ASSESSING EFFECTS OF INDUSTRIAL EFFLUENT ON WETLANDS SURROUNDING A WASTEWATER TREATMENT FACILITY USING A MULTIPLE LINES OF EVIDENCE APPROACH

By

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Abstract

A former tidal estuary, known as the Boat Harbour Treatment Facility (BHTF), in Pictou County, Nova Scotia has been used to treat industrial effluent from a chlor-alkali plant and a bleached kraft pulp mill since 1967. This effluent created large volumes of unconsolidated sediment impacted by inorganic and organic contaminants. The BHTF will no longer be used to treat effluent after January 2020 under the *Boat Harbour Act* (2015), with remediation efforts commencing thereafter. To inform remedial decisions, baseline assessments of the area have begun, including assessments of wetlands surrounding the BHTF, which were directly and indirectly contaminated by industrial effluent. This study builds on prior chemical assessments by evaluating potential effects on wetland biological communities through completion of contaminant and macroinvertebrate community analyses. Sediment, surface water and sediment-based biota samples from select wetlands were analyzed for polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans, metals and total mercury. Comparison of this data to provincial and federal guidelines, as well as reference wetlands, revealed several contaminant exceedances in wetland media. Specifically, exceedances were present in deep water samples (>150cm vertical water column) and currently impacted wetlands. Aquatic macroinvertebrate community analysis was based on the Environment and Climate Change Canada Wetland CABIN protocol. Metrics included total abundance, the Shannon-Wiener diversity index, nonmetric multidimensional scaling, and the Berger-Parker index. Metrics in BHTF wetlands showed little variation from reference wetlands, presumably due to attenuation of historical contaminant inputs. Recommendations for remediation include active remediation of deeper wetland sediments and passive remediation in less impacted wetlands using monitored natural recovery (MNR).

List of Abbreviations Used

As	Arsenic
ASB	Aeration Stabilization Basin
BHTF	Boat Harbour Treatment Facility
BP	Berger-Parker index
CABIN	Canadian Aquatic Biomonitoring Network
CCME	Canadian Council of Ministers of the Environment
Cd	Cadmium
COPC	Contaminants of Potential Concern
Cr	Chromium
Cu	Copper
ECCC	Environment and Climate Change Canada
eDNA	Environmental Deoxyribonucleic Acid
ERA	Ecological Risk Assessment
FCSAP	Federal Contaminated Sites Action Plan
ISQG	Interim Sediment Quality Guidelines
H’	Shannon Wiener diversity index
Hg	Mercury
MNR	Monitored Natural Recovery
NMDS	Nonmetric Multidimensional Scaling
NSE	Nova Scotia Environment
Pb	Lead
PCDD/PCDF	polychlorinated dibenzo-p-dioxin and dibenzofurans
PEL	Probable Effects Level
PLFN	Pictou Landing First Nation
REF	Reference Wetland
USEPA	United States Environmental Protection Agency
WL	Wetland
Zn	Zinc

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Chapter I

1.0 Introduction

1.1 Background to the Study

Contamination of ecosystems as a result of natural resource exploitation is a globally pervasive issue (Newman, 2010; Suter, 2006). Since the Industrial Revolution in the 18th century, atmospheric, aquatic and terrestrial ecosystems have been receiving harmful contaminants, such as metals, from industries (Dickson, 1971; National Ocean Service, n.d.). Effects of industrial contamination on environmental ecosystems vary, ranging from limited to severe impacts. Concern for impacted ecosystems has lead to governments, private and public sectors and community stakeholders taking action to characterize effects of contaminants through assessments, as well as studying how to rehabilitate, remediate or restore these systems back to a natural and healthy state (FCSAP, 2017). Forms of these assessments vary from jurisdiction to jurisdiction. A similar basic principle is present in all assessments in some capacity, and includes defining and refining contaminants of potential concern (COPC), characterizing effects, fate, transport and exposure pathways of COPC, and creating a conceptual model and decision matrix (EC & OMOE, 2008; USEPA, 2001). To understand what remediation strategies are required, and their potential consequences, ecological assessments comprising of multiple lines of evidence are recommended to provide a thorough and holistic understanding of ecological health (Burton et al., 2002; Hull & Swanson, 2006; Walker et al., 2015).

This thesis follows the aforementioned principle to identify impacts of industrial contamination on a former tidal estuary located in Pictou County, Nova Scotia, Canada. The former estuary, commonly referred to as the "Boat Harbour Treatment Facility"[1] (BHTF), has been receiving and treating industrial effluent from a bleached kraft pulp mill, located on Abercrombie Point, since 1967, as well as having received effluent from a chlor-alkali plant from 1971 to 1992 (Fig. 1) (GHD, 2018a; Hoffman et al., 2017a; Romo, Chaudhary & Walker, 2019). From 1967 to 1972, effluent was collected and conveyed in a gravity sewer (pipeline) from the pulp mill across East River. The raw effluent was then discharged into a ditch, which flowed

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[1] Boat Harbour is historically referred to as "A'se'K" by the local Mi'kmaq people of Pictou Landing First Nation.

into wetland areas located to the west-southwest of the estuary (Fig. 2). After flowing through the wetland areas, the effluent entered a settling pond before being released into the estuary, and then the Northumberland Strait. In 1972, a more regulated treatment facility, commonly referred to as the BHTF, was implemented to treat the effluent and is still presently in use (Dillon Consulting Limited, 2012). Instead of releasing raw effluent into a ditch and wetland areas, effluent is discharged into a lined ditch, which leads to two settling basins. Effluent is then transported to an Aeration Stabilization Basin (ASB), after which it is discharged into the Stabilization Lagoon (Boat Harbour) (GHD, 2018a; Province of Nova Scotia, n.d.) before being released into the Northumberland Strait. A dam at the outset to Northumberland Strait was also constructed to stop tidal influence into the area. These two treatment frameworks are outlined in Fig. 2.

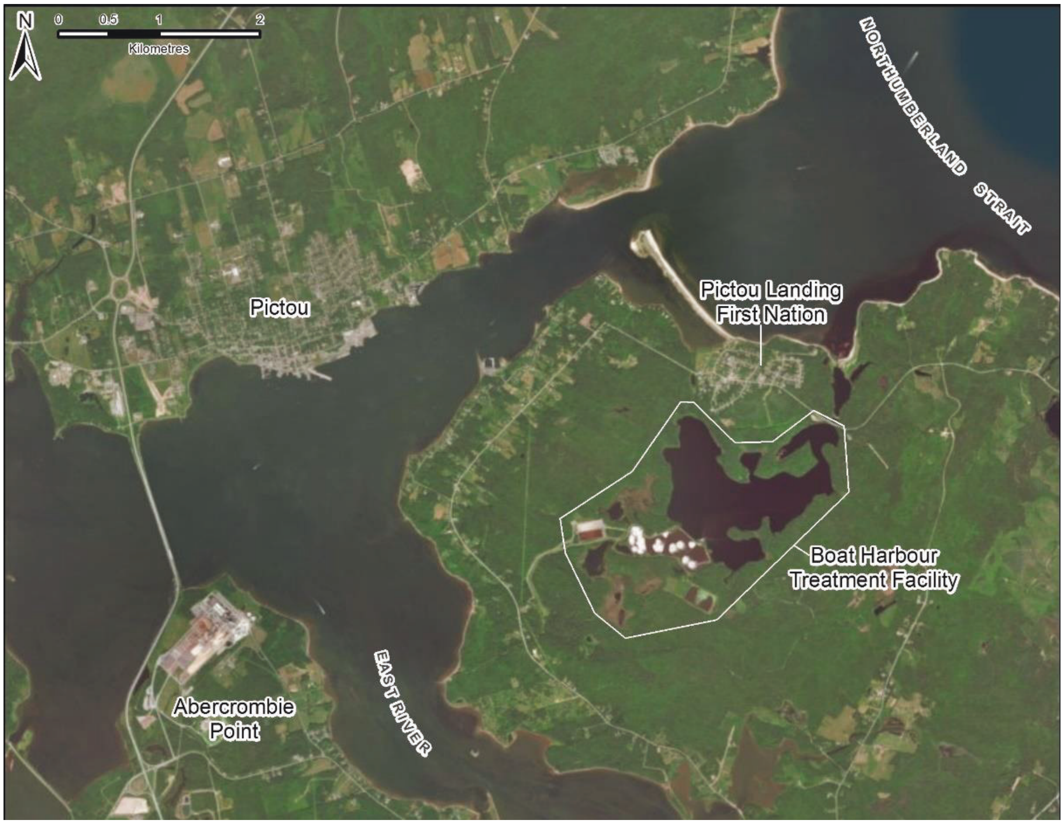

Figure 1: Boat Harbour Treatment Facility location in relation to Abercrombie Point, Pictou Landing First Nation and Pictou [Map produced in ArcGIS®].

Figure 2: Components of the early treatment framework (1967 – 1972) and the current treatment framework [Map produced in ArcGIS®].

In 2014, a pipe transporting effluent from Abercrombie Point to Boat Harbour leaked, sparking outrage in the communities of PLFN and Pictou County (Baxter, 2017). In 2015, the Nova Scotia government passed the *Boat Harbour Act* (2015) which mandated the closure of the BHTF by January 31, 2020. Following this closure, remediation of Boat Harbour back to its former tidal lagoon state will occur (GHD, 2018a; Province of Nova Scotia, n.d.).

To understand the extent of remediation that will be required, baseline assessments of the area began in 2016 by the retained consulting company, GHD. This baseline assessment sampled sediment, soil, groundwater and surface water in and around the BHTF, and will be used to delineate remediation efforts following the 2020 closure (GHD, 2018a). Although having not received direct discharge of raw effluents since 1972, there is concern about persistent contaminants, such polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and metal(loid)s in the wetland systems (GHD, 2018a; WSP, 2018). This concern must be addressed prior to remediation activities.

1.2 Thesis Objectives

This thesis focuses on understanding the effects, extent and magnitude of historic direct inputs of raw effluent, as well as current effluent inputs, on wetland systems surrounding the BHTF. Results described herein will support the current assessment process in delineating an effective and efficient remediation plan for the wetlands. Specifically, the objectives of this study are to:

1. Determine the contaminant concentration present in select wetland media around the BHTF to provide a delineation of impact on wetland areas for remediation,
2. Identify the macroinvertebrate community composition in the representative wetlands around the BHTF, and compare to reference wetlands to determine current effects of historic and current effluent inputs on the biota,
3. Provide a baseline of the BHTF wetlands against which future monitoring studies can be compared to during and after remediation of impacted sites in the BHTF.

1.3 Methodology

To complete this purpose, five representative wetlands surrounding the BHTF, as well as two representative reference wetlands, were sampled using two broad lines of evidence. The first line of evidence was contaminant concentrations in wetland media, specifically sediment, surface water and benthic organism tissue. Triplicate samples of sediment and surface water and a single, composite sample of Libellulidae larvae tissue were taken from each sampled wetland. These samples were analyzed at AGAT Laboratories (Canadian Analytical Laboratory Association (CALA) certified laboratory) for analysis of metals, total mercury, and PCDD/PCDF concentrations. Passive samplers were deployed in the BHTF wetlands, reference wetlands, the Stabilization Lagoon and a dry cove to test for metal concentrations. These samples were analyzed at Bureau Veritas Laboratories (CALA certified laboratory). A detailed description of the methodology used is described in Chapter III. The second line of evidence focused on wetland macroinvertebrate communities in the representative wetlands. Triplicate dip net sweeps were collected from each wetland, and a community analysis of each sweep was performed within a month of collection. A detailed description of this methodology is described in Chapter IV.

1.4 Thesis Layout

Five chapters follow this introduction. A literature review relating to the main topics of this thesis is presented in Chapter II. The next two chapters describe the background, methodology, results and discussion for the two lines of evidence. Chapter III focuses on the contaminant concentrations in various media in the wetlands. Chapter IV focuses on the macroinvertebrate communities within the wetlands. Lastly, Chapter V incorporates the results of the two previous chapters to determine the holistic health of the wetlands and provides final conclusions and recommendations.

Chapter II

2.0 Literature Review

2.1 Wetlands Overview

2.1.1 Definition

Wetlands are incredibly important ecosystems (Balliett, 2010; Ducks Unlimited Canada, n.d.; Mitsch & Gosselink, 2015). Besides being recognized as one of the most productive kinds of ecological systems, wetlands also provide many services that societies value, such as flood control, water supply and filtering contaminants (Ardrop et al., 2011; McCartney & de la Hera, 2004; Russi et al., 2013). They can be found worldwide, including Antarctica (Mitsch & Gosselink, 2007; Scheer & Moss, n.d.; Zhu, Liu, Sun, & Xu, 2007).

Defining these diverse ecosystems has been a difficult task for scientific and regulatory communities, as these systems occur worldwide and are therefore quite variable by nature (Mitsch & Gosselink, 2007). The first official North American use of the term “wetland” in a government document occurred in a 1956 United States (US) Fish and Wildlife Services landmark report on wetlands. In this report, wetlands are defined as: “lowlands covered with shallow and sometimes temporary or intermittent waters” (National Research Council, 1995). This definition has been refined over the years, and different national definitions now tend to include the ecosystem concepts of wetlands. Environment Canada’s National Wetlands Working Group defined wetlands as: “land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment” (National Wetlands Working Group, 1997). The Ramsar Convention, an intergovernmental treaty on the conservation and use of wetlands, provides a more detailed, albeit still broad, definition of wetlands, stating that wetlands are: “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres [and] may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies or marine water deeper than six metres at low tide lying within the wetlands” (Ramsar Convention Secretariat, 2016). Other definitions include aspects of terrestrial and aquatic systems, as wetlands transition between both (National Research Council, 1995).

Exceptions to all of the above definitions, as well as high seasonal variation and climate change, have made estimating the total land cover of wetlands difficult (Environment and Climate Change Canada, 2016). The United Nations Environment Programme World Conservation Monitoring Centre estimates global wetland cover at 570 million ha, which equates to 6% of the world's surface (Ramsar Convention Secretariat, 2016). In comparison, a review for Ramsar COP7 (1999) estimated a minimum global coverage of 748 to 778 million ha worldwide (Ramsar Convention Secretariat, 2016). Wetlands are estimated to cover approximately 129 million ha of land in Canada (Fig. 3), which equates to almost a quarter of global wetlands (Environment and Climate Change Canada, 2016).

