected is insufficient to thoroughly assess the mechanism that controls the treatment of the wastewater. In addition, in its current form, the monitoring programme does not monitor the condition of the infrastructure with the noted exception of the annual testing of the groundwater. As the current approach is reactive in nature, remedial actions are only taken once an issue has been identified. This results in a situation that can place additional risk on the local environment and the base's source water.

In order to assess the performance of the base's WWT lagoon system and determine if there is a concern of possible leaks or any other concern, a sampling programme was developed and realized. Groundwater, surface water, and wastewater grab samples were obtained and tested for the parameters listed in Table 3. The sampling programme was based on best practices and federal regulations. These parameters were selected as they address the two (2) possible failure mechanisms of concern in this research study.

18 locations of interest were identified and selected for sampling. The locations, as seen in Figure 4, included: the nine (9) monitoring wells, the creek at approximately 200 m upstream from the discharge point and approximately 300 m downstream from the northern berm of Cell #2 along with three (3) points in stagnant water bodies located immediately north of the WWT lagoon system. These 14 locations were sampled to obtain

background groundwater quality and to look for signs of possible leaks from any part of the WWT lagoon systems.

Table 3. Selected parameters of interest for this investigation

Sampling Parameters	
pH	Conductivity
Temperature	Dissolved Oxygen (DO)
Total Suspended Solids (TSS)	Total Dissolved Solids (TDS)
5-Day Biochemical Oxygen Demand (BOD ₅)	5-Day Carbonaceous Biochemical Oxygen Demand (CBOD ₅)
Thermotolerant Coliforms	Total Coliforms
E. Coli.	Groundwater Elevation

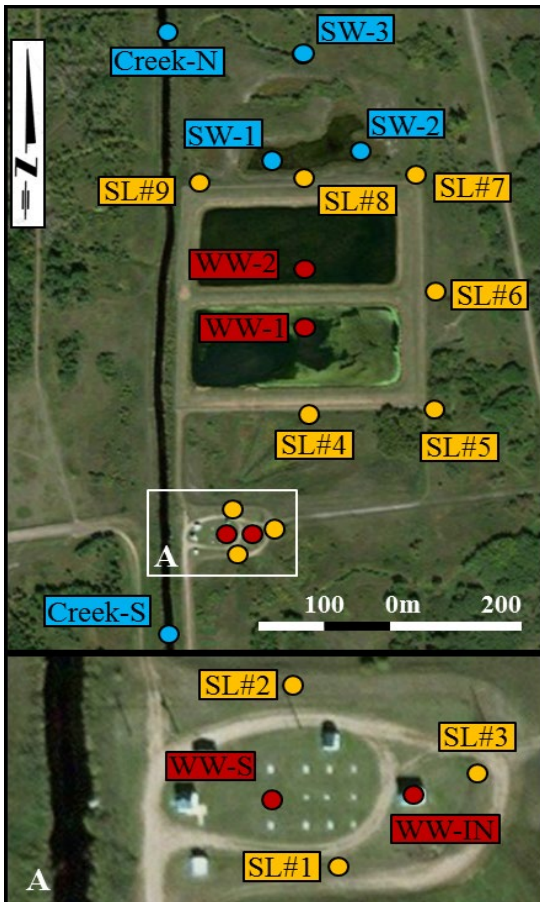


Figure 4. Approximate sampling locations (Imagery provided by Microsoft Corporation 2018)

The four (4) remaining sampling locations consisted of sites within the main treatment steps (i.e. the grit chamber, septic tanks, and both lagoon cells). These locations were selected to ascertain the spatial and temporal variation in the treatment of the wastewater and to assess the overall treatment performance.

All samples were sent to local certified laboratory for analysis using established testing methods as identified in APHA's Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WEF, 2012).

6 DATA ANALYSIS

An analysis of the various data sets collected was conducted to characterize the site, assess the performance of the WWT lagoon system and to determine possible environmental concerns. The data analysis focused on the components listed in Table 4.

