

Optimization of sewage lagoon systems operations: An investigation into the removal of metals from wastewater

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ABSTRACT

This study examines sewage lagoons and their operations in remote locations, including facilities located within military bases where the metal levels are required to be monitored in order to ensure due diligence. The scope of this paper is: (1) to summarize the current performance of a particular Canadian Armed Forces (CAF) sewage lagoon system located in the Canadian Prairies with regards to the removal of metals such as mercury, arsenic, copper, lead, zinc and cadmium from the effluent, and, (2) to present our preliminary results regarding the factors that may influence the effective removal of metals under various environmental conditions. The research adopts a laboratory comparative batch study in order to investigate the behaviour of the metals of interest within synthetic wastewater under varying pH conditions and temperatures, with a view to simulating average summer and winter conditions. Mass spectrometry will be used in the quantitative data collection and analysis, while observations and interviews will be employed for qualitative data collection and analysis. The overall expected outcome is to add value in terms of good operation and management practices of sewage lagoons, particularly regarding effluent quality and metal levels.

RÉSUMÉ

Cette étude examine les lagunes des eaux usées et leurs opérations dans des endroits éloignés, y compris les installations situées dans des bases militaires où les niveaux de métal doivent être surveillés afin d'assurer la diligence raisonnable. Le présent document a pour objet: (1) de résumer la performance actuelle d'un système de lagunage des eaux usées des forces armées canadiennes (CAF) situé dans les Prairies canadiennes en ce qui concerne l'enlèvement des métaux tels que le mercure, l'arsenic, le cuivre, le plomb, le zinc et le cadmium des l'effluent, et (2) de présenter nos résultats préliminaires concernant les facteurs qui peuvent influencer l'enlèvement efficace des métaux dans diverses conditions environnementales. La recherche adopte une étude comparative en laboratoire pour étudier le comportement des métaux d'intérêt dans les eaux usées synthétiques dans des conditions de pH et de températures variables, en vue de simuler des conditions d'été et d'hiver moyennes. La spectrométrie de masse sera utilisée dans la collecte et l'analyse quantitatives des données, tandis que des observations et des entrevues seront employées pour la collecte et l'analyse qualitatives des données. Le résultat escompté global est d'ajouter de la valeur en termes de bonnes pratiques d'exploitation et de gestion des lagunes des eaux usées, en particulier en ce qui concerne la qualité des effluents et les niveaux de métal.

1 INTRODUCTION

Passive wastewater treatment systems such as sewage lagoon systems, or wastewater stabilization ponds (WSPs), have been one of the earliest forms of treatment technologies used in the treatment of wastewater. WSPs, as shown in Figure 1, are a combination of one or more open ponds that rely on natural processes to treat domestic, industrial, agricultural or a mixture of wastewater (Glonya 1976, Huang 2017). The ponds may be natural or engineered as well as fully or partially lined. They are more common in rural and remote communities due to the availability of land and ease in operation (Glonya and World Health Organization [WHO] 1971, USEPA 2011). Although they are effective in removing wastewater contaminants, the extent of treatment is reliant on complex biological, chemical and physical natural interactions between the resident algae and bacteria which is largely influenced by local climatic conditions (Huang 2017, Paterson and Curtis 2005, Ragush 2016). While general

guidelines for WSPs' operation do exist, the exact mechanisms responsible for the removal of organic matter, nutrients, pathogens and metals are not fully understood or optimized within site-specific scenarios. Hence the need for localized research to improve our understanding of these interactions and mechanisms and inform overall operations accordingly. Wastewater quality monitoring and characterization are two integral components of localized research that can serve as effective tools in diagnosis and optimization of WSP processes for enhanced performance (Glonya 1976, Pearson et al. 1987, USEPA 2011).



Figure 1. Picture of a typical WSP (RMC Green Team 2019)

1.1 Purpose and Scope

This study focuses on the examination of the effluent quality of a two-pond WSP system treating wastewater from a Canadian Armed Forces (CAF) base in the Canadian Prairies. Although it is accepted that multiple and complex factors are responsible for metal removal in such ponds, this study primarily investigates the impact of temperature and pH variations on the effluent quality and particularly metal removal. This study attempts to use measurements of these parameters (temperature and pH) as indicators of effluent quality with regards to metals (arsenic, cadmium, copper, lead, mercury and zinc). As such, if little time is appropriated in terms of a decision as to whether or not to discharge effluents to the adjacent environment (for example, to a near-by river), this decision can be made by the WSP operators in the absence of analytical results for metal concentrations.