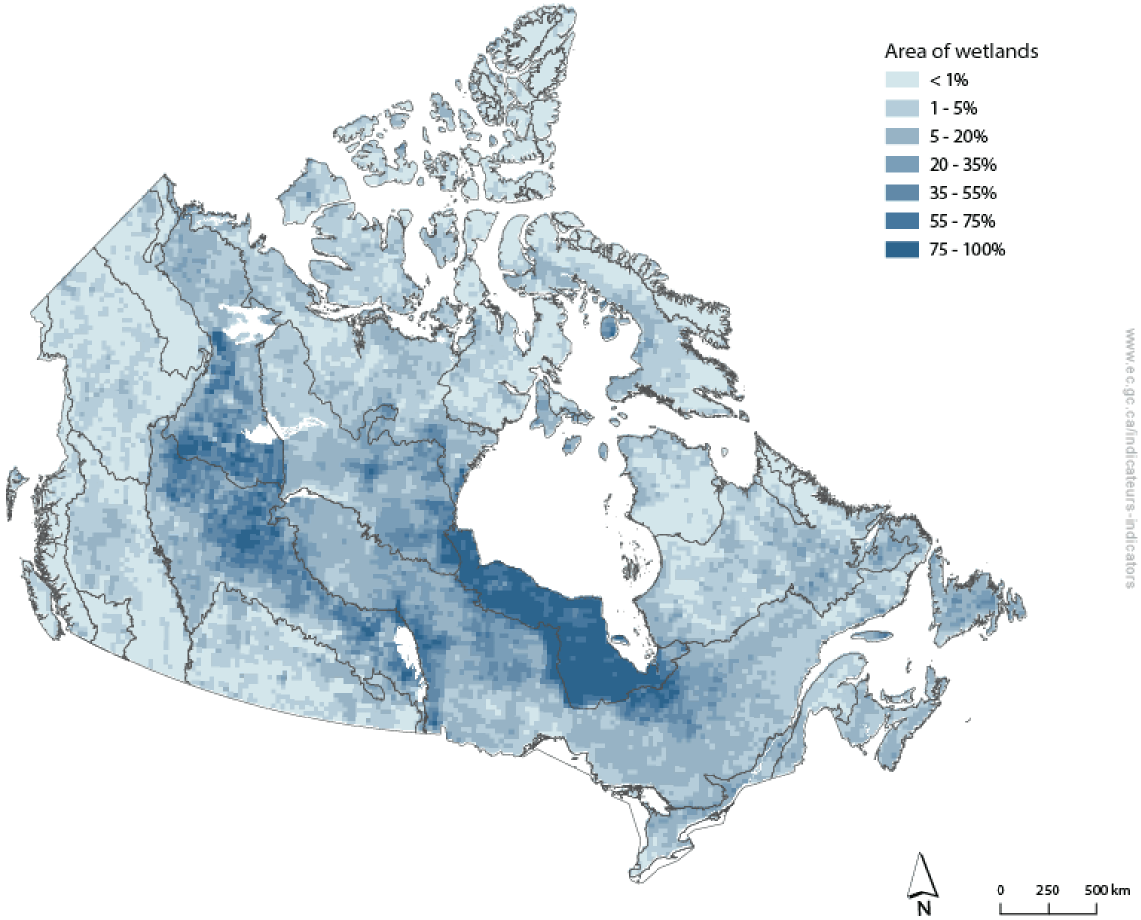

Figure 3: Distribution of wetlands across Canada (Environment and Climate Change Canada, 2016).

2.1.2 Types

Wetlands are produced by the interaction of various environmental factors, including hydrology, climate and geomorphology (National Wetlands Working Group, 1997). Differences in these factors result in diverse characteristics in wetlands (Fig. 4). The soil moisture regime is created by the annual average water regime. “Wet” refers to a water table located within 30 cm of the surface but holds an aerated surface layer for a portion of the year. “Very wet” refers to a surface that is saturated year round, with a water table above the soil (Banner & MacKenzie, 2000). Hydrodynamics is the degree of vertical water table fluctuations and rates of groundwater flow (Banner & MacKenzie, 2000). Soil acidity/alkalinity refers to the abundance of base cations which can greatly influence wetland characteristics, such as productivity (Banner & MacKenzie, 2000). The Canadian Wetland Classification System takes the aforementioned factors into account and subdivides wetlands into different wetland classes: marshes, swamps, bogs, fens and shallow water (National Wetlands Working Group, 1997).

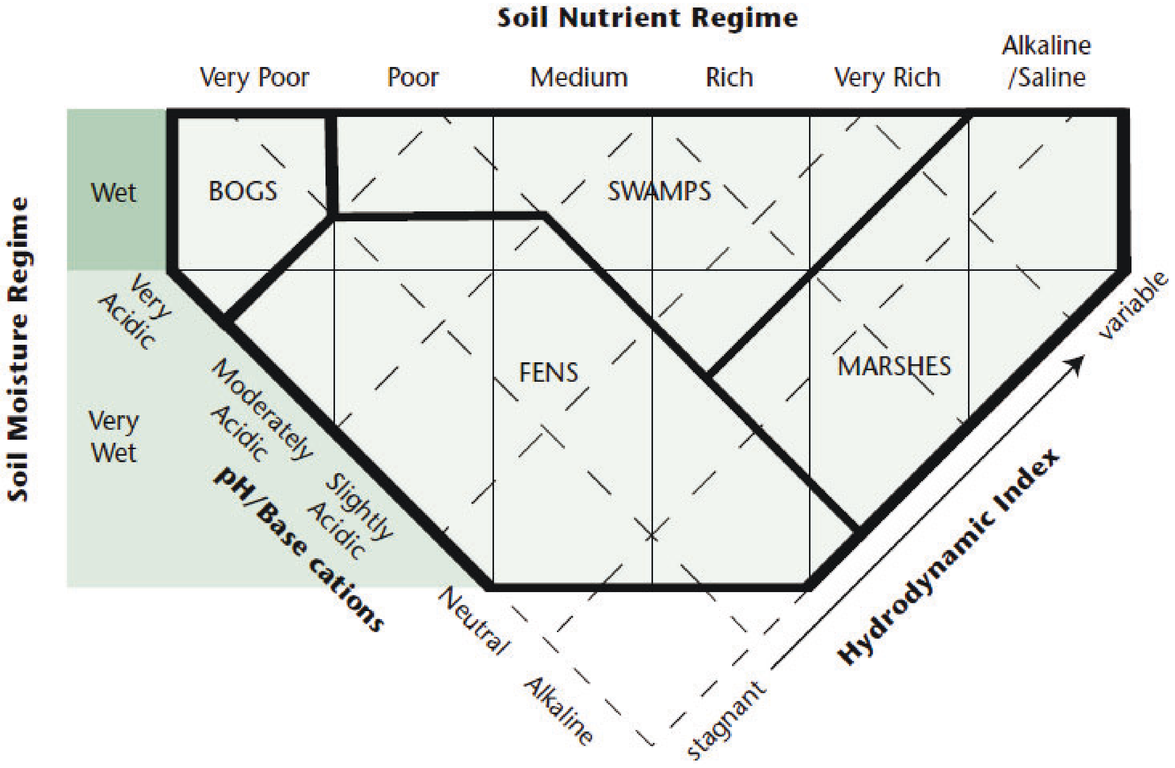

Figure 4: Environmental gradients affecting wetland classes (Banner & MacKenzie, 2000).

2.1.2.1 Marsh

Marshes are wetlands that are frequently or continually inundated with water (Balliett, 2010; Banner & MacKenzie, 2000; Mitsch & Gosselink, 2015). Marshes receive water through surface runoff, stream inflow, precipitation, storm surges, groundwater discharge and tidal actions, all of which tend to create substantial water fluctuations. In fact, marsh hydrology is known to respond more dramatically across seasons than any other wetland class, and can go through long dry and wet periods (National Wetlands Working Group, 1997). Marshes are characterized by emergent soft stemmed vegetation, including emergent aquatic macrophytes, shrubs and nonvascular plants (National Wetlands Working Group, 1997; USEPA, 2000). Vegetation within marshes is typically arranged in patterns according to water depth, drawdown frequency and water chemistry (National Wetlands Working Group, 1997). Marshes receive a significant amount of minerals and undergo periodic aeration, leading to high nutrient and neutral pH levels (Watson, 2012). The high nutrient levels tend to create high productivity and biodiversity within marshes (Moore & Garratt, 2008; Nova Scotia Environment, 2017). High productivity during the growing season leads to high decomposition rates which increases the quantity of gases, such as methane and carbon dioxide, in marsh environments (Moore & Garratt, 2008; National Wetlands Working Group, 1997). Sediment within marshes is a mix of unconsolidated organic and inorganic material. Marshes that seasonally dry up tend to have less organic material when compared to permanent marshes (Mitsch & Gosselink, 2015; National Wetlands Working Group, 1997).

Marshes are further defined as being either tidal or non-tidal (Balliett, 2010; USEPA, 2000). Tidal wetlands occur along coastlines and include salt and estuarian marshes (USEPA, 2000). The hydrology of tidal marshes is greatly influenced by saltwater tides, but freshwater systems can also have effects (National Wetlands Working Group, 1997). Tidal marshes consist of soft-stemmed vegetation, such as grasses and sedges, which anchor in mud and sand flats (Balliett, 2010). Salt marshes compose 4.5% of the total wetland area in Nova Scotia (Nova Scotia Environment, 2017).

Non-tidal marshes are commonly found in poorly drained depressions, floodplains and along the edges of rivers and lakes (USEPA, 2000). Non-tidal marshes can be further separated depending on the location of the marsh, as in:

- Riparian: marshes located along the riparian zones of streams and rivers;

- Lacustrine: marshes located along permanent water body shores;
- Basin: marshes located in inland depressions and receive water from groundwater discharge, surface runoff and stream/river inflow;
- Hummock: marshes located on high land in areas of groundwater upwelling, on slopes or in depressions;
- Spring: marshes located in small water courses with point source discharge of springs; and,
- Slope: marshes located on wet seepage areas where groundwater discharge occurs (National Wetlands Working Group, 1997).

They can also be divided into:

- freshwater marshes: periodic or permanent shallow water, little to no peat deposition and mineral soils;
- wet meadows: occur in poorly drained areas between shallow marshes and upland areas, and may lose all surface water during dry seasons;
- wet prairies: similar to wet meadows except for the extended saturation period;
- prairie potholes: develop when snowmelt and precipitation fill cavities from glaciers, with potholes remaining year-round to support established biota;
- playas: small basins that collect precipitation and surface water runoff; and,
- vernal pools: created when bedrock or a clay lens retains water on the surface in pools
  (Balliett, 2010; USEPA, 2000).

2.1.2.2 Swamp

Swamps are permanently saturated wetlands that are permanently to frequently waterlogged and occasionally contain standing water (National Research Council, 1995; USEPA, 2000). The water table of swamps occurs at or below the surface. Swamps are dominated by trees or tall shrubs, and root growth occurs in the aerated or partially aerated zone of substrates above the water (National Wetlands Working Group, 1997; USEPA, 2000). The primary water source for swamps is surface water and minerotrophic groundwater (Mitsch & Gosselink, 2015; National Wetlands Working Group, 1997; Zoltai & Pollett, 1983). Swamps occur on mineral and/or peat soils, with a range of soil texture. The nutrient content of swamps is variable and can span from poor nutrient conditions in oligotrophic swamps to rich nutrient conditions in eutrophic swamps (Moore & Garratt, 2008; National Wetlands Working Group, 1997). Swamps are composed of highly decomposed woody peat and organic matter. Three general forms of swamps exist in Canada, namely shrub swamps, coniferous swamps and deciduous swamps. Deciduous and shrub swamps tend to occur in swamps with richer nutrient content, with deciduous swamps having drier conditions and shrub swamps having wetter conditions. Coniferous swamps can occur over a range of nutrient contents (National Wetlands Working Group, 1997). Forested swamps can contain trees 4.5 to 18 m tall (Balliett, 2010). It is estimated that approximately 20% of global wetlands are swamps (2005) (Balliett, 2010).

2.1.2.3 Bog

Bogs can be created in two ways: through a process known as terrestrialization, where plant matter, specifically *Sphagnum* moss, decays and fills a lake or pond over many years (Watson, 2012); or through paludification, which occurs when *Sphagnum* grow over dry land, effectively containing groundwater (Moore & Garratt, 2008). The decaying of plant matter creates layers of what is referred to as peat. Wetlands that contain peat deposits of at least 40 cm, such as bogs and fens, are known collectively as “peatlands”. Canada has the largest area of peatlands in the world, covering 1.1 million km^2 (Tarnocai, Kettles, & Lacelle, 2011). Bogs come in a variety of shapes and sizes and are generally at or raised above the surrounding terrain (Nova Scotia Environment, 2017). This raised topography results in the bog water table located above the surrounding landscape’s water table. Given this, bogs’ primary water sources come from precipitation, fog and snowmelt, creating ombrogenous conditions. Precipitation is mildly acidic and does not contain dissolved minerals, resulting in low acidity and mineral content in bogs (National Wetlands Working Group, 1997; Zoltai & Pollett, 1983). Bog pH is also decreased through the decomposition of peat and the acids present in *Sphagnum* leaves (National Wetlands Working Group, 1997). *Sphagnum* also contributes to the acidity by removing minerals from surface water and replacing with hydrogen ions (Galbrand, 2004). The slow level of decay also creates a very nutrient-poor environment. Bogs are frequently dominated by *Sphagnum* mosses with tree, shrub or treeless vegetation cover. Vegetation present in bogs is adapted to acidic conditions. Bog forms can be differentiated by surface form, relief or proximity to water bodies, and include domed bogs, flat bogs and riparian bogs (National Wetlands Working Group, 1997). An estimated 30% of global wetlands are bogs (2005) (Balliett, 2010).

2.1.2.4 Fen

Fens are similar to bogs in that they are created with an accumulation of peat and are therefore considered a peatland (Banner & MacKenzie, 2000; Tarnocai, Kettles & Lacelle, 2011). Fens differ from bogs, however, in that the primary water source includes groundwater and surface water. Therefore, the water table, which lies close to the surface, has an increased amount of dissolved minerals and nutrient content and is minerotrophic (National Wetlands Working Group, 1997). This varied water source also decreases acidity. Fens can vary in mineral content, with waters low in dissolved minerals defining poor fens, and waters with higher concentrations of minerals defining rich fens (National Wetlands Working Group, 1997). The increased nutrient content and decreased acidity allows for less tolerant vegetation, such as sedges, brown moss peat, graminoids and shrubs to establish. Black spruce and willows can be found in fens (National Wetlands Working Group, 1997; USEPA, 2000; Zoltai & Pollett, 1983). Fen conditions allow for more rapid decomposition than bogs, which results in slower and thinner peat accumulation (Langlois, 2013). Fen forms can be differentiated by surface pattern, relief, topography and proximity to water bodies, and include spring fens, slope fens and riparian fens (National Wetlands Working Group, 1997). An estimated 26% of global wetlands are fens (2005) (Balliett, 2010).

2.1.2.5 Shallow Open Water Wetland

Although not recognized as a distinct wetland class by the National Wetlands Working Group, shallow open water wetlands can also be considered a wetland type (Canadian Wildlife Foundation, 2013). Shallow open water wetlands are wetlands with a well-defined basin, with precipitation, snowmelt and surface runoff acting as the primary water source (Balliett, 2010). Vegetation in a shallow open water wetland include bottom-rooted plants, such as water lilies and submerged plants, such as milfoils. These wetlands have the potential to dry up due to evaporation, transpiration and seepage losses, and mud flats can be exposed (Canadian Wildlife Foundation, 2013).

2.1.3 Ecosystem Services

Wetlands are diverse natural systems that provide many benefits and functions that are of high importance to the natural and human world. These benefits can include: biodiversity, storm protection, commercial products, water purification and climate change control (Ardrop et al., 2011; Mitsch & Gosselink, 2015; Moseley, 2015).

2.1.3.1 Biodiversity

Wetlands provide critical habitats for numerous species of waterfowl, amphibians, reptiles, fish and mammals, and are particularly important for migratory bird species (Ducks Unlimited Canada, n.d.; Moseley, 2015; National Park Services, 2016). In the US, wetlands comprise only 5% of land cover, but contain approximately 31% of the US's plant species (Watson, 2012). As well, more than a third of the species on the US Endangered Species list live solely in wetlands, and half of all Endangered Species use wetlands in some capacity during their life cycle (Mitsch & Gosselink, 2007; National Park Services, 2016). Many animals need wetlands for part or all their lifecycles. For example, salamanders use wetlands seasonally to lay eggs and for larval development, whereas animals such as beavers (*Caster spp.*) or mud minnows (Umbridae) use wetlands year-round (USEPA, n.d.-a). Wetlands are essential for maintaining biodiversity within Canada (Environment Canada & Ducks Unlimited Canada, n.d.). Coastal wetlands support more than half of the commercially harvested seafood in the US (Dahl & Stedman, 2013; Office of Habitat Conservation, 2019).