Table 4. Major components of the data analysis

Data Analysis	
Weather	Influent volumes and quality
Effluent volumes and quality	Wastewater quality (system-wide)
Surface water quality	Groundwater elevations and quality

Daily effluent discharges from 2015 through 2018 were compared to both the federal and provincial regulations. Three (3) parameters were investigated which included 5-day biochemical oxygen demand, total suspended solids, and ammonia. These parameters were investigated for a period of four (4) years from 2015 to 2018. As seen in Table 5, the overall quality of the 2018 effluent discharge was inferior to the average. This is to be expected as this treatment period received 53% more influent than the average treatment period. The increase is due to an influx of personnel at this base during the 2017-2018 treatment period. Such an influx is unique to military facilities and its effects are more acute on small bases such as this one.

7 HYDROGEOLOGICAL NUMERICAL MODEL

The hydrogeological condition of the base renders it vulnerable to potential sources of contamination. Lack of a formalized wellhead protection programme would further increase this risk. As such, a numerical model was developed in an attempt to determine the groundwater flows and to investigate; how the base's production wells and the WWT lagoon system interacts with the groundwater. i.e. source water vulnerability assessment. In addition, the model attempted to determine the conditions required for the groundwater located at the WWT lagoon to migrate to the productions wells.

MODFLOW 2005 was selected as the numerical tool for this model. MODPATH v7 was also utilized as a particle-tracking post-processing program. Both open-source software was produced by the USGS and operate seamlessly together (Harbaugh 2005, Pollock 2017). With those numerical tools, a steady-state finite difference model was developed to reflect the site conditions of September 2015. The model was restricted to a steady-state analysis regarding water elevations and flow rates in the creek. This creek plays a significant role in the hydrogeology of the site of interest.

Table 5. Discharge effluent quality for 2015, 2016, 2017, and 2018. ("A" indicates absent data)

Discharge Day	5-Day Biochemical Oxygen Demand				Total Suspended Solids				Ammonia (NH ₃)			
	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018
1	4	4	3	20	9.0	5.0	4.3	13.30	0.14	0.12	0.08	1.22
2	3	3	2	9	8.0	5.0	21.4	6.00	0.10	0.09	0.10	A
3	3	3	4	27	6.0	A	15.9	7.60	0.09	0.06	0.09	A
4	3	4	8	10	6.0	5.0	10.2	16.90	0.08	0.16	0.10	A
5	3	5	8	10	8.0	5.0	8.9	10.90	0.13	0.14	0.12	A
6	4	3	-	A	A	5.0	-	18.10	0.12	0.10	-	A
7	8	4	-	16	23.0	5.0	-	A	0.36	0.11	-	A
8	8	5	-	22	16.0	A	-	11.20	1.10	0.18	-	A
9	-	12	-	-	-	A	-	-	-	0.78	-	-
10	-	12	-	-	-	A	-	-	-	A	-	-

The model was developed with a 45 x 62.5 m mesh covering an area of 31 km³ centred on the base's three (3) production wells. The model space was divided into two (2) layers based on ground geology and attributed known hydraulic conductivity values. Groundwater recharge was estimated based on available watershed data. Evapotranspiration and precipitation were omitted in this model. The majority of the constant head boundary conditions were established using several groundwater elevations from the 67 monitoring wells located on the base. These wells are regularly sampled twice a year as part of the base's groundwater monitoring programme.

Several of these groundwater monitoring wells were also used for the calibration and validation of the model's results. Calibration was conducted using hydraulic conductivity values of both layers in all direction (i.e. x, y, z) and groundwater recharge.

7.1 Model Results

The model was calibrated by verifying that the model's results met a series of established conditions. These conditions included: all values for the calibration variable needed to fall within a range of realistic values based on literature, the model could not result in the flooding or drying of any cell, and production well needed to be able to draw water. Lastly, the model needed to provide the lowest sum of squared residuals when comparing the computed results to the calibration targets.