2 METHODOLOGY

The proposed methodology for this study follows a two-fold approach: (1) Initial assessment of the WSP system's performance regarding its metal removal efficiency, based on a four-year effluent quality dataset collected during annual discharges, and (2) laboratory batch scale experiments under controlled temperature and pH variations in order to examine their influence on metal removal.

2.1 Initial Performance Evaluation

The purpose of a site characterization is to delineate the intrinsic and environmental factors that may potentially influence the performance of the WSPs. The initial evaluation of the metal removal efficiency of the WSPs under study included a site characterization that was based on a suite of resources: Relevant technical reports and documents obtained from the CAF base, daily/monthly/annual facility performance data as well as literature on previous studies conducted in the region.

The effluent quality of the WSPs of interest was characterised by analysing the annual spring discharge data that were obtained for a period of four (4) years, i.e. from 2015 to 2018, as they were provided by the operators of this facility. It is noted that all federal operated wastewater treatment facilities (including WSPs) are required to meet federal guidelines (Wastewater Sewage Effluent Regulations [WSER] 2012); they are even expected to strive to achieve the provincial standards if the latter are more stringent than the federal regulatory framework. This study focuses on the parameters presented in Table 1, while the remaining monitoring parameters (as per the Federal regulations), i.e. unionized ammonia, total suspended solids (TSS) and 5-day biochemical oxygen demand (BOD₅) have been carried out in other studies and briefly discussed (J.J-L. Armstrong, personal communication 2019).

Degree days used as one of the parameters is defined as the daily average temperature above a certain threshold temperature accumulated daily over a time frame (Edey 1977, Ragush et al. 2015)

Table 1. Wastewater Quality Parameters used in WSP Characterization

Wastewater Quality Parameters used in Performance Evaluation	
Temperature	Arsenic (As)
Degree days	Cadmium (Cd)
pH	Copper (Cu)
Total phosphorus (TP)	Lead (Pb)
Total Dissolved Solids (TDS)	Mercury (Hg)
	Zinc (Zn)

2.2 Site Characterization

The WSP system under study is located in the Canadian Prairies in an area that is characterized by long cold winters and short summers. Average annual temperature recorded is 2.6 ± 1.2 °C. July is the warmest month with average temperature of 18.5 ± 1.3 °C. January is the coldest month that records average temperature of -15.5 ± 4.8 °C. Average temperatures below 0°C are observed from November to March while temperatures above 10 °C are recorded from May to September. Degree days of 860.8, 312 and 124 are reported for temperatures above 10, 15 and 18 °C respectively. Also, 1677.3, 2515.6 and 3556.8 days are recorded for < 0, 5 and 10 °C degree days respectively. Annual rainfall of 276.7 ± 91.3 mm and snowfall of 91.3 mm result in total yearly precipitation of 353.7 mm. Wind speed of 15.3 km, predominantly in the southward direction is reported. The climate data were

recorded from a weather station located about 40km north of the site (Government of Canada-2018).

The surficial soil consists of sandy to loamy sand, extending to depths of approximately 8.1 m with hydraulic conductivity ranging from 5×10^{-5} to 3.9×10^{-4} m/sec. The near surface groundwater table is reported to be 2-4 m below grade (P. Machibroda Engineering Ltd 2004, WorleyParsons Canada 2011, Skordaki and RMC Green Team 2017). Shallow lateral groundwater is perceived to flow across the WSP area in the northwest direction. Drainage within the vicinity of the WSPs (Figure 2) is a small creek about 200 m from the WSPs, which empties into a northerly flowing major river, located 12 km west of the site at its nearest point (Skordaki and RMC Green Team 2017, WorleyParsons Canada 2011). There are drinking water production wells of depth 20 m, located 900 m from the WSPs.



Figure 2. Map of study area showing WSP system (modified from Skordaki and RMC Green Team 2017)

2.3 WSP System Overview (Structure, Operations and Maintenance)

Wastewater from the base flows through underground sewer pipes made of clay-tile pipes and cast iron. The sewage flows by gravity and enters a pretreatment stage via a temporary lift station. The pretreatment stage consists of a grit chamber and five double-celled septic tanks operated in parallel. The septic tanks retain the sewage for about 2-4 days, in accordance with the provincial guidelines (Mathavan and Viraraghavan 1991, Skordaki and RMC Green Team 2017). In the septic tanks, anaerobic digestion and sedimentation reduce the settleable solids and organic loading after which the

supernatant is transferred to two WSPs: WSP1 and WSP2, operated in series. WSP1 is designed as the main treatment pond while WSP2 serves as a storage pond with minimal treatment.