2.1.3.2 Storm Protection

Wetlands, particularly coastal wetlands, help to mitigate the effects of storm events (Boutwell & Westra, 2015; Gedan et al., 2011; Salgado & Martinez, 2017; Wamsley et al., 2010). This service has economic value. For example, mangrove wetlands in Thailand are quite important for storm protection from flood and tsunami damages (Russi et al., 2013). However, mangrove deforestation is estimated to cost $3.4 million USD (1996) annually from increased city vulnerability to flood damage (Barbier, 2007). Similarly, it's been estimated that the average value of wetlands in the north Gulf coast is approximately $26,000 USD (2010) per ha per coast km per storm (Boutwell & Westra, 2015). Research done in the Chesapeake Bay region found coastal wetlands provide protection to nearby coastal communities, with effectiveness of protection influenced by proximity to coastal communities and sufficient relationships of size to surge attenuation (Haddad, Lawler & Ferreira, 2016). Protection by wetlands is dependent on the surrounding landscape and the strength and duration of the storm forcing. Models of these processes are key for integrating wetlands into storm protection plans (Wamsley et al., 2010). Vegetation is crucial, as plant stems and leaves will slow water velocity by providing a drag counter force. High vegetation density also reduces turbulence (Nepf, 1999) and erosion (Gedan et al., 2011). Coastal wetlands are negatively impacted by human activities, and it is critical to reduce this pressure by minimizing coastal development so as to maintain the storm surge benefit (Salgado & Martinez, 2017). Restoration of these systems is also key. Communities are likely to support the restoration activities when aware of the sub-Category 3 storm surge benefits (Kim & Petrolia, 2013).

2.1.3.3 Commercial Products

Wetlands are important for numerous agricultural industries worldwide (Balliett, 2010). In the US, approximately 75% of commercially harvested fish and shellfish and 90% of recreational fish require wetlands for a portion of their life cycle. The commercial value for US crab, shrimp and salmon in 2014 was valued at $167 billion USD, highlighting the economic importance of wetlands (USEPA, n.d.-a). Rice paddies are managed wetlands created to grow rice and are generally found in south and east Asia (Sheth, 2017). Produce from these paddies feed approximately half of the global population (Mitsch & Gosselink, 2015).

Additionally, bogs in North America are frequently used to grow cranberries. Nova Scotia is recognized as having ideal climatic conditions for growing cranberries, and cranberries have been commercially grown in the province for over 100 years. Varities of Nova Scotia cranberries include Stevens, Ben Lear and Early Black. Once a cranberry bog is firmly established, a grower can harvest 175 barrels of wet harvest cranberries per acre, which can sell from $40 to $80 per barrel (Jones, 2009). Commercial products from wetlands also include trapping furbearing animals, such as muskrats, for fur pelts. Economic value from these activities is approximated at $124 million USD (2010) (USEPA, n.d.-a).

2.1.3.4 Water Purification

Wetlands are known as the “kidneys of the Earth” because of their water purification abilities (Liu & Sun, 2010). Wetlands act as effective filters because the plants present in wetlands slow down water entering the system, which then cause sediment carrying various contaminants to settle out. Plant roots and microorganisms present in the water column absorb these contaminants, essentially purifying the water. Scientists have taken this process and applied it to create treatment wetlands, which can be used to treat wastewater at a fraction of the price of traditional wastewater treatment facilities (Mitsch & Gosselink, 2015; USEPA, 2006). Many anaerobic and aerobic processes occurring within and near wetlands promote denitrification and other chemical reactions that act to remove certain chemicals from water (Mitsch & Gosselink, 2007).

2.1.3.5 Climate Change Control

Wetlands play an interesting role when considering climate change. Wetlands are estimated to emit approximately 20 to 25% of global methane emissions, considered a greenhouse gas, per year (Mitsch & Gosselink, 2015). However, wetlands also sequester and store great quantities of carbon due to fast growing vegetation, as well as their water-logged soils preventing decomposition. Peatlands cover an estimated 3% of global land and contain 30% of terrestrial carbon (Perceval & Cadmus, 2015). Additionally, coastal wetlands sequester large amounts of carbon in present biomass and soil in a process known as "coastal wetland blue carbon" (Howard et al., 2017). These processes are important for regulating climate temperatures. However, climate change negatively effects wetlands through processes such as increased evapotranspiration which causes wetland drying (Mitsch & Gosselink, 2015; Springer, Manker & Pigati, 2015). This drying, as well as wetland destruction due through human activities, releases the carbon stores, which in turn increases the amount of carbon in the atmosphere. Dried coastal wetland areas cannot store as much carbon. Stored and atmospheric carbon is then consumed by microorganisms, which then respire the carbon quickly into the atmosphere (Fig. 5) (Howard et al., 2017).

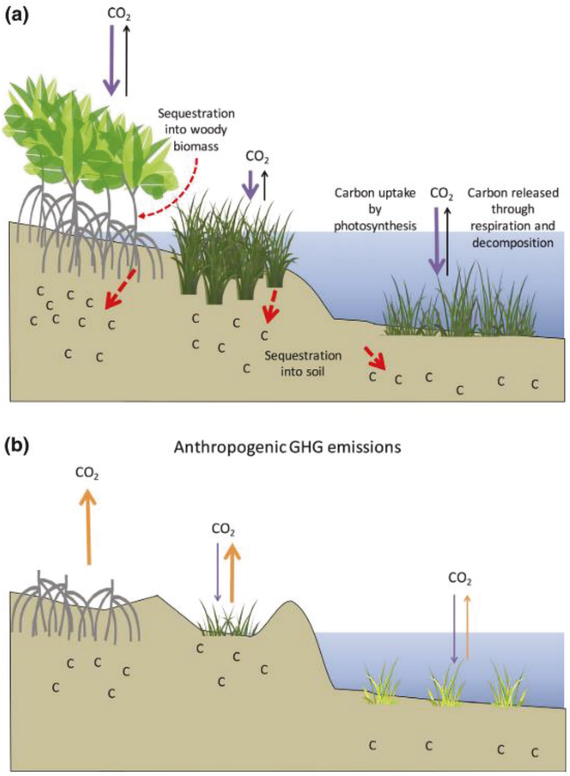

Figure 5: Carbon sequestration between an intact coastal wetland (a) and a dried coastal wetland (b). In an intact coastal wetland, carbon is taken up through photosynthesis and stored long-term in soil and biomass. In a dried coastal wetland, carbon is consumed by microorganisms, which respire the carbon back into the atmosphere. Image from Howard et al. (2017).

2.1.3.6 Recreation

There are numerous recreational activity opportunities in wetlands, including boating, hunting and birdwatching (ANR Department of Environmental Conservation, n.d.). In 2006, an estimated 31% of US citizens photographed, observed or fed wetland wildlife, spending a collective $45 billion USD to partake (Ramsar Convention Secretariat, 2008). Money generated from these activities can benefit local businesses, economies and provide funds for conservation efforts (USEPA EnviroAtlas, 2016). American waterfowl hunters generate $50 billion USD annually through hunting and conservation, and provide a strong wetland preservation focus (Ramsar Convention Secretariat, 2008).

2.1.4 Wetland Hydrology

Wetland hydrology is important for maintaining a wetland's unique structure and function and is closely interconnected with abiotic and biotic features (Moore & Garratt, 2008). Hydrology affects many abiotic features, such as soil anaerobiosis, nutrient availability, pH and sediment transport, which determine the biota that can establish in the wetland. Hydrologic changes can dramatically affect the species composition and ecosystem productivity in a wetland, as species adapted to particular water depths and oxygen compositions will flourish in certain conditions (Mitsch & Gosselink, 2007). The seasonal pattern of the water level, or hydroperiod, can vary greatly year to year, and influence wetland features such as the wetland macroinvertebrate composition (Tarr, Babar & Babbitt, 2005). In turn, the biota affects wetland hydrology through productivity, decomposition and nutrient cycling (Cherry, 2011).

Understanding of the hydrology of the wetland begins with the climate and basin geomorphology. Cool or wet climates tend to encourage wetland presence, as less water loss through evapotranspiration occurs in cool climates, and wet climates provide excess precipitation (Mitsch & Gosselink, 2007). As well, geomorphology affects the location of wetlands, as gentle slopes provide a better landscape for wetland development than steep slopes (Mitsch & Gosselink, 2007). The hydroperiod is a result of three factors: the balance between water inflow and outflow, landscape surface contours, and soil, geology and groundwater conditions. The inflow and outflow balance can be calculated with a water budget (Equation 1), which is expressed as:

$$\frac{\Delta V}{\Delta t} = Pn + Si + Gi - ET - So - Go \pm T \qquad \text{(Eq. 1)}$$

Where:
$\frac{\Delta V}{\Delta t}$ = change in volume of water storage over time
P_n = net precipitation
S_i = surface inflows
G_i = groundwater inflows
ET = evapotranspiration
S_o = surface outflows
G_o = groundwater outflows
T = tidal inflows (+) and outflows (-)

The presence and strength of each input and output in the generalized water budget (Fig. 6) varies depending on wetland types (Mitsch & Gosselink, 2015; Moore & Garratt, 2008). For example, the precipitation input for a bog would dominate all other inputs, whereas inputs in a marsh would be dominated by surface and groundwater.

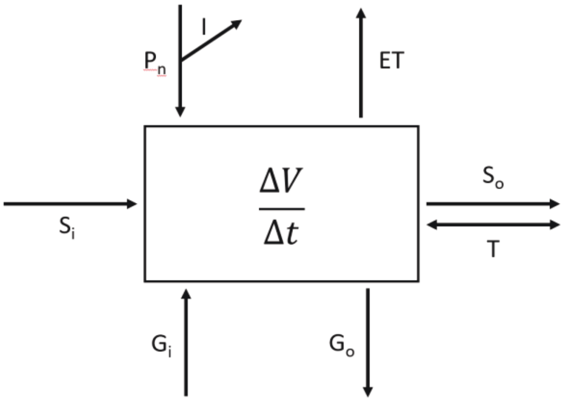

Figure 6: General wetland water budget, terms corresponding with equation above (modified from Mitsch and Gosselink, 2007).

When considering precipitation (P) in the water budget, consideration of interception (I) by overlying vegetation canopy must be given. The intercepted water is lost in the equation, and only the precipitation that passes through, called the throughfall or net precipitation, is added to the water budget. Interception depends on factors such as density of vegetation and the intensity of precipitation, with anywhere for 8 to 35% of precipitation being intercepted (Mitsch & Gosselink, 2007). The influence of surface water (S) and groundwater (G) varies between and within wetland types. For example, some wetlands receive surface water inputs in the form of overland flow following a flooding event, whereas others receive streamflow from a channel year-round. The positioning of the wetland's surface water to groundwater affects the amount of inflow, with discharge wetlands having surface water levels below the groundwater and recharge wetlands have groundwater below surface water levels (Mitsch & Gosselink, 2007). Both broad types of inputs provide high mineral contents for wetlands. Evapotranspiration (ET) is the term given to water loss from evaporation and moisture passing through vascular plants to the atmosphere (Allen, Raes, Smith, & Pereira, 1998). When water supply is limited, ET is limited as well (Mitsch & Gosselink, 2007).

Hydrology affects several features of wetland function, including species richness, primary productivity, accumulation of organic material and nutrient cycling. Hydrologic conditions will generally cause selection of water-tolerant vegetation to thrive. Relatively few plant species are well adapted for waterlogged soil and can therefore dominate wetland systems (Cherry, 2011; Mitsch & Gosselink, 2007). Hydrologic pulses can also increase species richness and productivity as pulses, such as flooding events, can renew minerals and reduce anaerobic conditions in wetlands (Odum, Odum & Odum, 1995). The pulse frequency affects whether it is a subsidy or a stress on the wetland (Fig. 7). Productivity tends to be low when water is stagnant or frequently flooded, and highest during seasonal flooding (Odum et al., 1995). Nutrients are carried into wetlands by hydrologic inputs and are carried out of wetlands by outflows (Mitsch & Gosselink, 2007).

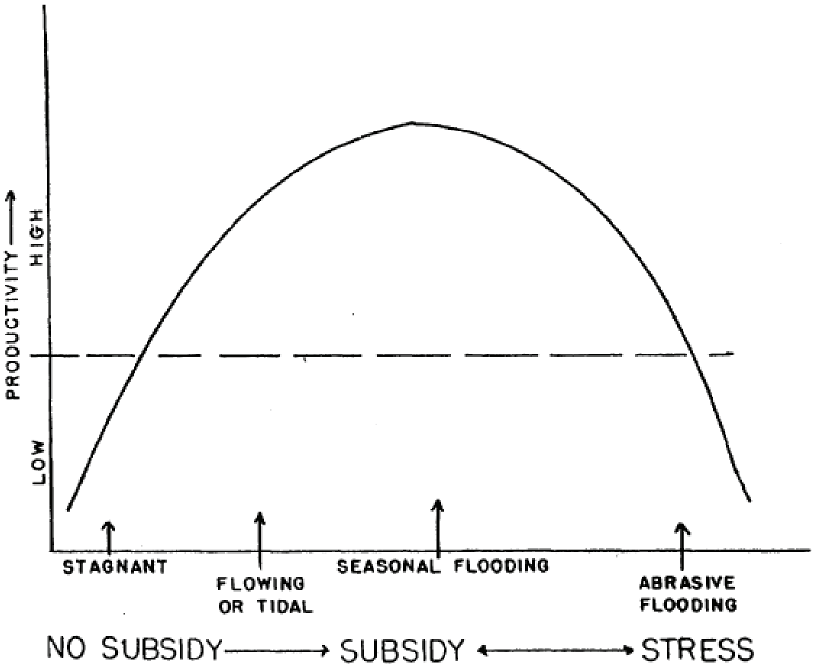

Figure 7: The relationship between flooding gradient and wetland productivity (Odum et al., 1995).

2.1.5 Wetland Biogeochemistry and Physical Processes

Biogeochemical cycling is the transport and transformation of chemicals in an ecosystem, and wetland biogeochemistry is unique from other ecosystems due to permanent or intermittent flooding events (Moore & Garratt, 2008). For example, wetland soils are waterlogged for all or part of the year, resulting in reduced conditions. These reduced conditions cause anaerobic biogeochemical transformations to occur (Mitsch & Gosselink, 2015). Wetland soils are often referred to as hydric soils as they form during periods of saturation or flooding, resulting in anaerobic upper layers. Wetland soils are described as either being mineral soils or organic soils (Balliett, 2010).

Mineral soils are typically black, grey or blue-grey when created in a flooded environment as the result of iron reduction, whereas in unsaturated mineral soils, the oxidation of iron results in red, brown, yellow or orange soils (Mitsch & Gosselink, 2007). Mineral soils contain little to no organic matter and are associated with nutrient rich wetlands. The lateral groundwater flow and pulsing hydroperiods in mineral soils result in higher plant productivity and more rapid decomposition (Banner & MacKenzie, 2000). Mineral soils also contain an oxidized rhizosphere, which is formed when hydrophytes diffuse excess oxygen into the soil matrix (Mitsch & Gosselink, 2007).

Organic soils contain at least 20 to 35% organic matter and 12 to 18% organic carbon. This percentage varies depending on the clay content (Mitsch & Gosselink, 2015). Organic soils are made of decomposed plants that accumulate due to anaerobic conditions. Organic soils are classified based on the botanical origin, such as moss, herbaceous material and wood litter, and the state of decomposition (Mitsch & Gosselink, 2007). Mineral soils differ from organic soils in that organic soils have lower bulk densities and higher water-holding capabilities than mineral soils. Organic soils generally have more unavailable organic forms of minerals than mineral soils, as well as a greater cation exchange capacity (Mitsch & Gosselink, 2007). Wetland soils are the medium in which most of the following transformations take place.