The calibrated model resulted in residual errors for all targets between 0.002 m to 0.270 m from their respective observed values. Exemptions existed for three (3) targets which had residual errors ranging from 0.453 m to 1.046 m. The spatial distribution of the residuals indicated that these three (3) targets were located near boundary conditions with suspicious or estimated values. In addition to the residual error analysis, head profiles across the model space was also analysed along with the model's mass balance.

Despite the residual errors obtained, the model in its current state was deemed acceptable for the objective of this research project. As the objectives of the model was to identify the general provenance of the detachment's source water and ascertain its risk of contamination from the WWT lagoon system for this purpose, general trends based on a sound understanding of the site conditions was what all that was required.

7.2 Particle Tracking

Once the model's groundwater flow was validated, two (2) particle tracking analyses were conducted. The first particle tracking analysis was done to identify the provenance of the detachment's water supply. This was completed by reverse tracking of particles that were positioned around all three (3) production wells. The second particle tracking analysis was done to trace the path of the groundwater originating from the site of the WWT lagoon system. This analysis was carried out in order to identify the path that a theoretical contamination plume would follow if released from the WWT lagoon system. This was accomplished by conducting forward tracking of particles around the both lagoon cells along with the septic tanks and grit chambers.

Based on the two (2) particle tracking analysis, the conditions of September 2015 are such that the base's source water is not likely to be contaminated from the WWT lagoon system. The first particle analysis (as seen in Figure 5) indicated that the base's water was sourced from areas west of the production wells and away from the WWT lagoon system and the administrative area. The second analysis (not shown) indicated that the creek is acting as an effective barrier that would capture any possible contamination leaks from the WWT lagoon system from migrating west of the creek and into the well field.

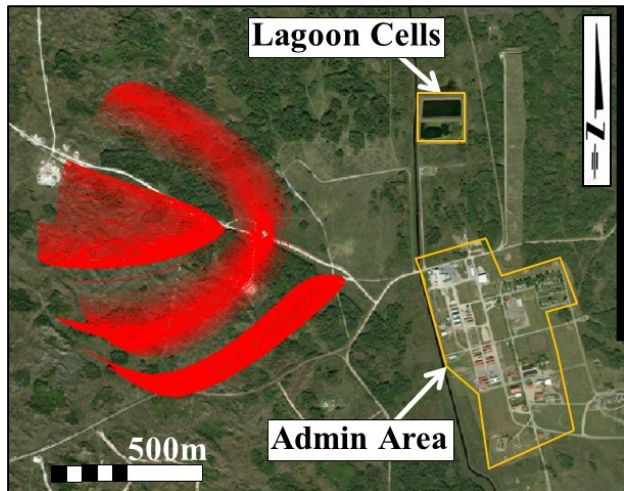


Figure 5. Particle tracking of the base's production wells (Imagery provided by Microsoft Corporation 2018)

8 OPERATIONS REVIEW AND RECOMMENDATIONS

A review of both the WWT lagoon's infrastructure and the operational procedures followed by the RP Ops and operators was conducted. Several recommendations were proposed to facilitate the management of the facility, facilitate troubleshooting practices, improve future performance, improve the base's environmental and real-property stewardship, and to minimize the operator's workload.

8.1 Operational Practices

The majority of the information regarding the operation of the WWT lagoon system was gathered using a series of semi-structured interviews. The initial interviewing process was carried out using a questionnaire developed by the RMC Green Team for assessing WWT lagoon systems. All aspects of the operation of the WWT lagoon was assessed including: flow control, vegetation & animal control, desludging & other maintenance practises, sampling practices, along with data collection, management, and record keeping.

The interview process revealed that official standard operating procedures (SOPs) regarding the operation of the WWT lagoon system were required in order to capture the activities that were being conducted. This study provided a list of items that should be included in the SOPs along with guidelines for their development that is tailored for this facility.

Based on the flow control practises and the infrastructure, this study determined that, despite the facility employing control discharge, short circuiting of Cell #1 is expected to occur during the annual equalization of the wastewater between Cell #1 and Cell #2 post-discharge. A tracer study was recommended to ascertain the effects of the short circuiting and assess the possibility of installing a baffling system to reduce or

eliminate short circuiting in order to improved overall effluent quality.