Wastewater entering WSP1 is through an inlet pipe located off the center, toward the west of the pond. Wastewater is transferred from WSP1 to WSP2 via gravity and valve control. Each WSP is designed to retain wastewater for a minimum of 180 days but the practice has been retention time of about 365 days for each WSP. The supernatant (effluent) from WSP2 is discharged into the small creek through an outflow pipe. Discharge occurs annually in the spring, over a period of 10 days at an average rate of $1089 \text{ m}^3/\text{day}$ after which the valve between WSP1 and WSP2 is open for about a week until content from WSP1 flows into WSP2. WSP2 remains isolated until the next discharge period while WSP1 continues to receive wastewater from the septic tanks (Skordaki and RMC Green Team 2017, Skordaki and Vlachopoulos 2018).

Prior to discharge, grab wastewater samples are taken by the base staff from the following locations (one sample per location): The septic tank, WSP1, WSP2, and along the creek that receives the treated effluent. These samples are analysed for water quality parameters as stipulated by the guidelines and regulations of the Provincial Government in which the facility is located. During discharge, grab wastewater samples are taken from the effluent daily and once from the creek. After discharge, samples are taken from the receiving creek by the base staff. All of the samples taken are delivered to an external accredited laboratory for analysis. There are 9 monitoring wells around the perimeter of the WSP system which are also sampled once a year as part of the environmental monitoring program of the military base. Figure 2 shows the WSP system under study with sampling locations used for characterization in this study.

3 PRELIMINARY RESULTS AND DISCUSSION

The annual spring discharge data from 2015 to 2018 for the septic tank, WSP1, WSP2 and final effluent for wastewater quality parameters as presented in Table 1 have been used to characterize the effluent as well as the treatment performance for two complete treatment cycles, together with climatic data amassed from Environment Canada's website. The preliminary results of this investigation are described in the following sections.

3.1 Climate

The influence of temperature on the performance of WSPs in continental climate is well known. It has been established that there is a strong correlation between air temperature and pond surface water temperature (Abis and Mara 2006, Crisp and Howson 1982, Webb and Nobilis 1997). In this study, air temperature is used in assessing the effect of temperature on treatment performance. The average air temperature reported from the closest weather station, as shown in Table 2, was between -18.1°C in February 2018 and 19.4°C in July. For each of the years from 2015 to 2018, average temperatures below 5°C were recorded

from November to March whereas minimum and maximum monthly temperatures above 0 °C were only reported for the months of June, July and August. Temperature changes in WSPs have been reported to influence chemical and biological processes in an exponential manner and depicted by the Arrhenius equation (Glonya and WHO 1971). Temperature of 10 °C is suggested as the limit below which biological activity is very low and treatment performance would also be low (Bartsch and Randal 1971, Lettinga et al. 2001, Ragush et al. 2015).

Table 2 further suggests that effective treatment in the WSPs may occur between May and October with average temperatures between 10.1 and 6.7 °C respectively. This is when biological activity would be at its highest. Very little effective treatment may generally be attributed to the period between November to April since maximum temperatures are generally above 10 °C, with the exception of January and February, which consistently recorded

temperatures below 10 °C for the entire period under study (2015-2018).

Degree days have been used as a measure of the potential of phytoplankton growth. It is noted that degree days do not actually correspond to days of the month. The calculation is based on the difference between mean temperature for a day and a reference temperature. For example, if the reference temperature is 2 degrees but the average temperature recorded for that day is 5 degrees, then the degree days will be 3 degree days. For a particular month, degree days are added up for each day.

Degree days above 5 °C indicate a healthy phytoplankton growth and microbial activity (Ragush et al. 2015). Degree days above 5 °C were recorded for 7-9 months during the study period and degree days above 20°C were between 3 and 5 months, as shown in Table 3. This suggests longer periods of low productivity which is similar to results of studies with comparable climate (Ragush et al. 2015; Vendramelli et al. 2016).