2.1.5.1 Reduction/Oxidation

As previously stated, anaerobic conditions generally occur when soils are inundated with water. This is the result of slower diffusion rates of atmospheric gas in an aqueous solution than in a porous solution, causing a decrease in oxygen and an increase in carbon dioxide in wetland soil (Pezeshki & DeLaune, 2012). The lack of oxygen prevents plants from performing aerobic root respiration (Mitsch & Gosselink, 2007). However, most wetland soils contain a thin oxidized layer of sediment above the anaerobic, or reduced, layer. The thickness of this layer is influenced by the rate of oxygen transport across the atmosphere-surface water interface, the present population of oxygen-consuming organisms, the amount of oxygen produced by algae, and surface mixing through convection and wind action (Mitsch & Gosselink, 2007). An oxygen rich area, called the rhizosphere, is created by plant root aeration facilitating diffusion of atmospheric oxygen from aerial portions of plants, to the roots and finally to the surrounding soil. This rhizosphere creates a complex, high surface-area hyporrheic zone which is important for reduction-oxidation reactions (Neori & Agami, 2017; Winton & Richardson, 2017).

Reduction-oxidation, also known as redox reactions, are chemical processes that involve transfer of electrons from one compound or solution to another (Galbrand, 2004). Oxidation occurs when a hydrogen atom is removed during the uptake of oxygen, and usually occurs in oxygen rich soils. Reduction releases oxygen and gains hydrogen and usually occurs in oxygen deficient soils (Mitsch & Gosselink, 2007). More generally, oxidation is the loss of an electron, and reduction is the addition of an electron (Pezeshki & DeLaune, 2012). Redox reactions facilitate the transformation and cycling of many chemicals, as described below.

2.1.5.2 Carbon Transformation

The carbon cycle occurs in wetlands under aerobic and anaerobic conditions, as seen in Fig. 8 (Wetlands and Waterbirds Taskforce, 2012). Aerobic driven carbon transformations occur through photosynthesis and aerobic respiration, with water as the main electron donor in photosynthesis and oxygen as the main electron acceptor in respiration (Mitsch & Gosselink, 2007). This process is quite efficient. However, due to the general anoxic quality of wetlands, anaerobic processes occur, which are less efficient than aerobic processes (Mitsch & Gosselink, 2015).

The two major anaerobic processes are fermentation and methanogenesis. Fermentation occurs when organic matter is the electron acceptor, with major products being ethanol and carbon dioxide (Mitsch & Gosselink, 2007; Wetlands and Waterbirds Taskforce, 2012). Fermentation has low adenosine triphosphate (ATP) production, and therefore may lead to carbohydrate depletion in plants (Wetlands and Waterbirds Taskforce, 2012). Methanogenesis occurs when methanogens use carbon dioxide or a low-molecular-weight organic compound as an electron acceptor for the production of gaseous methane. Methane production requires reduced conditions (Mitsch & Gosselink, 2007). Methane emissions are higher in permanently flooded wetlands, suggesting that seasonal pulsing can reduce these fluxes (Altor & Mitsch, 2008). Salinity also inhibits methane production. When wetlands are dry, they can act as methane sinks (Wetlands and Waterbirds Taskforce, 2012).

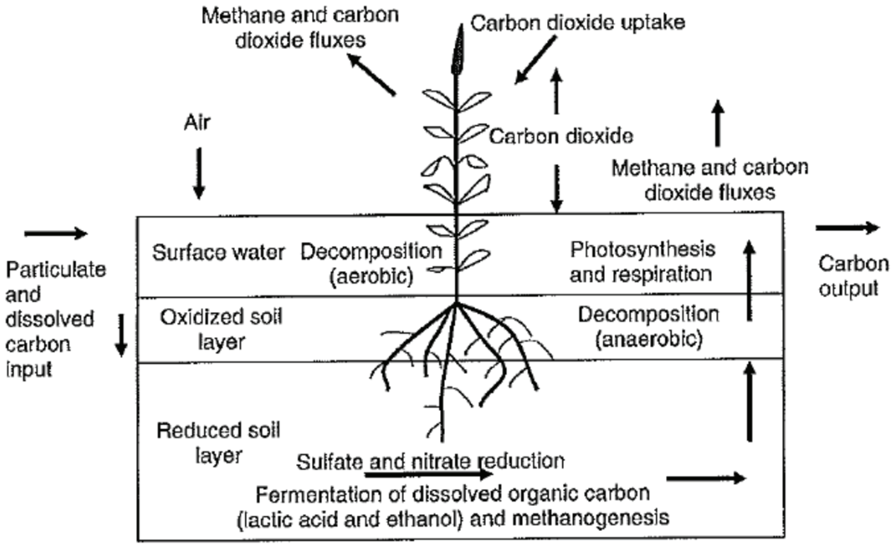

Figure 8: Carbon cycle in wetlands in aerobic and anaerobic conditions (Wetlands and Waterbirds Taskforce, 2012).

2.1.5.3 Nitrogen Transformation

Nitrogen is one of the most important compounds for wetlands, and its cycle within wetlands has been extensively studied (Mitsch & Gosselink, 2007; Zhou, Zhao & Shen, 2014). Sources of nitrogen in wetlands include runoff, atmospheric deposition and biological nitrogen fixation, and the primary forms of attenuation are denitrification, anaerobic oxidation and plant absorption (Zhou et al., 2014). Nitrogen is often the most limiting nutrient in flooded soils.

Nitrogen transformation includes a series of pathways. Nitrogen in organic matter is released as ammonia during decomposition and degradation in a process known as nitrogen mineralization or ammonification (Galbrand, 2004). This process can occur under aerobic and anaerobic conditions (Mitsch & Gosselink, 2007). In oxygen poor areas, ammonia can be converted back to nitrogen through microbial action, uptake by plants, or diffusion into sediment. In aerobic conditions, ammonia then undergoes nitrification, where it is oxidized to nitrite by the bacteria *Nitrosomonas,* followed by oxidation to nitrate by *Nitrobacter* (Zhou et al., 2010). Nitrate can then be assimilated into plants, reduced by bacteria to nitrogen gas through dentrification, or converted back to ammonia through dissimilatory nitrate reduction (Mitsch & Gosselink, 2007; Zhou et al., 2010).

2.1.5.4 Metal Transformation

A plethora of metals are common in wetlands, and include cadmium, iron, lead and zinc (Galbrand, 2004). Transformation of these metals in wetland systems is complex. Heavy metal transformation and removal mechanisms vary, and include: 1) adsorption to fine sediments and organic matter through processes such as sedimentation, flocculation, or cation/ion-exchange; 2) removal as insoluble salts; 3) absorption through plant and bacteria biogeochemical cycles and 4) deposition in sediments in lentic conditions (Galletti, Verlicchi & Ranieri, 2010; Lesage et al., 2007; Mohammed & Babatunde, 2017). Heavy metals accumulate more readily in fine-grained, high organic-matter sediments than in coarse-grained sediments (Gambrell, 1994). The presence of oxygen also influences the transformation of metals in wetlands, as metals in anaerobic conditions generally precipitate as insoluble salts (Kröpfelová, Vymazal, Švehla, & Štíchová, 2009). Plants can accumulate metals by first mobilizing metal ions, where hydrated ions are taken up via various uptake systems in the plasma membrane. The metal ions are then transported to the shoot through the xylem. When ions reach the leaf, they are captured by different leaf cell types and stored in the trichomes (Clemens, Palmgren, & Krämer, 2002). Once in the leaf tissue, contaminants can be released back into the environment through leaf excretion or decomposition (Galletti et al., 2010). The ability of plants to remove, transform and sequester micro and macronutrients has applications for phytoremediation which has been used heavily in constructed wetlands for treatment of wastewaters (Clemens et al., 2002; Vymazal & Březinová, 2016).

2.1.5.5 Other Transformations

Several other transformations occur in wetland systems, involving phosphorus, iron and manganese. Sulfur occurs in many different states of oxidation and is transformed through several different pathways (Mitsch & Gosselink, 2007). Sulfur can be reduced through anaerobic respiration to produce hydrogen sulfide, which produces the classic “rotten egg” smell in wetlands (Chen et al., 2016). Chemoautotrophic and photosynthetic microorganisms can oxidize sulfur to sulfate and elemental sulfur (Mitsch & Gosselink, 2007).

Phosphorus is the limiting nutrient for primary productivity in freshwater ecosystems (Galbrand, 2004). Phosphorus occurs in both soluble and insoluble complexes in organic and inorganic forms and cycling of phosphorus involves transformations between these phases (Galbrand, 2004; Mitsch & Gosselink, 2007). The proportion of these phases depends on soil, vegetation and surrounding land use (Reddy, Kadlec, Flaig & Gale, 1999). A majority of wetland phosphorus is contained in organic litter, peat and inorganic sediments (Mitsch & Gosselink, 2007). Dissolved inorganic phosphorus is generally bioavailable, whereas organic phosphorus must undergo transformations to become bioavailable. Soluble, inorganic forms of phosphorus, such as PO_4^{3-}, HPO_4^{2-} and H_2PO^{4-} are readily assimilated and released in plant, periphyton and microbial tissue (Reddy et al., 1999).

Iron and manganese reduction occur in tandem following flooding events, making these elements more soluble and available to organisms (Mitsch & Gosselink, 2015). Iron and manganese can be oxidized by chemosynthetic bacteria in the presence of oxygen. In their reduced form, iron and manganese can reach toxic concentrations (Mitsch & Gosselink, 2015).

2.1.6 Wetland Loss and Need for Restoration

Wetlands are important ecosystems, yet historically societies have viewed them as harsh and dangerous “wastelands” which could not be built on, hosted disease carrying insects and contained impassable vegetation (Balliett, 2010). This negative perception led to wetlands being drained, filled and used for agriculture, thus affecting the surrounding hydrology (McCartney & de la Hera, 2004). Wetlands are also overexploited due to the abundance of fish, fuel and water present in those systems (National Research Council, 1995). It was not until recently that the true value of wetlands was realized, albeit late. It is estimated that long term loss of natural wetlands is 54 to 57% worldwide, but may be as high as 87% since 1700 AD (Davidson, 2014). In the US, an estimated 53% of wetlands have been lost from the 1780s to the 1980s (Mitsch & Gosselink, 2007). Following increased awareness and desire for protection, wetland losses have slowed in the US since the 1980s, from 2.5% loss between 1970 to 1980, to 0.6% loss in the subsequent decade (Mitsch & Gosselink, 2007). Wetland loss still remains high in Asia (Davidson, 2014).

Canada has an estimated wetland area three times greater than the US. Attempts to estimate wetland loss are difficult because of the vastness of this area; however, in highly populated urban areas of southern Ontario, wetland loss is estimated at 80 to 90%. Coastal marshes in the Atlantic and Pacific regions have suffered a 65 to 80% loss rate (Mitsch & Gosselink, 2007). Wetland loss in Nova Scotia has had limited analysis therefore making estimations difficult. However, it is anticipated that 50% of salt marshes within the province have been lost due to dyking. Wetland loss has also occurred with inland freshwater wetlands due to agriculture and urban developments (Nova Scotia Government, 2017). These extreme losses highlight the need for effective reclamation and restoration strategies. Wetlands are unique in their ecological makeup, and therefore research and practice are required to understand how these systems should be restored (Biebighauser, 2007). Part of this research involves understanding how different practices, including contaminant release have affected wetlands. The types of contaminants being released into wetlands is vast, each coming with unique negative effects, and each requiring a different restoration tactic (Biebighauser, 2007). Effects of contaminants can include decreased biota biodiversity, decreased biota abundance and altered biogeochemistry transformations (Jamshidi-Zanjani & Saeedi, 2013; Jones et al., 2009). Due to the decrease in wetlands, wetland restoration science has started to gain traction and restoration processes have advanced in the last couple of decades (Biebighauser, 2007).

2.2 History of Boat Harbour

2.2.1 Pre-1967

In Nova Scotia in the late 1950s, the Progressive Conservative government, under the leadership of Premier Stanfield, was attempting to encourage provincial economic growth. Following the end of the Second World War, many communities in the province had become economically depressed (Baxter, 2017). A US pulp company, known as Scott Paper Company, had purchased land on Abercrombie Point in the early 1950s to build a new mill. In 1964, Premier Stanfield announced that an agreement had been reached for Scott Paper Company to build the mill and begin operation (Baxter, 2017; Nova Scotia Crown Corporation, 1965). However, this deal came at great cost to the government. Originally, the province offered Scott Paper Company 230 000 acres of Crown land in Halifax County to harvest timber (Nova Scotia Crown Corporation, 1965). The province also agreed to build and pay for a causeway across Middle River, as well as a pumping station to provide fresh water (Nova Scotia Crown Corporation, 1965).

In addition to these incentives, the government agreed to cost, own, operate and maintain a facility to treat the mill's wastewater effluent at a substantial discount to the mill at a cost of either $12.03 per million Imperial gallons or $100 000 a year. As part of this deal, the government agreed to indemnify Scott Paper Company from liability relating to the effluent (Baxter, 2017). Following this agreement, a tidal estuary located just over 4 km northeast of Abercrombie Point, was chosen to act as a treatment area. This estuary is located within the Mi'kmaq Pictou Landing First Nation (PLFN) community and has historically been referred to as "A'se'K". A'se'K held great value with the people of PLFN as it was used as a place to gather, swim, fish and forage. A'se'K also held great spiritual and cultural importance to PLFN (Bennett, 2013; Castleden et al., 2016; Castleden, Bennett, Lewis, & Martin, 2017). When the government decided A'se'K would be ideal for the mill's treatment purposes, officials were sent to the community to gain permission. The chief of the Pictou Landing Band and a band councillor were taken to a "similar treatment facility" in New Brunswick, which appeared clean and healthy. This lessened concerns, and rights to A'se'K were sold for $65 000 CAD (Baxter, 2017). In 1967, the mill began operating and commenced releasing effluent into A'se'K. Years later, PLFN learned the chief and councillor were not taken to a similar facility, but instead to a non-operational, sewage treatment facility, and were not properly informed of effluent effects on A'se'K (Baxter, 2017; Castleden et al., 2016).

2.2.2 1967-1972

In 1967, effluent input into A'se'K began. The early treatment scheme consisted of the collection of raw effluent at the mill into gravity sewers, and transport in pipelines under East River. The raw effluent was released into an effluent ditch near Highway 348, where it flowed into a wetland area southwest of A'se'K (GHD, 2018a). As discussed previously (Section 2.1.5), wetland values were not fully understood until the 1970s. Therefore, discharging the raw effluent into these "wastelands" was likely not an issue for the planners at the time.

Following the discharge into the wetlands, the effluent would then enter a settling pond before being discharged into A'se'K, or, as it is more commonly referred to today, the Boat Harbour Treatment Facility (BHTF) (GHD, 2018a). The ultimate destination for the effluent was the Northumberland Strait, after treatment at BHTF. Due to the nature of the contaminants within the effluent, including high biological oxygen demand, this "treatment plan" was not able to adequately remove the contaminants, resulting in death "en masse" of biota within the BHTF (Baxter, 2017; Bennett, 2013; Castleden et al., 2016). A'se'K could no longer be used by PLFN for recreational, spiritual or hunting/food gathering use. This treatment scheme continued for five years.

2.2.3 1972 to 2014

To address the issues with the original treatment facility, improvements were made which are still in use. Raw effluent from the mill continues to be piped across East River but is discharged into a lined ditch, which empties into two settling basins to allow for sedimentation (GHD, 2018a; Hoffman et al., 2017a). Effluent then flows into the aerated stabilization basin (ASB). The ASB utilizes microbes and aerators to treat the effluent (Hoffman et al., 2017a). The treated effluent is released into the Stabilization Lagoon (Boat Harbour), where it remains for approximately 20 to 30 days before being released into the Northumberland Strait (GHD, 2018a). A dam was also constructed in 1972 that disconnected Boat Harbour from the Northumberland Strait. This dam stopped the tidal influences, and effectively turned the tidal lagoon into a freshwater lake (Province of Nova Scotia, n.d.).