As the current facility received little to no modifications since its upgrade to the current system in 1988, it relies heavily on manual operations for both flow control and data collection. The only automation currently present on site is the pump controls located in the lift station. This WWT lagoon system would benefit from the installation of Supervisory Control and Data Acquisition (SCADA) system to improve data collection and management whilst reducing the daily burthen imposed on the operators. This study detailed all aspects of the facility management which would benefit from a SCADA system and provided guidelines for the requirements of such a system.

8.2 Infrastructure Assessment

The condition of the infrastructure at the base's WWT lagoon system was assessed by conducting a visual inspection of the infrastructure along with conducting a Light Detection and Ranging (LiDAR) survey.

The inspection revealed that, despite the facility approaching the end of its expected service life as defined by Statistics Canada and Infrastructure Canada (2016b), the facility is exhibiting only minor visible issues. Such issues included damage to the northern berm due to muskrat intrusions. As the WWT lagoon system was in operation at the time of the investigation, the condition of the HDPE liner along with the condition of the pipes and the various chambers could not be assessed. A detailed assessment of these items was recommended to be completed in the near future.

A LiDAR survey of the entire WWT lagoon system including the site of the derelict sludge drying beds was conducted on the 24–26 Oct 2018. The scans of the LiDAR survey were obtained from a tripod-mounted laser scanner. In total, 23 separate 360° scans were required to adequately cover all the area of interest and minimize shadows. The scans were set with a resolution of either 1.66 m or 3.10 mm at 10 m. An example of the resulting point cloud from the survey can be seen in Figure 6.

9 CONTRIBUTION OF THE STUDY

The study, from which the methodology is presented in this paper, provided several tangible contributions to the base. These contributions include:

- Creating a sampling and analysis database tailored for the base's WWT lagoon facility;
- Evaluation of the current sampling protocols and SOP and provision;
- Recommendations on sampling locations, sampling procedures, and testing parameters that are based on guidelines and the legal framework;
- An environmental site characterization of the WWT lagoon system and the surrounding environment;

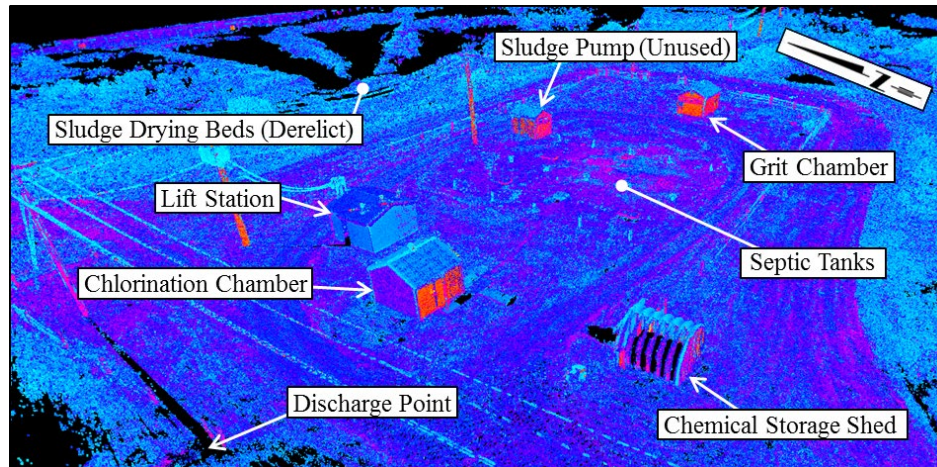


Figure 6. LiDAR point cloud of septic tank site (Oct 2018)

- An assessment of the potential risk to the base's source water and the environment associate with the continued operation of the lagoon facility;
- An evaluation and assessment of the physical condition and functionality of the lagoon system and its design; and,
- Recommendation on the design, operation, and maintenance practises.

10 ACKNOWLEDGEMENTS

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