Table 2. Historical Temperature Data for Study Area (Environment Canada 2018)

Month	2015 Temperature (°C)			2016 Temperature (°C)			2017 Temperature (°C)			2018 Temperature (°C)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
Jan	-11.8	6.1	-37.6	-12.9	4.2	-37.1	-13	6.7	-35.9	-12.9	5.7	-32.5
Feb	-17.4	1.5	-35.3	-7.9	4.8	-23.1	-9.3	7.5	-30.4	-18.1	2.3	-32.4
Mar	-2.4	19.6	-33.6	-1.5	12.6	-17.1	-5.2	12.6	-26.8	-8.6	4.1	-24.4
Apr	5.6	27.8	-9.6	5.5	24.9	-10.1	4.3	21.6	-8.7	-0.7	26.2	-24.6
May	10.1	28.9	-5.7	13.7	32.6	-4	12.1	31.2	-2.1	14.3	32.1	-1.4
Jun	17.2	33.4	2.3	17.4	30.2	4.6	16.1	33.8	2.1	17.3	31.1	4.3
Jul	19.4	35.8	4.4	18.7	29.3	7.7	19.6	33.2	5.9	18.7	34.6	5.7
Aug	17.4	31.8	1.8	16.9	29	1.8	17.8	31.8	4.2	17.1	38.2	1.6
Sep	11.9	29	-5.5	11.8	28.7	-1.8	12.8	32.7	-0.3	7.4	23.5	-8.7
Oct	6.7	26.2	-5.3	2.1	16.6	-8.6	5	23.5	-9.1	2.5	21.2	-11.1
Nov	-3	10.2	-23.5	1.9	19.8	-12.2	-9.8	5.6	-24.8	-6.8	4.1	-23.3
Dec	-9.3	6.8	-28.2	2.1	16.6	-8.6	-12.3	5.5	-36.5	-10.2	5.6	-31.4

Table 3. Historical Degree Days Data for Study Area (Environment Canada 2018)

Month	2015 Degree days			2016 Degree days			2017 Degree days			2018 Degree days		
	Above 0°C	Above 5°C	Above 20°C	Above 0°C	Above 5°C	Above 20°C	Above 0°C	Above 5°C	Above 20°C	Above 0°C	Above 5°C	Above 20°C
Jan	1.9	0	0	0	0	0	2.7	0	0	0	0	0
Feb	0	0	0	1.1	0	0	11.2	0	0	0	0	0
Mar	49.7	8.3	0	39.2	0.8	0	36.4	2.8	0	0	0	0
Apr	176.2	69.7	0	170.7	60.2	0	137.4	33.8	0	115.1	51.6	0
May	304.2	155.1	0	396.5	256	3.4	374.6	219.6	2.3	444.5	290.5	4.1
Jun	516.8	366.8	11.8	521.1	371.1	9.1	483.6	333.6	6.3	501.6	356.6	11.9
Jul	601.6	446.6	35.1	580.4	425.4	9	607.4	452.4	25	578.8	423.8	24.4
Aug	537.9	382.9	16.5	524.3	369.3	2.7	552.1	397.1	6.1	529.4	374.4	15
Sep	346	203.1	0	352.5	202.5	2.5	383.1	233.5	5.4	225.5	105.8	0
Oct	201	68	0	74.5	15.3	0	154.2	48	0	88.3	14	0
Nov	30.1	0	0	99.6	35.3	0	0.5	0	0	2.6	0	0
Dec	2.9	0	0	0	0	0	1.8	0	0	0	0	0

3.2 Effluent Characterization and Selected Results

3.2.1 Total Phosphorus (TP)

Effluent phosphorus levels, as shown in Figure 3, did not meet WSER guideline of 1mg/L for TP for all discharge days in all 4 years under study with the exception of 2017. Total phosphorus concentration varied between 0.46 and 1.3 mg/L in 2015; 0.54 and 2.44 mg/L in 2016; 0.38 to 0.63 mg/L in 2017; and 2.21 to 4.12 mg/L in 2018. This trend shows an average increase in TP levels as the years move from 2015 to 2018. Further, the assessment of the performance of the WSPs of interest revealed inconsistencies regarding phosphorus removal. As shown in Tables 4 and 5, in the 2015-2017 treatment cycle, an overall 82.82 and 83.56 % orthophosphate and TP (respectively) removal efficiency was achieved. In 2016-2018 treatment cycle, TP and orthophosphate concentration in the septic tanks were 2.79 mg/L and 2.6 mg/L while effluent concentrations were 9.23 and 11.52 % higher, indicative of accumulation rather than removal. Sediment/sludge resuspension is attributed to higher phosphorus concentrations in the effluent than the influent.