Ownership of the mill has changed several times since its conception in 1967; to Kimberly Clark Inc. in 1997, Neenah Paper in 2004 and Northern Pulp in 2008. In 1991, operation of the BHTF transferred to the Nova Scotia Department of Supply and Services. In 1996, operations were transferred to the mill owner at the time, Kimberly Clark Inc., under a lease agreement with the government (GHD, 2018a). Several updates have been made to BHTF since 1972. In 1993, the aeration system was modified to improve aerobic treatment. In 1996, further alterations increased aeration, as well as the addition of three curtains in the ASB to improve mixing. In 1997, an automated nutrient addition system was installed prior to the ASB. This system provides urea and diammonium phosphate to the effluent to improve microbial growth and reduce biological oxygen demand levels. In 2004, more aeration units were added to the ASB to improve treatment (Dillon Consulting Limited, 2019a).

PLFN have been frustrated about the use of A'se'K since the mill began operations (Bennett, 2013; Castleden et al., 2016, 2017). The community has been fighting to have the treatment facility closed and remediated back to its original state. Promises have been made, and subsequently broken, between PLFN and the government to close and remediate the BHTF. For example, in 1995, a promise was made to close the BHTF by 2005. However, in 2005 the mill (owned by Neenah Paper) and the government requested an extension from PLFN to 2008, which was granted. In 2008, the license was extended without consulting PLFN (Castleden et al., 2016).

2.2.4 Boat Harbour Act (2015)

In 2014, a pipe carrying effluent from the mill leaked, spilling 47 million L of raw effluent on sacred burial grounds at Indian Point (Baxter, 2018; Castleden et al., 2016; Hoffman et al., 2017a). Following this, demand for the closure of the facility was high. In 2015, the government consented, and created the *Boat Harbour Act* (2015), which mandated the closure of the facility by January 31, 2020. The *Boat Harbour Act* also promised the BHTF would be remediated back to the original tidal lagoon state, so that PLFN could resume their original use of the land (Castleden et al., 2016).

2.2.5 Baseline assessments looking towards January 2020

Before remediation can occur, assessments of the area must be completed to properly delineate remediation areas (GHD, 2018a; WSP, 2018). Nova Scotia Lands, the proponent in charge of the remediation, hired GHD, an environmental consulting firm, to complete these assessments. Starting in 2017, GHD collected media deemed appropriate by the Phase 1 Environmental Site Assessment (ESA), including sediment, surface water, groundwater and soil samples, at all Areas of Potential Concern (APEC). These samples were then analyzed for the contaminants of potential concern (COPC), described in Section 2.4.

2.3 Kraft Pulp

2.3.1 Pulping Process

The mill at Abercrombie Point uses a kraft pulping process. The objective of the pulping process is the extraction of cellulose from wood through dissolving lignin. Lignin is a phenylpropanoid polymer that surrounds the cellulose-hemicellulose framework in wood. Due to the random polymerization structure, lignin can be quite difficult to degrade (Murray, 1992). The kraft process cleaves lignin ether bonds in wood chips at elevated temperatures and pressures in a chemical known as “white liquor”. White liquor is a water solution of sodium sulfide (Na_2S) and sodium hydroxide (NaOH) (Costa, Bakhtiari, Shuster & Paris, 2009; USEPA, 1995). In general, there are five main steps to the kraft process: Digesters, Blow Tank, Washing, Bleaching, and Drying (Fig. 9) to transform ligno-cellulosic material (wood chips) to a finished paper product (pulp).

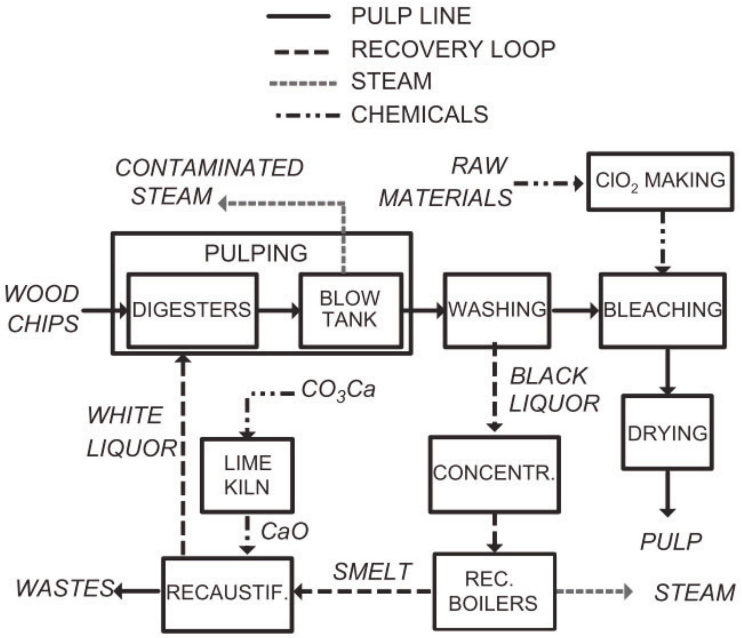

Figure 9: Kraft pulp process, including waste processing (Costa et al., 2009).

A digester is a large tank that contains a combination of chemicals, as well as heat and pressure. The initial product, wood chips, are treated with white liquor, a delignifying agent composed of a mix of alkaline NaOH and Na_2S in the digesters at temperatures of 160 – 180°C (Costa et al., 2009). Depending on the mill, there can be several digesters working in tandem. The delignifying agent dissolves 90 to 95% of lignin ether bonds, hemicellulose, wood extractives and small quantities of polysaccharides from wood chips (Murray, 1992). Contents from digesters are then sent to atmospheric tanks called blow tanks (USEPA, 1995). The blow tanks depressurize the products. Steam is released in this process that contains wood volatiles and other contaminants, and cannot be reused (Costa et al., 2009). Following the blow tanks, a series of washers are used to separate any fibers from the residual digesting liquor, called black liquor (Costa et al., 2009). The pulping and washing process is complete with a lignin content of 5 to 10% to avoid any unnecessary degradation of fiber quality (Murray, 1992).

Generally, washed pulp is bleached on site. In elemental chlorine bleaching, the washed pulp is prepared into a 3% slurry, which is treated with a chlorine charge of 60 to 70 kg/t at a low pH. Following this, the slurry is filtered and undergoes an alkali treatment at 35 to 40 kg/t at a high pH (Murray, 1992). The bleaching process then varies depending on the mill, but generally the pulp is treated with a hypochlorite treatment, a chlorine dioxide treatment and an alkali treatment (Murray, 1992). In 1991, it was estimated that 47 Canadian mills used chlorine bleaching, and collectively released 610 000 tonnes of chlorine annually (Minister of Supply and Services Canada, 1991). Concerns about the presence of toxic chlorinated substances in effluent due to this process, including polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF), led to companies utilizing chlorine dioxide instead of elemental chlorine (Beckenstein & Webb, 1995; Solomon, 2007). Chlorine dioxide reacts differently with lignin, creating muconic acid esters during lignin oxidation. Chlorine dioxide is then reduced to chlorite ions and hypochlorous acid. The chlorite ions can decompose to form chlorine dioxide and chlorine ions or can react with hypochlorous acid to from chlorinated organic compounds. The total creation of chlorinated organic compounds can be controlled through pH, as acidic conditions result in chlorine ions, neutral conditions result in hypochlorous acid, and alkaline conditions form hypochlorite (Solomon, 2007).

The bleached fibers, now effectively "pulp", are formed into sheets as they pass through a sheet former. The sheets are then pressed and dried to remove any remaining water (USEPA, 1995). Sheets are cooled, cut and baled. Following this step, the bales are wrapped and shipped to customers to complete the pulping process.

2.3.2 Waste Management

Several steps in the pulping process result in waste that must be managed. Black liquor is produced during the washing stage. It is rich in organic components, such as degraded lignin, as well as residual chemicals from the digesting process (Costa et al., 2009). After by-products are recovered from the black liquor in the Washing stage, the black liquor is then evaporated to higher concentration, generally 65% solids, in an evaporator (Murray, 1992; USEPA, 1995). The concentrated liquor is then fired in a furnace for recovery of energy and inorganic materials. Inorganic compounds in the black liquor collect at the bottom of the recovery boilers as smelt. The smelt is then redissolved to form green liquor, which is purified and recaustified with lime to form white liquor. The white liquor is used in the Digestor process (Costa et al., 2009; USEPA, 1995). The evaporated phase from the black liquor contains inorganic sulphur, such as sulphate or sulphite, and is trapped in a condenser. Escaped volatile emissions and burnt concentrated black liquor from the condenser can be released into the atmosphere (Murray, 1992). Additionally, the pulping phase releases air contaminants such as particulate matter, sulphur dioxide and total reduced sulphur compounds, which contribute to the characteristic foul odour associated with pulp mills (Murray, 1992). During the bleach plant process, approximately 1 t of softwood pulp produces 1 kg of extractives, 19 kg of polysaccharides, and 50 kg of lignin.

2.3.3 Focus Mill Process: Past and Present

The mill at Abercrombie Point follows a very similar pulping process to the one outlined above. From 1967 to 1992, a chlor-alkali plant generated sodium hydroxide and chlorine for the pulping and bleaching process. In 1994, the mill began replacing elemental chlorine with chlorine dioxide for the bleaching process, and by 1998, the bleaching process used 100% chlorine dioxide (Dillon Consulting Limited, 2019a).

2.4 Contaminants of Potential Concern

2.4.1 Metals

There are several metals present in pulp wastewater effluent that can be toxic at certain concentrations. These include cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg) and zinc (Zn). Cd, Cr, Hg and Pb are non-essential elements that may be toxic to aquatic biota at elevated concentrations (CCME, 1999a, 1999b, 1999c, 1999d). In addition to pulp mill effluent discharges, these metals enter aquatic environments through aerial deposition and runoff and accumulate in bed sediments (CCME, 1999a, 1999b, 1999c, 1999d) .

Cadmium will associate with particulate matter, such as organic matter or iron and manganese hydroxides. The effects of increased metals above toxicity thresholds on benthic invertebrates include decreased abundance, increased mortality and behavioural changes. Site specific factors influence bioavailable uptake and may become more bioavailable as a result of ambient environment changes (such as sediment resuspension, metal remobilization or drops in pH). Dissolved Cd is the most available form (CCME, 1999a).

Chromium can exist in nine oxidative states, but the most common states are Cr^{6+} and Cr^{3+} (CCME, 1999b; Nriagu & Kabir, 2011; Oliveira, 2012). Cr^{6+} in the forms of chromate, dichromate and chromium trioxide have been identified as the most toxic forms because of the compounds' high oxidizing potential, solubility and mobility (Oliveira, 2012). Cr is most dominant and bioavailable in dissolved states (CCME, 1999b). Since Cr is found predominately in sediments, this pathway offers the main course for uptake (Oliveira, 2012). Likely, all forms of Cr in sediments is Cr^{3+} (CCME, 1999b). Cr^{3+} binds strongly to aquatic particles and can accumulate and persist in sediments (Moreno-Sánchez et al., 2006). Bioavailability of Cr depends on its partitioning between dissolved and particulate phases and can increase with changes in environmental conditions (such as sediment resuspension) (CCME, 1999b). Toxicity of Cr, especially forms of Cr^{6+}, includes inhibiting the growth of roots and shoots in plants (Skeffington, Shewry & Peterson, 1976).

Copper concentrations vary across Canada, but background concentrations are generally below ISQG values (CCME, 1999c). Cu pollution in the environment is caused by both natural sources and human activities, such as Cu mining and Cu piping in buildings (Kiprop, 2018). Toxic levels of Cu inhibit mineralization of nutrients in plants and damage to kidneys, respiratory tracts, livers, and metabolite abundance in biota (Jeppe et al., 2017; Kiprop, 2018). Toxicity of Cu can be mitigated by several factors, such as the addition of peat or organic matter (Malueg, Schuytema, & Krawczyk, 1986). Cu toxicity can also be reduced in plants through competition between cations, including Al^{3+} , Mn^{2+} and K^{+}, at the plasma membrane, and in bacterial pathogens through siderophores selectively binding Cu ions (Garénaux & Dozois, 2012; Wang et al., 2012).

Inorganic Pb poisoning has occurred for thousands of years (Gidlow, 2015). Adverse effects of Pb include increased mortality, abnormal development and decreased abundance in invertebrates (CCME, 1999d). In humans, Pb can negatively affect every organ in the body, particularly the nervous system (Wani, Ara & Usmani, 2015). High levels of Pb can be associated with increased rates of miscarriages (Nordstrom, Beckman & Nordenson, 1979), decreased sperm mobility (Lerda, 1992), delayed fetal and infant development (Hildebrand, 2011). Neurotoxicity (Rice, 1990) and anemia (Newman, 2010) are other common results of Pb poisoning. Organic Pb is generally more toxic than inorganic Pb (Prosi, 1989).

Zinc is an essential metal, and is predominantly found in nature in the oxidation state of Zn^{2+} (CCME, 2018). Zn metal is insoluble in water, but can form several salts that are soluble (CCME, 2018). Zn compounds are commonly used to coat iron and steel products, and can also be found in dentistry, medicine, paint and household products (Agency for Toxic Substances and Disease Registration, 2005; Natural Resources Canada, 2018). Zn occurs in suspended and dissolved forms in sediments. Abiotic factors, including pH, alkalinity and dissolved organic matter can affect the speciation of Zn (CCME, 2018). At high Zn concentrations, Zn can inhibit uptake of calcium in fish and invertebrates (Hogstrand, Wilson, Polgar & Wood, 1994; Spry & Wood, 1985).

Mercury is found naturally in nature, but at excessive amounts is considered one of the most toxic metals (CCME, 2003). Natural sources of Hg include rock weathering, forest fires and volcanic activity (CCME, 2003). Human activities that introduce Hg into the environment include gold mining (Taylor et al., 2005), kraft pulp processing (Murray, 1992) and coal burning (ECCC, 2016). The most toxic form of Hg is methylmercury (MeHg), which is created through the methylation of inorganic Hg by aquatic bacteria (Eagles-Smith et al., 2016). MeHg accumulates quite readily in biota and can cause risks to growth, breeding and survival (Eagles-Smith et al., 2016; ECCC, 2016). Several parameters can affect MeHg concentrations. De Klerk, De Klerk and Wepener (2013) found increased manganese concentrations in sediments increases the potential for Hg methylation. Health effects of Hg contamination include neurotoxicity in humans (ECCC, 2016).

2.4.2 Organic

PCDD/PCDFs are planar tricyclic aromatic hydrocarbons that are the by-products of anthropogenic activities (CCME, 2001a; Newman, 2010). PCDD/PCDFs can also be produced through natural processes, such as forest fires (WHO, 2016). There are 210 congeners of PCDD/PCDFs. Seventeen of these congeners contain chlorine in the 2,3,7 or 8 positions (positions shown in Fig. 10), and are known to be the most toxic (CCME, 2001b; Kanan & Samara, 2018). The most toxic of these congeners is 2,3,7,8-tetrachloro-p-dibenzo-dioxin (USEPA, n.d.-c). Ingestion is the main exposure route for human populations (Kanan & Samara, 2018).

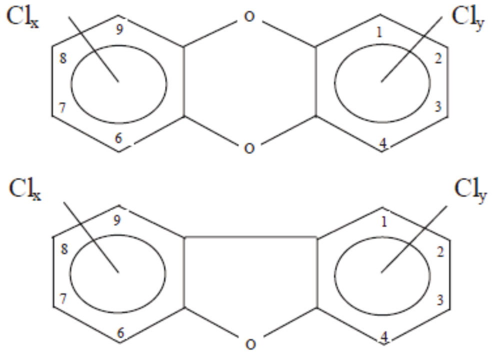

Figure 10: Chemical structure of PCDD/PCDF, with chlorine positions displayed.

2.5 Ecological Risk Assessments

Anthropogenic activities causing contamination of ecological sites is a global issue requiring trans-jurisdictional management practices (Suter, 2006). Majority of countries utilize similar assessment frameworks to manage and assess environmental sites. Assessments are important in understanding the effects, both realized and assumed, of contaminating activities. Ecological assessments began gaining traction in the 1990s with the increasing environmental impact awareness (Perrodin, Boillot, Angerville, Donguy & Emmanuel, 2011).

A common assessment framework that is used to study the effects of anthropogenic activities, including pulp mill effluent, is the ecological risk assessment (ERA). ERAs estimate the likelihood of negative effects to environmental factors from contaminant exposure, and provide a basis for remediation decision purposes. There are a variety of ERA types. In the US, ERAs follow a three tiered process (USEPA, 1992), whereas ERAs in Canada and the European Union follow a four tiered process (CCME, 1996; COA, 2008). Other ERA frameworks follow a cylindrical (Gormley, Pollock & Rocks, 2011) or triad approach (MacDonald et al., 1997).

ERA frameworks are commonly used to assess the potential of contamination from anthropogenic or other activities (Suter, 2006) or to characterize the extent of contamination post-event (USEPA, 2001).

2.5.1 Assessment Frameworks

In general, ERAs involve identifying the problem or hazard, analyzing the exposure and characterizing the risk (CCME, 1996; COA, 2008; USEPA, 1992). In Canada, there are both federal and provincial frameworks. An example of a Canadian federal framework is the Federal Contaminated Sites Action Plan (FCSAP), which provides an approach to managing federal contaminated sites (Contaminated Sites Management Working Group & Dillon Consulting Limited, 1999). The FCSAP follows a ten-step, tiered approach (Fig. 11) to determine whether remediation is required, and to what extent (Contaminated Sites Management Working Group & Dillon Consulting Limited, 1999; FCSAP, 2017). FCSAP assessments begin with a historical review of the site to identify potential environmental contaminants and concerns. If issues are identified, further assessment in Steps 3 and 4 determine what contaminants are present and if the site is contaminated. Steps 5 and 6 then confirm the contaminant classification and determine whether remedial action is warranted. If it is, the last four steps develop, implement and monitor the chosen remediation plan (Contaminated Sites Management Working Group & Dillon Consulting Limited, 1999).

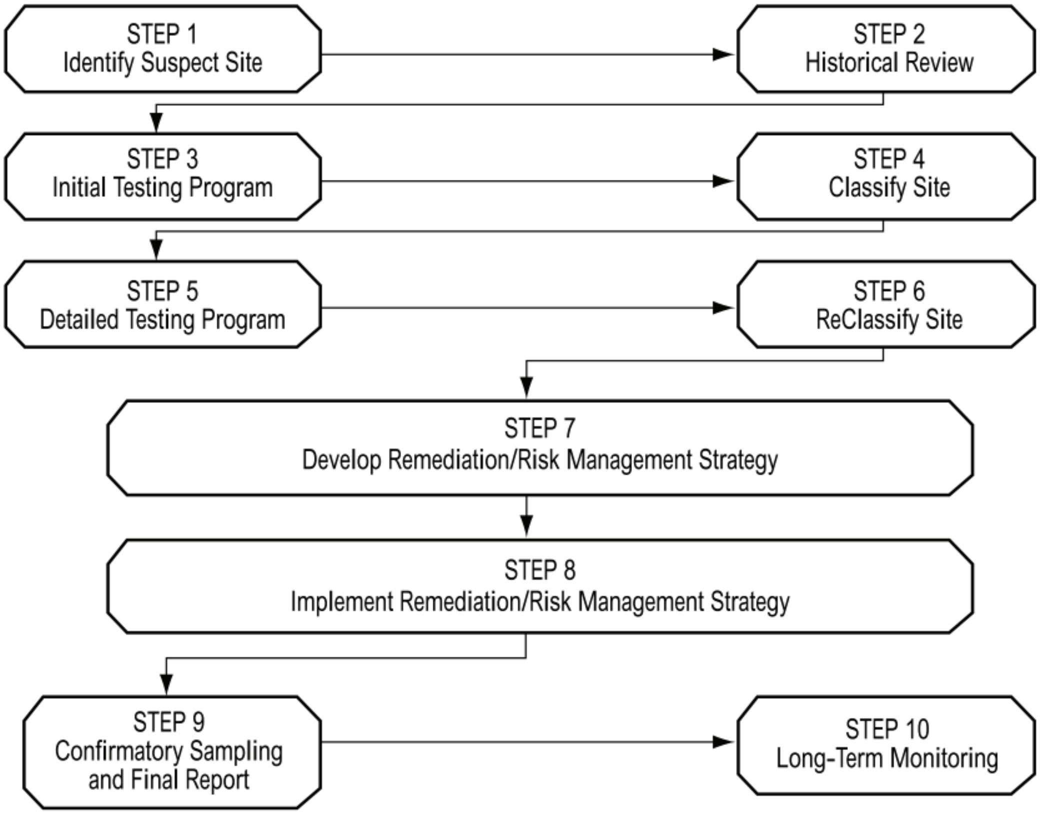

Figure 11: FCSAP's 10 step process, as outlined above (Contaminated Sites Management Working Group & Dillon Consulting Limited, 1999).

Further characterization of contaminants, including transport, fate, exposure pathways and site specific endpoints are identified (USEPA, 2001). Several lines of evidence (LOE) related to an assessment endpoint are commonly used during ERAs as a part of a weight of evidence (WOE) approach (Hull & Swanson, 2006; Walker et al., 2015). Incorporating multiple types of data results in conclusions with a more comprehensive lens of the natural system in question. To be effective, WOE processes should include both observational and exploratory elements (Burton et al., 2002). One framework, suggested by Burton et al. (2002), outlines the use of three "Certainty Elements" (Critical Receptors, Environmental Quality, and Stressor Characterization/Exposure Dynamics) during Problem Formulation. Following this, a conceptual model is developed, measurement endpoints, such as tissue contaminant levels and biota characterizations, and appropriate reference areas are selected. With this knowledge, appropriate LOEs, such as water/sediment/tissue chemistry, biomarkers and resident biota, are chosen (Burton et al., 2002). Each LOE has advantages and disadvantages, therefore, choosing multiple LOEs helps to mitigate the disadvantages of individual LOEs. After the data has been collected and analyzed for each LOE, integration into a WOE matrix occurs. This step involves careful consideration of LOE variable weights and uncertainties (Burton et al., 2002). Another framework called the Sequential Analysis of Lines of Evidence approach, suggested by Hull and Swanson (2006), identifies options to exclude risks when identified. This transparent and iterative approach addresses site-specific uncertainties and allows for common sense. As well, unnecessary discussions can be avoided when risk levels are deemed low (Hull & Swanson, 2006). This approach also encourages consideration of indirect effects (Hull & Swanson, 2006).

2.5.2 Challenges with ERAs

There are several challenges with ERA frameworks, including unclear linkages between outcomes and ecological endpoints of concern (Rohr, Salice & Nisbet, 2016), uncertainties with multiple species responses (Luttik, Hart, Reolofs, Craig and Mineau, 2011; Rohr et al., 2016), multiple stressors (Halstead et al., 2014), and unclear definitions of ecological health (Lackey, 1996). Advances in assessment technology can address some of these issues, such as macroecological approaches (Beketov & Liess, 2012), adverse outcome pathways (Ankley, et al., 2009), bioenergetic and multi-species models (Rohr et al., 2016), and use of passive samplers (Burgess, 2012).

Chapter III

3.0 LINE OF EVIDENCE ONE: Contaminant Characterization in Wetland Media

Abstract: Three types of wetland media (sediment, surface water and Libellulidae tissue) were collected from wetlands surrounding an industrial effluent treatment facility prior to the facility's closure. Samples were tested for metal, total mercury and polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans (PCDD/PCDF) concentrations. Passive samplers were deployed to analyze metal concentrations in porewater. Sediment and surface water concentration comparisons were made to provincial and federal guidelines, as well as reference wetland concentrations. Exceedances of several metals and PCDD/PCDF guidelines were found in deep areas of wetlands historically contaminated from effluent, as well as wetlands exposed to current effluent inputs. Composite Libellulidae samples were collected from wetlands, and comparisons were made to reference tissue concentrations + 20%. Exceedances of tissue As, Cu and Pb concentrations were present in two site wetlands, but reference tissue THg and PCDD/PCDF concentrations were greater than site wetlands. Spearman rho tests identified a significant correlation between sediment and tissue concentrations for Pb and between surface water and sediment concentrations for total mercury. From this, there appears to be a relatively low level of risk to macroinvertebrates within the site wetlands from current effluent inputs. During remediation, wetland areas containing high exceedances should be actively remediated, whereas monitored natural recovery (MNR) should be implemented in low risk areas. MNR is a remediation tactic that relies on natural processes to remove contaminants.

3.1 Introduction

Wetland contamination from industrial activities has been an ongoing issue for decades (Jamshidi-Zanjani & Saeedi, 2013; Jones et al., 2009; Moore, 2008). Increasing public appreciation for the value of wetlands has in turn led to research on the negative effects of contaminants on wetlands (De Klerk et al., 2013; Messing et al., 2011; Nasirian & Irvine, 2017; Sinclair, Xie, & Mitchell, 2012).

One industry in Canada with high contamination potential is wood pulp production (Ali & Sreekrishnan, 2001; Minister of Supply and Services Canada, 1991; Pokhrel & Viraraghavan, 2004). Wood based pulp and paper industries in Canada began in the 1860s and grew rapidly in the early 1900s due to increased newsprint demands (Bogdanski, 2014). This industry creates over 54,000 jobs (2017) in Canada (Natural Resources Canada, 2017). This industry also creates effluent with a significant amount of pollutants (Hoffman et al., 2017b, 2019; Munkittrick, McMaster, & Servos, 2013; Pokhrel & Viraraghavan, 2004). If effluent is poorly managed, these contaminants can enter the natural environment and cause deleterious effects (Ali &

Sreekrishnan, 2001; McMaster & Hewitt, 2010; Murray, 1992; Toczylowska-Maminska, 2017). To avoid or reduce such effects, Canadian pulp mill effluents are regulated under the Pulp and Paper Effluent Regulations (PPER) under the *Fisheries Act* (*Fisheries Act*, 1985; PPER, 1992; Roach & Walker, 2017).

This study focuses on a pulp effluent treatment facility, known as the Boat Harbour Treatment Facility (BHTF), in Boat Harbour[2], Pictou County, Nova Scotia. Historically, Boat Harbour was a tidal estuary located on Pictou Landing First Nation (PLFN) land, and was used by the PLFN community for recreational, spiritual and cultural practices (Castleden et al., 2016; Hoffman et al., 2015, 2017a). In 1967, a pulp mill, located approximately 4 km southwest of Boat Harbour on Abercrombie Point, began operation and used Boat Harbour as a treatment facility (BHTF) for the mill's outgoing effluent (Fig. 12).

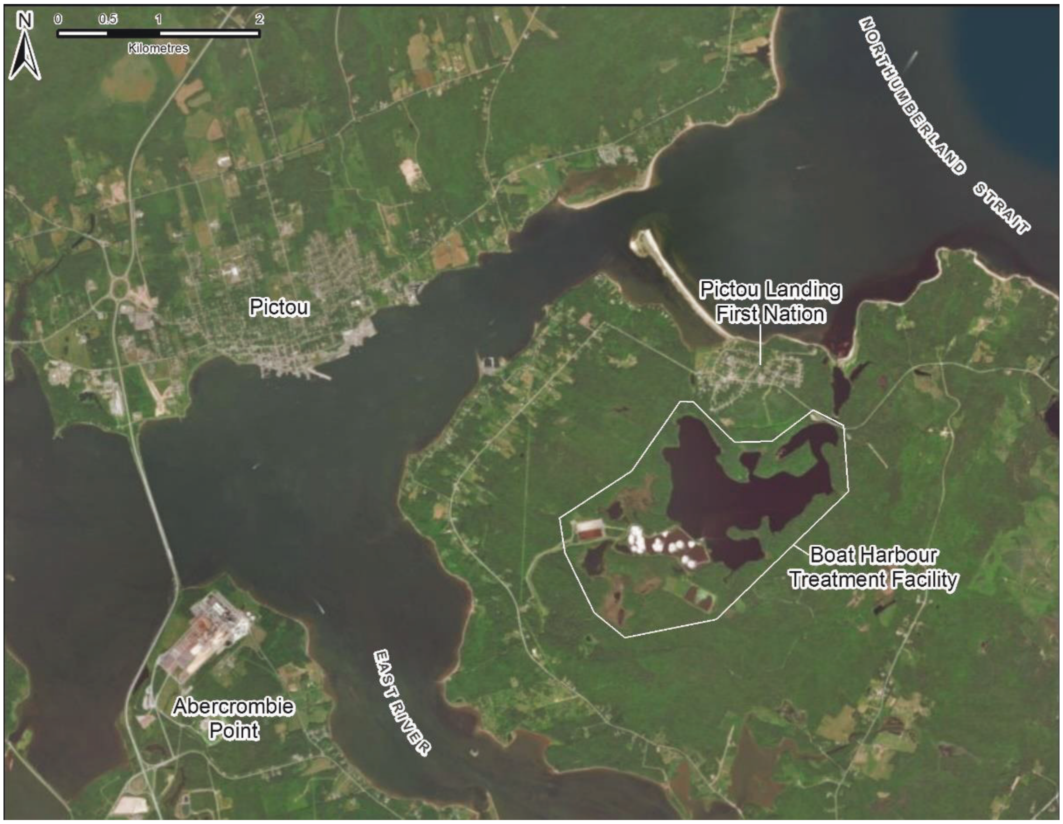

Figure 12: Location of the Boat Harbour Treatment Facility in relation to Abercrombie Point, Pictou Landing First Nation, Pictou and Northumberland Strait. [Map produced in ArcGIS®].

Originally, the treatment infrastructure began at the mill site, where gravity sewers collected and transported raw effluent across East River and into an effluent ditch. The ditch led

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[2] Boat Harbour is historically referred to as A'se'K by the people of Pictou Landing First Nation.

into a natural wetland area, where raw effluent was released. Effluent then flowed through the wetland area into an earthen dam called “Settling Pond 2” before being discharged into the BHTF and then the Northumberland Strait (GHD, 2018a). The raw effluent contained common pulp mill contaminants, including metals and polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/PCDFs) (GHD, 2018a). Due to the nature and concentration of these contaminants in the effluent, this natural treatment process was unable to adequately remove the contaminants. The biota within the BHTF suffered mass fatalities and the surrounding residents experienced strong odours from the area (Baxter, 2017; Bennett, 2013; Castleden et al., 2016). In 1971, effluent from a nearby chlor-alkali plant was discharged into the BHTF, a practice which continued until 1992 (Hoffman et al., 2017b).

Upgrades were made to the BHTF in 1972. Effluent was rerouted beyond East River into a lined ditch that discharged effluent into one of two 50,000 m^3 settling basins, therefore bypassing the original wetland discharge area. Following the settling basins, effluent was treated in an aeration settling basin (ASB) using microbes, and discharged into the stabilization lagoon (Boat Harbour) before release into the Northumberland Strait (Dillon Consulting Limited, 2012, 2019a). A dam was also constructed to stop tidal influences into the BHTF, altering the chemistry from saltwater to freshwater (Province of Nova Scotia, n.d.). Components of both treatment frameworks are outlined in Figure 13.

Figure 13: Components of the early treatment framework (1967 - 1972) and the upgraded treatment framework (1972 - present). [Map produced in ArcGIS®].