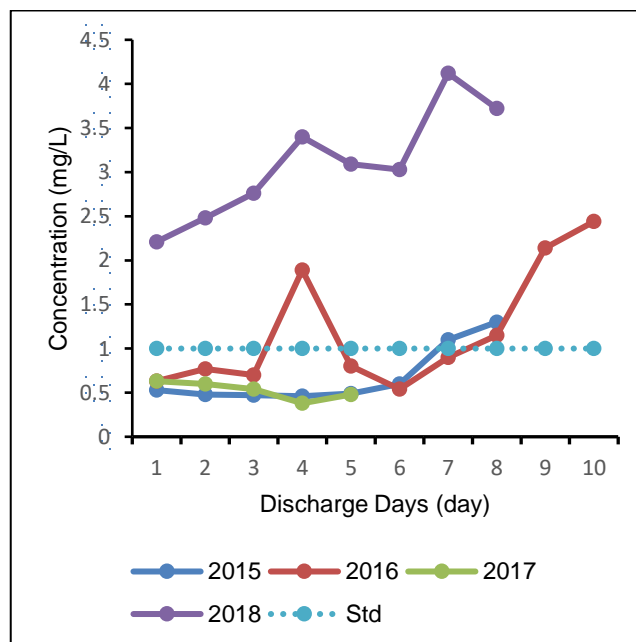


Figure 3. Total Phosphorus Effluent Quality from Base Staff Annual Monitoring Data.

3.2.2 Metals

As shown in Tables 4 and 5, the concentrations of the metals of concern (As, Cd, Cu, Pb, Hg and Zn) in WSP1, WSP2 and effluent were sometimes below the detection limit of the method used (inductively coupled plasma mass spectrometry [ICP-MS]). As such, the estimation of the removal efficiency was calculated based on assumption that the detection limits represented the concentration of metals. Based on this assumption, the trend of Cd < Pb < Zn < Cu < As < Hg is shown for the removal of metals in the 2017 effluent data. The efficiency of the WSPs with respect to the removal of the metals based on a full treatment cycle reveal a removal rate of 99.90, 90.88, 58.33, 99.97 and 78.02 % of As, Cu, Pb, Hg and Zn respectively. However, Cd concentration increased by 97.33 % in the effluent during the 2015-2017 treatment cycle. During the 2016-2018 treatment period, the removal efficiencies of the metals followed a different pattern: As < Hg < Zn < Pb < Cu < Cd. Here, 95.67 % Cd, 82.38 % Cu, 81.75 % Pb, 52.38 % Hg and 74.18 % Zn were removed between the septic tank and effluent while As concentration increased by 9.36 % from the initial 0.00707 mg/L in septic tank in 2016 to 0.007731 mg/L in the effluent in 2018. Metal removal in WSPs is by sedimentation, biological uptake, adsorption and precipitation. The factors that can influence the extent of removal of different metals are: pH, temperature, redox potential, alkalinity and its associated ions, inorganic and organic complexing agents and concentrations of competing metals (Laxen 1983, Stumm and Morgan 1981).

The analysis of the data to date indicate that the metal removal rates could be influenced by co-precipitation with phosphates. Higher metal removal is recorded for the 2015-2017 treatment cycle than the 2016-2018 treatment cycle, which also correlates with the phosphorus removal trend for the same cycles (Table 4, 5). Similarly, the metals could also be adsorbed on the minerals (Ca, Mg, K) or precipitated with carbonates, sulphates or hydroxides of

other metals such as iron and manganese (Canadian Council of Ministers of the Environment [CCME] 2003, Stumm and Morgan 1981). Competitive adsorption for the same adsorption sites on sediments and minerals could also be the reason why some metals were effectively removed while others like cadmium were higher in the effluent than the initial concentration in the septic tank for the 2015-2017 complete treatment cycle (CCME 2003). Laxen (1983) attributes the occurrence of cadmium in the water column to its high affinity to form complexes with organics and thus evade removal by adsorption and/ or precipitation.