In total, the fifty years of discharge has deposited more than 570,000 m^3 of unconsolidated sediments containing industrial contamination (Alimohammadi et al., 2019; Hoffman et al., 2015). In 2014, an effluent pipe leak led to the passing of the *Boat Harbour Act* (2015) which mandates the closure of the BHTF by January 31, 2020 with remediation following thereafter. Prior to remediation activities, characterization of the extent and magnitude of contaminants must be completed. Pre-remediation assessments often follow a very similar format. In Canada, there are several frameworks that outline a common structure, such as the Federal Contaminated Sites Action Plan (FCSAP, 2017) and the Canada-Ontario Decision-Making Framework (EC & OMOE, 2008). Such assessment frameworks usually begin with a historical review of the site to determine the potential contaminants of concern (COPC). Initial testing then follows this, usually with abiotic elements such as sediment and surface water. These lines of evidence (LOE) are then compared to conservative sediment quality guidelines (SQG) (EC & OMOE, 2008; Walker et al., 2015). Exceedance of these guidelines can warrant further investigation, such as the use of deeper sediments sampling and biota tissue sampling (EC & OMOE, 2008). Generally, biota lower in the food web are sampled, as collecting multiple organisms of more species is easier. Macroinvertebrates are well known to be useful indicators for aquatic and wetland systems, as they are ubiquitous, species rich, sedentary, and fairly long-lived (Armellin et al., 2017; Mandaville, 2002; Mendez-Fernandez et al., 2017; Rodriguez & Reynoldson, 2011). Models can then be used to estimate the effects higher up the food web, given known values of ingestion and uptake (Pascoe, Blanchet, & Linder, 1996). Odonata, commonly referred to as dragonflies and damselflies, are frequently used for assessment purposes, as they are widespread across the globe, are ubiquitous in aquatic environments and have diverse life stages (Oertli, 2008). As well, odonates prey on smaller invertebrates, and therefore are likely to accumulate contaminants such as methyl-mercury (Buckland-Nicks et al., 2014; Nasirian & Irvine, 2017; Nummelin et al., 2007). They are also important prey for higher trophic levels (Cordoba-Aguilar, 2008; Tollett et al., 2009).

Multiple LOEs can be used harmoniously to better understand the potential effects contamination has had, or will have, on a natural ecosystem. This can include sampling of several types of media and the integration of previous studies' outcomes (Burton et al., 2002; Suter II, 1996; Walker et al., 2015). In this way, potential causal relationships between stressors and effects, or lack thereof, can be identified (Hull & Swanson, 2006; Walker et al., 2015). Despite a plethora of studies assessing contaminants in sediments, surface water and select biota within the BHTF (as described in Dillon Consulting Limited, 2012; Hoffman et al., 2015, 2017b, 2019; Romo et al., 2019), very little research has addressed contamination in wetland areas surrounding the BHTF. In 2017, GHD undertook a sampling event in the former discharge wetlands in the BHTF as part of the Phase Two Environmental Site Assessment (ESA). Sediment and surface water samples were collected, and several metal and PCDD/PCDF exceedances were found (GHD, 2018a). In 2019, additional sampling was done for the Human Health and Environmental Risk Assessment (HHERA), including sediment, surface water and biological media (GHD, 2019). The following study builds on the work completed by GHD through use of multiple LOE in the former discharge wetlands, as well as other wetlands surrounding the BHTF.

3.2 Methods

3.2.1 Location of Sample Sites

There are 25 identified wetland areas surrounding the BHTF that cover approximately 86.24 ha (Fig. 14) (WSP, 2018). Wetlands were evaluated using desktop reviews of the Nova Scotia Wetland Vegetation and Classification Inventory, and field studies identifying hydrophytic vegetation, hydric soils and wetland hydrology (WSP, 2018). The wetland areas were classified as either marsh (3), swamp (10), marsh-swamp complexes (11) or marsh-swamp marsh complexes (1) (WSP, 2018).

Figure 14: Delineation of the 25 wetland areas surrounding BHTF (WSP, 2018).

Five wetlands surrounding the BHTF were chosen as representatives to be investigated for this study, as well as two far-field reference wetlands (Fig. 15)[3], with marsh areas being selectively sampled. Sampled wetlands were chosen for several reasons. Two wetlands (WL1, WL2) were chosen based on the direct discharge point from 1967 to 1972. These wetlands were

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[3] Wetland names were changed from original WSP wetland identifiers.

a priori considered to have the highest contamination potential. Three wetlands (WL3, WL4, WL5) located around the BHTF were chosen based on similar wetland type to WL1 and WL2 as well as accessibility. WL4 was of interest due to its proximity to the sludge disposal cell. These wetlands were *a priori* considered to have moderate contamination potential, due to their connection to the BHTF and therefore are currently exposed to effluent. Two reference wetlands (REF1, REF2) were chosen using the Provincial Landscape Viewer (Nova Scotia Department of Natural Resources, 2015) based on similarity in size and wetland type to the BHTF wetlands.

Figure 15: Study area and sampling stations. [Map produced by ArcGIS®].

3.2.2 Sediment Sampling and Analysis

Sampling occurred from July 23 to 27, 2018. Triplicate sediment samples from each wetland were collected using a Petite Ponar Grab sampler, All 316 Stainless Steel, 152 x 152 mm (Wilco®) from the top 10 cm horizon (Fig. 16). Previous studies had found contamination to be concentrated at the upper horizons, including 0-10 cm (GHD, 2018a). The grab sampler was placed into the water and lowered to the sediment bed, where it was subsequently pulled upright and out of the water. This action closed the grab while in the sediment, collecting the sample. A sub-sample from the grab was thoroughly mixed using a stainless-steel spoon, which was pre-washed in wetland surface water, and then transferred to individual clean glass jars (250 mL jars for metals, Hg and PCDD/PCDF, and 120 mL jars for total organic carbon (TOC)). Samples were kept on ice during transport and stored in a refrigerator kept at temperatures below 4ºC prior to lab delivery. The grab was thoroughly rinsed in wetland surface water between sampling points.

To assess variations in sediment contamination spatially and between vertical surface water columns, three sediment samples were collected from three water column depths (e.g. one from: shallow = <50cm, medium = 50 – 150cm, and deep = >150cm). Three grab samples were collected at each wetland. Samples from REF2 could not be collected due to equipment failure. Samples for PCDD/PCDF were only collected from WL1, WL4 and REF1 due to monetary constraints.

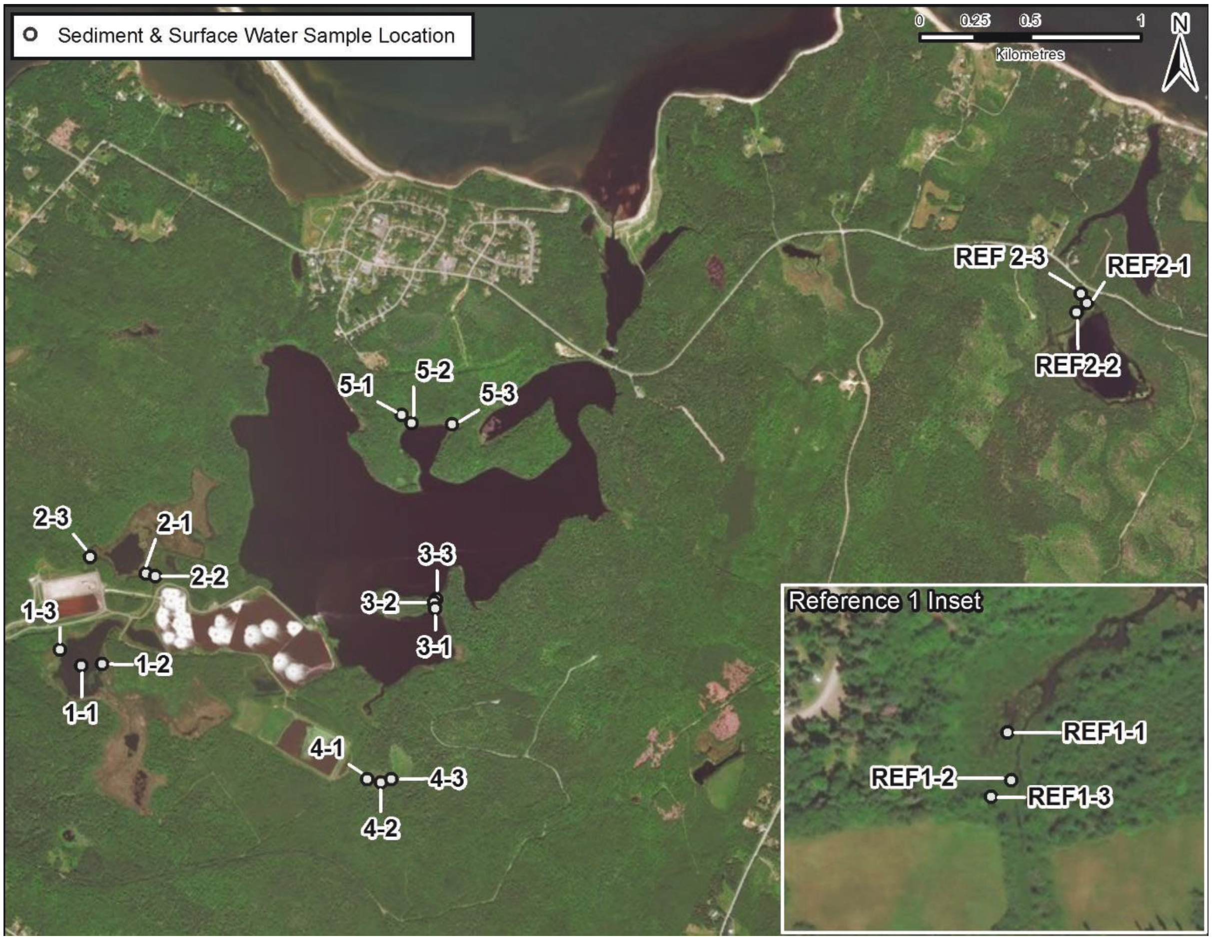

Figure 16: Individual stations for sediment and surface water samples [Map produced in ArcGIS®].

Samples were analyzed at AGAT Laboratories (Canadian Association for Laboratory Accreditation certified) for total organic carbon (TOC), 25 metals (Al, Sb, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, THg, Mn, Mo, Ni, Se, Ag, Sr, Tl, Sn, U, V, Zn – but only As, Cd, Cr, Cu, Pb, THg, Zn are presented herein), and PCDD/PCDFs. The Chain of Custody forms can be found in Appendix C. Sediment analysis for metals followed the EPA method for acid digestion of sediments, sludges and soils using inductively coupled plasma mass spectrometry (ICP-MS) from EPA SW 846 6020A/3050B (USEPA, 1996, 1998) & SM 3125 (Standard Methods for the Examination of Water and Wastewater, 2017c). TOC analysis followed the MA. 405-C 1.1 titrage method (Center of Expertise in Environmental Analysis of Quebec, 2014). Total mercury (THg) analysis was based on the EPA cold vapour (CA/VV) method from 245.5 (USEPA, n.d.-b) and SM 3112B (Standard Methods for the Examination of Water and Wastewater, 2017b). PCDD/PCDF analysis followed the MA. 400- DF 1.0 method (Center of Expertise in

Environmental Analysis of Quebec, 2014) and the EPA 1613 method using high resolution mass spectrometry (HRMS) (USEPA, 1994b). Mean values ±SE are depicted in the following figures and are reported throughout.

3.2.3 Surface Water Sampling and Analysis

Triplicate surface water samples were collected immediately prior to sediment sampling at the same location to avoid sediments entering the sample (Fig. 15). Samples were collected in clean 250 mL plastic tubes containing nitric acid as a preservative. Samples were placed on ice during transport and transferred to a refrigerator kept at temperatures below 4ºC for short term storage. Within one week of collection, samples were transported to AGAT Laboratories (Canadian Association for Laboratory Accreditation certified) for analysis. The Chain of Custody forms can be found in Appendix C. Samples were analyzed at AGAT Laboratories for 25 metals (Al, Sb, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, THg, Mn, Mo, Ni, Se, Ag, Sr, Tl, Sn, U, V, Zn – but only As, Cd, Cr, Cu, Pb, THg, Zn are presented herein). Surface water analysis of metals followed a modified method from SM 3125/SM3030B/SM 3030D using ICP-MS (Standard Methods for the Examination of Water and Wastewater, 2017a, c). THg was analyzed using the SM 3112B method (Standard Methods for the Examination of Water and Wastewater, 2017b). Mean values ±SE are depicted in the following figures and are reported throughout.

3.2.4 Tissue Sampling

Initially, tissue samples were to be collected from aquatic oligochaetes, as these organisms have been well documented for use in contamination testing (Rodriguez & Reynoldson, 2011). However, insufficient oligochaete tissue for proper analysis was able to be collected. Odonata, commonly referred to as dragonflies and damselflies, are frequently sampled for contaminants such as Cd, Cr, Hg and methyl-mercury (Me-Hg) (Azam et al., 2015; Buckland-Nicks, 2011; LeBlanc, 2019; Nummelin et al., 2007). Odonata are important members of aquatic systems, serving both as key predators and prey for other aquatic organisms (Tollett et al., 2009). In addition, Odonata are ubiquitous in many aquatic systems, are relatively easy to collect, and larvae can exist for many years (Jeremiason, Reiser, Weitz, Berndt, & Aiken, 2016; Nummelin et al., 2007). Odonata larvae were present in all studied wetlands and were therefore chosen for this analysis. Due to differences in body forms and habitat uses between Odonata families and genera (Fletcher et al., 2017), the family Libellulidae was solely selected for sampling. Samples were collected using a triangular dip net. Following sweeps through the vegetated areas of the wetlands, dip nets were emptied into a Fieldmaster® 35 mesh, 500 micron sieve (Fig. 17) where Libellulidae of similar size (three to four cm length) were selectively removed. Given the limited number of specimens collected, samples were consolidated into one composite sample per wetland. Adequate tissue amounts were collected in WL1, WL2, WL4 and REF 1 for metals analysis, WL1, WL2 and REF1 for THg, and WL 2, WL4 and REF 1 for PCDD/PCDF analysis. Organisms were identified in the field using standardized keys from Batzer, Rader and Wissinger (1999). The entire organism was analyzed. This was done in order to be able to estimate contaminant concentrations that would be available for Libellulidae predators.

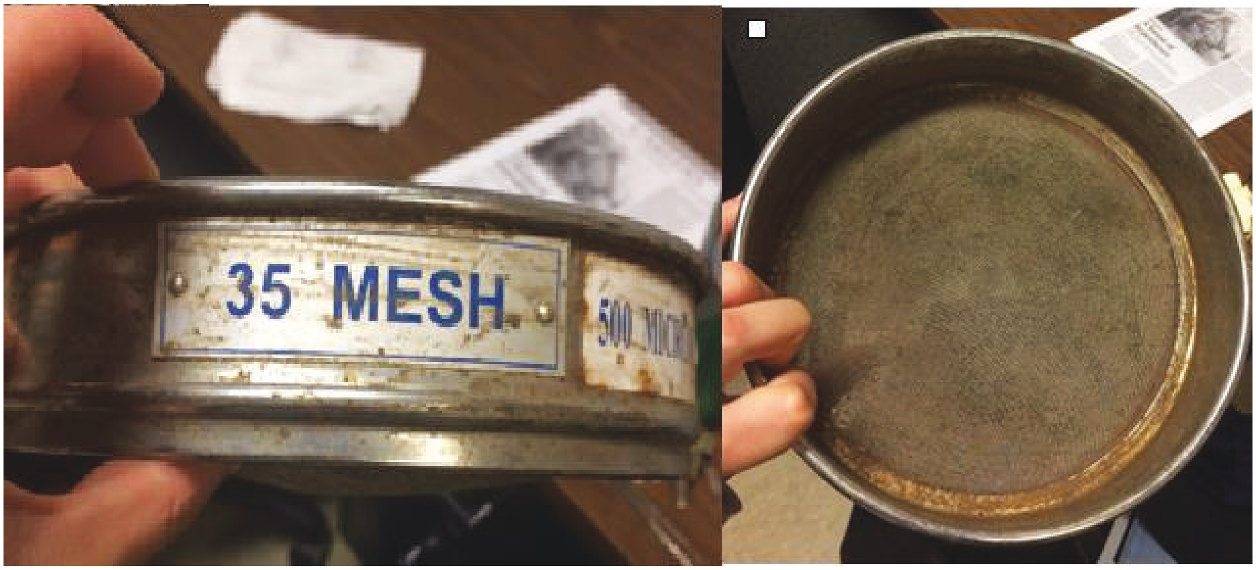

Figure 17: Sieve used for Libellulidae collection.