3.2.3 pH

pH in all of the components of the wastewater treatment during the four-year period, as shown in Tables 4 and 5, was always in the alkaline range. In the 2015-2017 treatment cycle, pH ranged from 7.93 to 9.37 with the following trend: septic tank < WSP2 < WSP1. In the absence of data for WSP2 in 2018, a trend of septic tank < Effluent < WSP1 was observed with pH values ranging from 8.12 to 9.46. pH is important for the removal of metals, pathogens and phosphates in WSPs; high pH values generally favour the removal of these contaminants (Sekomo et al. 2012, Stumm and Morgan 1981). The alkaline pH values of the raw wastewater is indicative of the absence of metal-laden industrial wastewater which is generally characterized by low pH values.

Furthermore, pH values that are higher in WSP1 than in other components of the treatment system are the result of higher algal growth and, thus, indicate that the WSP1 is the primary treatment pond. Thus, in the absence of Chlorophyll "a" measurements, the differences in pH values between the two ponds can signify the extent of algal concentration between the various components of the WSP system.

Table 4. WSP Complete treatment cycle from 2015-2017 (Based on Monitoring Data from Base staff)

Parameter	Unit	Septic tank (2015)	WSP1 (2016)	% R	WSP2 (2017)	% R	Effluent (2017)	Overall % R
Conductivity	µS/cm	2800	2650	5.36	4310	-62.6	4512	-61.14
pH	--	7.7	9.37	--	8.86	--	9.102	--
TDS	mg/L	1470	1440	2.04	2420	-68.1	2448	-66.53
Alkalinity (CaCO ₃)	mg/L	380	186	51.05	213	-14.5	192.8	49.26
Orthophosphate	mg/L	2.6	0.378	85.46	0.515	-36.2	0.4468	82.82
TP	mg/L	3.2	0.88	72.50	0.64	27.27	0.526	83.56
Aluminum (Al)	mg/L	0.026	0.0158	39.23	0.02	-26.6	0.02306	11.31

Arsenic (As)	mg/L	7.2	0.00707	99.90	0.0051	27.86	0.00744	99.90
Cadmium (Cd)	mg/L	0.00003	0.000031	-3.33	0.000027	12.90	0.000059	-97.33
Copper (Cu)	mg/L	0.008	0.0026	67.50	0.0025	3.85	0.00073	90.88
Iron (Fe)	mg/L	0.91	0.248	72.75	0.065	73.79	0.0902	90.09
Lead (Pb)	mg/L	0.0006	0.00021	65.00	0.00025	-19.1	0.00025	58.33
Manganese (Mn)	mg/L	0.32	0.103	67.81	0.158	-53.4	0.0296	90.75
Mercury (Hg)	mg/L	0.02	0.0000066	99.97	0.000005	24.24	0.0000053	99.97
Zinc (Zn)	mg/L	0.053	0.0062	88.30	0.015	-142	0.01165	78.02

Note: "% R" represents the removal efficiency

Table 5. WSP Complete treatment cycle from 2016-2018 (Based on Monitoring Data from Base staff)

Parameter	Unit	Septic tank (2016)	WSP1 (2017)	% R	Effluent (2018)	Overall %R
Conductivity	µS/cm	2070	2640	-27.54	5147.142	-148.7
pH	--	8.12	9.46	--	8.21	--
TDS	mg/L	1060	1440	-35.85	2806.67	-164.8
Alkalinity (CaCO ₃)	mg/L	362	210	41.99	328.86	9.16
Orthophosphate	mg/L	2.6	1.02	60.77	2.84	-9.23
TP	mg/L	2.79	1.99	28.67	3.1114286	-11.52
Aluminum (Al)	mg/L	0.0573	0.015	73.82	0.0477143	16.73
Arsenic (As)	mg/L	0.00707	0.00486	31.26	0.0077314	-9.36
Cadmium (Cd)	mg/L	0.000577	0.000025	95.67	0.000025	95.67
Copper (Cu)	mg/L	0.0142	0.0025	82.39	0.0025	82.39
Iron (Fe)	mg/L	0.377	0.129	65.78	0.4508571	-19.59
Lead (Pb)	mg/L	0.00137	0.00025	81.75	0.00025	81.75
Manganese (Mn)	mg/L	0.279	0.205	26.52	1.7028571	-510.3
Mercury (Hg)	mg/L	0.0000105	0.000005	52.38	0.000005	52.38
Zinc (Zn)	mg/L	0.0581	0.015	74.18	0.015	74.18

3.2.4 Other Physical and Chemical Characteristics (Total Dissolved Solids (TDS), Conductivity, Alkalinity)

An increase in TDS levels across the treatment process for both treatment cycles (Tables 4 and 5) suggests an accumulation of minerals as the treatment progresses. High evaporation and low rainfall, characteristics of the climatic conditions of the area where the WSPs of interest is located, could account for high TDS in the effluents. High TDS in the influent wastewater from the septic tank could be attributed to contributions by the filter backwash wastewater from the drinking water treatment plant of the military base. Specifically, salts used in the softening process of the drinking water end up in the sewer lines during backwash (Skordaki 2018, Skordaki and RMC Green Team 2017). The influent and effluent concentrations of TDS from 2015 to 2018 were above both drinking water guideline of 500 mg/L and 1500 mg/L for Health Canada and the Province (Health Canada 1991). Although this guideline is primarily for aesthetic purposes, consumption of water with high TDS is associated with distress and sometimes death in animals (Health Canada 1991, Prince 1995)

Conductivity data, as included in this study, follow the same pattern with TDS. In the 2015-2017 treatment cycle, conductivity increased from 2800 $\mu\text{S}/\text{cm}$ in the septic tank to 4512 $\mu\text{S}/\text{cm}$ in the effluent. Since conductivity is directly related to the concentration of ions in the water and since conductivity and TDS are from soluble minerals, ion precipitation and evaporation could account for their increase with time (Government of Saskatchewan 2008). High conductivity levels have also been reported in groundwater in the region. Alkalinity, which measures the ability of the water to resist changes in pH, tended to decrease across the treatment process for both treatment cycles. Alkalinity as CaCO_3 , reduced from 380 mg/L in the septic tank to 192.8 mg/L in effluent during the 2015-2017 treatment cycle. Alkalinity is important when industrial waste usually acidic in nature is added to wastewater streams (Metcalf and Eddy 2003). As the wastewater from a military base can be a mix of domestic and industrial wastewaters (due to the impact from military activities, such as runoff from military vehicles' car wash stations), the monitoring of alkalinity can point towards changes in the wastewater characteristics (Skordaki 2018, Skordaki and RMC Green Team 2017).

3.2.5 BOD₅ and TSS

Organic matter in the form of BOD₅ and TSS reported for effluent discharge from 2015 to 2018 has not always met the WSER standard of 25 mg/L for each parameter (J.J-L. Armstrong, personal communication 2019, Skordaki and RMC Green Team 2017). Effluent BOD₅ ranged from 2 to 32 mg/L while TSS values were from 5 to 38 mg/L (J.J-L. Armstrong, personal communication 2019). Generally, TSS levels up to 150 mg/L have been recorded for many WSPs but such high values are mostly a result of algal biomass (USEPA 2011). Short-circuiting from WSP1 to WSP2 during annual transfer might be responsible for the untreated or partially treated wastewater entering WSP2 and promoting algal growth in this pond. WSP2 has been

designed as a storage pond and the excessive growth of algae indicative in high TSS values shows the pond is not functioning as intended and in need of corrective measures.

4 FUTURE ACTIVITIES

Based on the information gathered from the historical data, it is evident that the WSPs' performance for all of the selected parameters varied over the two complete treatment cycles. Also, data collected just once a year do not provide a complete picture of the factors (and combination of factors) that influence the achieved treatment. A laboratory comparative batch study is proposed to be carried out under controlled conditions of temperature and pH in order to assess the seasonal variation on the removal of six selected metals from the historical data: As, Cd, Cu, Hg, Pb and Zn. Inconsistent treatment efficiencies are indicative of either operational failure or inadequacy of a facility's capacity to treat wastewater; comparisons of the data from the laboratory experiments with the historical performance data would both help us understand the root cause of the inconsistent removal of phosphorus and metals used in the performance evaluation in section 3.2.

4.1 Overview of Laboratory Experiments

4.1.1 Description of Experimental WSPs

Nine experimental WSPs of a 5-liter capacity, made of clear polyvinyl chloride (PVC) tube of length 1.3 m and sealed at the bottom, adapted from Ragush (2016), shown in Figure 4, are in the process of being conducted in order to determine the influence of low temperature (5 °C) and warm temperature (20 °C) on the extent of wastewater treatment with respect to the 6 metals mentioned earlier. The two selected temperatures are indicative of winter and summer conditions respectively.

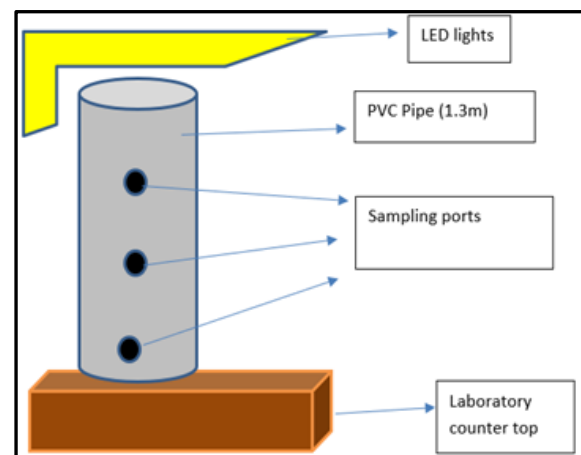


Figure 4. Schematic Diagram of Experimental setup

4.1.2 Operating Conditions

Simple low strength synthetic wastewater modified from the recipe by Herman and Glonya (1958) would be spiked with a combination of the selected metals to evaluate the efficiency of the experimental WSPs. The experimental design will yield 9 experimental units which would be operated for a suggested retention time of 90 days with weekly monitoring of the wastewater parameters that are shown in Table 5.

Table 3: Parameters for Experimental WSP monitoring

Wastewater Quality Parameters used in Performance Evaluation		
Temperature	BOD ₅	
Degree days	Total suspended solids (TSS)	
Dissolved oxygen (DO)	Nitrogen species	
pH	Total Phosphorus (TP)	
Total Dissolved Solids (TDS)	Metals (arsenic, cadmium, copper, mercury, lead and zinc)	
Factor	Level	
Temperature	5 °C	20 °C
Initial pH	6	8
Metals	1 mg/L	10 mg/L

5 CONCLUSIONS

The performance of waste stabilization ponds varies with local climatic conditions. As such, site specific wastewater characterization and monitoring are important tools for understanding the mechanisms and dynamics of the treatment process. This study focuses on the removal of metals as part of the wastewater treatment within a WSP system operated by the CAF under the conditions of long cold winters and short warm winters prevalent in the Canadian Prairies. Our review of the results of historical effluent monitoring data showed variability in annual phosphorus and metals' removal efficiencies, indicative of inadequate performance of the WSP system.

In order to optimize the operational performance of the WSP system, this research proposes a laboratory batch scale experiment under simulated temperature and pH conditions to ascertain the influence of these factors on the extent of metal removal of 6 metals of interest: As, Cd, Cu, Hg, Pb, and Zn. Temperature and pH measurement of wastewater from WSP2 prior to annual discharge could be

used as a rapid and cost-effective monitoring tool in estimating the extent of removal of metals. In line with the strategy of Department of National Defence (DND) to be a leader in promoting good environmental stewardship, the results of this proposed experimental study could provide general guidelines to the WSP plant operators on the evaluation of the effluent quality for discharge with respect to metal levels.

Clearly, pollution as a result of wastewater effluents in riverine ecosystems cannot be overemphasized. There have been public and health concerns of wastewater effluents worldwide and specifically in Canada. As such results of this study could provide a proactive management approach in the operations of WSP systems within the CAF. The findings of this evidence - based research could provide the framework for the development of a policy on the operations of WSPs within the DND (Skordaki 2018, Vlachopoulos, Skordaki and Alexakis 2012). In spite of the relatively low concentration of metals present in the WSP system studied, adopting the methodology used in this research as best management practices could help other CAF facilities operating WSPs that receive higher concentrations of metals in their wastewater practice good environmental stewardship. The practice of monitoring pH and temperature to a level to which further reduction in metal concentration is reached, reduces the potential risks associated with metals in effluents, even at low concentrations. In addition to promoting the DND as a good environmental steward, the research approach, if adopted helps to avoid any future conflicts that could arise as a result of effluent containing deleterious substances leaving federal property and entering provincial and private lands.

This research could also contribute to the body of research on the improvement of low technology and cost-efficient wastewater treatment systems such as WSPs whose operations are pertinent for rural and remote communities. Further, the study satisfies the need for site specific research recommended for WSPs operations whose dependence on myriad of interconnecting factors is not fully understood. Having understood the contribution of the factors (pH, temperature and metal content) studied in this research, other factors such as wind, irradiance, sludge/sediment composition and biological composition could be further explored to expand our understanding of their contribution to WSP operations. In addition, data from this research could be used in developing computer models to predict the effluent quality of site specific WSPs thus contributing to early troubleshooting and environmental management.

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