Samples were stored in clean 250 mL glass jars and kept on ice during transport. Jars were transferred to a refrigerator at temperatures below 4ºC for short term storage. Within one week of collection, samples were transported to AGAT Laboratories for analysis. Samples were analyzed at AGAT Laboratories for COPC similar to sediment and surface water samples. The Chain of Custody forms can be found in Appendix C. Metals in tissue were analyzed using a modified method from EPA 200.8 (USEPA, 1994a) and EPA 3050 (USEPA, 1996). THg analysis followed a modified EPA 245.6 method (USEPA, 1991). PCDD/PCDF analysis followed MA. 400- DF 1.0 method (Center of Expertise in Environmental Analysis of Quebec,

2013) and the EPA 1613 method using high resolution mass spectrometry (HRMS) (USEPA, 1994b).

3.2.5 Diffuse Gradient in Thin Film Samplers

Use of passive samplers for ecological assessments is a relatively new technique. Passive samplers are devices made of organic polymers which are deployed in the studied media to measure target contaminants in an area. In order to do this, passive samplers must be left for sufficient duration to reach equilibrium with the surrounding environment (Peijnenburg et al., 2014; USEPA, 2017). Passive samplers have many advantages over traditional bulk sampling, including low detection limits, simple implementation, possibilities to mimic bioaccumulation and limited ecological impact (Peijnenburg et al., 2014). The passive sampler known as "Diffuse Gradient in Thin Film®" samplers (DGTs) was used for this study. DGTs contain a resin layer which can selectively bind labile ions for analysis (USEPA, 2017) (Fig. 18).

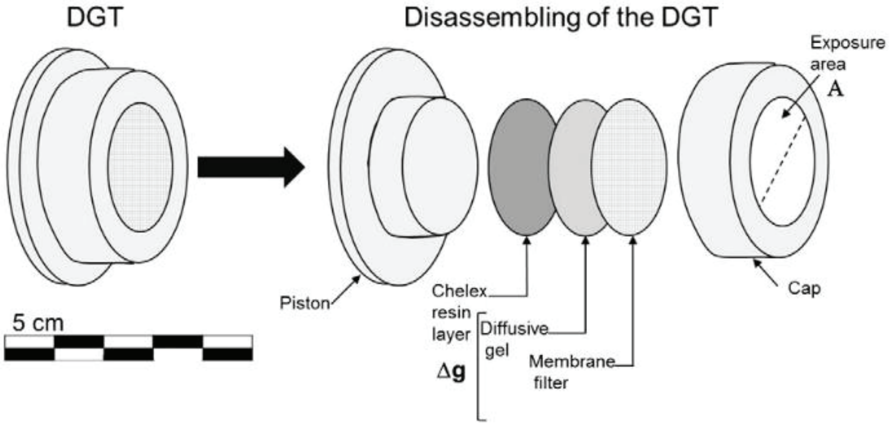

Figure 18: Composition of the DGT disks used for this study (Desaulty, Méheut, Guerrot, Berho, & Millot, 2017).

WL1, WL2, WL5 and REF1 were chosen for this analysis. Nine disk DGTs were deployed on May 22-23, 2019 for analysis of metals, and ten disk DGTs were deployed for analysis of THg. Metal and THg DGTs were paired for deployment ("DGT pairs"). In both WL1 and WL2, one DGT pair was deployed in a deep-water area and was attached to a brick using zip ties (Fig.19). Bricks were slowly lowered to the sediment surface. A buoy was attached to the brick for removal. In WL1 and WL2, the other DGT pair was attached to a post and driven into the sediment (Fig. 19). In WL5, two DGT pairs and one THg disk were also attached to a post and driven into the sediment. The same sampling technique was used for three DGT pairs in REF1. Ten DGT pairs were also deployed in the Boat Harbour Stabilization Lagoon (BH) using the brick deployment method and in a dry cove (DC) currently being used for remediation testing using the post deployment method.

Samples remained in the sediment for one month and were retrieved on June 18-19, 2019. Disks were rinsed in wetland surface water and placed in a cooler for transport. Disks were analyzed at Bureau Veritas Laboratories (Canadian Association for Laboratory Accreditation (CALA)) for 25 metals (Al, Sb, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, THg, Mn, Mo, Ni, Se, Ag, Sr, Tl, Sn, U, V, Zn – but only As, Cd, Cr, Cu, Pb, THg, Zn are presented herein) using ICPMS methods for metals (USEPA, 1996) and the 2013 Cold Vapour BCLM methods for THg (Austin, 2015). The Chain of Custody form can be found in Appendix D.

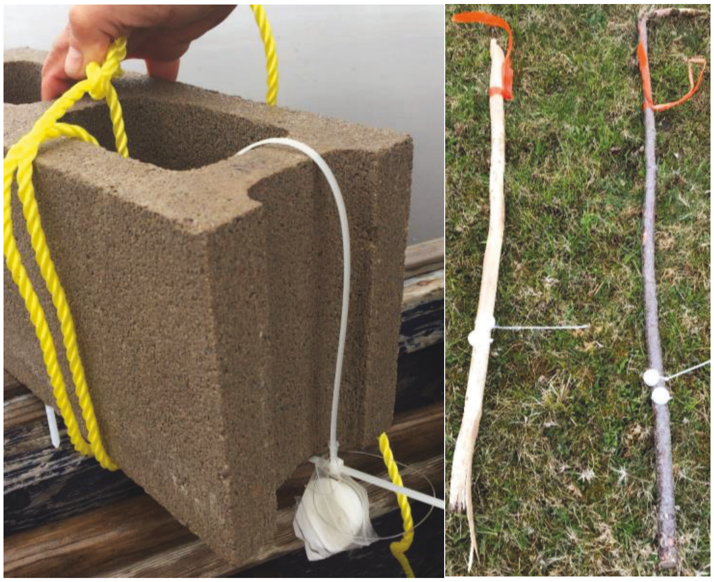

Figure 19: Left - DGT disks attached to a brick using a zip tie. This deployment method was used for DGT 1 and DGT3 (deep wetland samples), and DGTs in BH. Right - DGTs attached to posts. DGTs were deployed using this method for shallower wetland samples (DGT 2, 4-10), and in the dry cove.

3.2.6 Statistical Analysis

To validate parametric test assumptions of normal distribution and equal variance, formal normality tests were run in *Minitab® 18.1* (Minitab Inc., 2017) for the sediment, surface water and tissue samples. Three tests of normality are available in *Minitab® 18.1*: Ryan-Joiner, Anderson-Darling and Kolmogorov-Smirnov. The Ryan-Joiner normality test is similar to the Shapiro-Wilks test in that the test is based on regression and correlation (Yap & Sim, 2011) with the test statistic measuring the correlation between the data and the normal scores (Minitab 18

Support, 2019). Yap and Sim (2011) tested eight normality tests, including the three (Shapiro-Wilks in place of Ryan-Joiner) provided by *Minitab® 18.1*. From the three, Shapiro-Wilks displayed the highest power for both symmetrical and asymmetrical distributions. Anderson-Darling had fairly good power, and Kolmogorov-Smirnov performed poorly (Yap & Sim, 2011). Given the results of Yap and Sim's (2011) test, the decision for this study was to test normality for each contaminant with Ryan-Joiner at a significance value of 0.05. If the significance value was below 0.05, the data were deemed non-normal. If the significance value was above 0.05 for Ryan-Joiner, the data were deemed normal, and tested for equal variance using Bartlett's Test in *Minitab® 18.1*. If the significance value for equal variances was below 0.05, the data were deemed non-normal; if above, the data were deemed normal.

Data that were deemed non-normal were then log-transformed and retested for normality using the above framework. If the log-transformed data failed normality testing, the data were analyzed non-parametrically. If the log-transformed or original data passed normality testing, the data were analyzed parametrically. From sediment data, As passed both normality and equal variance testing. Cd, Cr, Cu, Pb, THg, Zn, PCDD/PCDF and TOC failed normality testing. Log-transformed THg was found to be normal, but log-transformed Cd, Cr, Cu, Pb, Zn, PCDD/PCDF and TOC were not. Examples of normality and equal variance test graphs and statistics can be found in Appendix A.

As and log-transformed THg were tested with a one-way ANOVA, followed by a Dunnett's test comparing BHTF wetlands against REF1. Cd, Cr, Cu, Pb, Zn, PCDD/PCDF and TOC were tested with the Kruskal-Wallis test, followed by a nonparametric post-hoc test comparing BHTF wetlands against REF1. An example of these tests can be found in Appendix A. For surface water data, Cu and Pb passed normality and equal variance testing. Log-transformed Cr was found to be normal, but log-transformed Cd and Zn were not. Cu, Pb and log-transformed Cr were tested with a one-way ANOVA, followed by a Dunnett's test comparing BHTF wetlands against REF1 and REF2. As and THg, although passing the Ryan-Joiner test, did not display enough variability to test variation, and were therefore run parametrically. As, Cd, THg and Zn were tested with a Kruskal-Wallis test, followed by a post-hoc test comparing BHTF wetlands against REF1 and REF2.The relationship between As, Cd, Cr, Cu, THg, Pb and Zn in sediment and surface water, sediment and tissue, and surface water and tissue at each site was assessed using linear regression and quadratic regression. Correlation between all three media and COPCs was assessed using Spearman rho correlation.

3.2.7 Comparison with Applicable Guidelines

Sediment and surface water concentrations were also compared to applicable guidelines. As the BHTF is located in Nova Scotia, provincial Environmental Quality Standards (EQS) for sediment from Tier 1, Table 2 standards were used when available (Nova Scotia Minister of the Environment, 2013). Comparison also occurred with national guidelines in the form of Interim Sediment Quality Guidelines (ISQG) and Probable Effect Level (PEL) guidelines from the Canadian Council of Ministers of the Environment (CCME) were used (CCME, 2019). Often, the two sets of guidelines were identical. Sediment concentrations below ISQGs were considered uncontaminated. Sediment concentrations between ISQGs and PELs were considered moderately contaminated. Sediment concentrations exceeding PELs were considered heavily contaminated. NSE Tier 1 EQS, Table 3 were used when available for surface water (Nova Scotia Minister of the Environment, 2013). Additionally, national Water Quality Guidelines (WQG) were used (CCME, 2019). Similar to sediment, concentrations below guidelines were considered uncontaminated. Concentrations that exceeded guidelines were considered moderately to severely contaminated, depending on the degree of guideline exceedance. Due to the insufficient Libellulidae tissue collected, statistical analysis was not possible. As well, guidelines do not exist for contaminant concentrations in Odonata tissue. Therefore, concentrations were compared against reference concentrations +20%, a common practice in ERAs (EC & OMOE, 2008; Walker et al., 2015).

DGT results were given in porewater concentrations. As guidelines do not exist for this media, DGT results from the BHTF wetlands were compared to reference wetlands, the BH and the DC.

3.3 Results

3.3.1 Sediment Concentrations

Wetland sediment was visually inspected. Generally, sediment was fine-grained and black-brown in colour. Sediments from shallow areas had more organic material (e.g., roots, decomposing plant matter) than deeper areas. Grain size analysis on six sediment samples in WL1 and WL2, completed as part of GHD’s Human Health and Environmental Risk Assessment

(HHERA), identified sediment as a mix of primarily sand (mean 28.2%), clay (mean 40%) and silt (mean 28.0%) (GHD, 2018).

Sediment TOC varied across the study site (Fig. 20). WL1 and WL5 contained the highest TOC at 26.7% and 35.7% respectively, which exceeded the mean REF1 TOC of 17.3%. WL2, WL3 and WL4 displayed lower TOC of 11.8%, 0.9% and 12.3% respectively. Following the post-hoc test, no TOC levels differed significantly from the reference wetland. However, WL1 and WL5 TOC differed significantly from WL3 TOC. Some TOC varied considerably within each wetland. For example, TOC in the deep water column WL2 sediment sample was 27.8%, but was much lower (0.8% and 8.4%) for shallow samples. This will be discussed further in Section 3.4

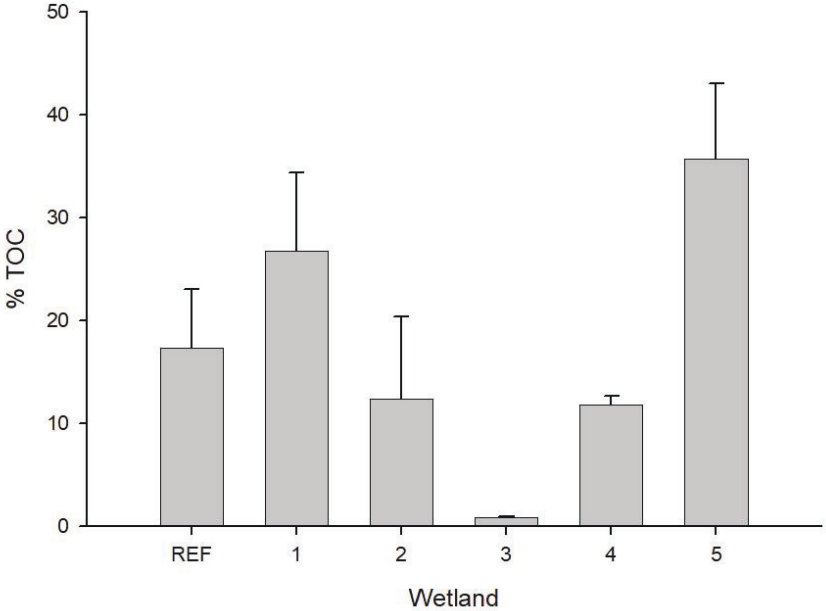

Figure 20: Mean TOC percentages for each wetland (*n*=3, ±SE).

WL3 and WL4 exceeded the CCME ISQG guideline for As (5.9 mg/kg), but were below guidelines for other COPCs (Fig. 21). WL1 exceeded CCME ISQG guidelines for As, Cd (0.6 mg/kg), Cr (37.3 mg/kg) and Zn (123 mg/kg) (Fig. 21). WL2 exceeded CCME ISQG guidelines for As, Cd, Cr, Cu (35.75 mg/kg) and Zn (Fig. 21). WL5 exceeded the CCME ISQG guidelines for As, Cu and Pb, as well as exceeding the NSE Tier 1 and CCME PEL guidelines for Cd (3.5 mg/kg) and Zn (315 mg/kg) (Fig. 21). WL1 and WL2 are considered moderately contaminated for As, Cd, Cr, Cu and Zn. WL3 and WL4 are considered moderately contaminated for As. WL5 is considered moderately contaminated for As, Cu and Pb, and more heavily contaminated for Cd and Zn. WL1, WL2 and WL5 exceeded the THg CCME ISQG guideline of 0.17 mg/kg (Fig. 22).

The Dunnett's test identified significant differences from REF1 with WL2 and WL5 for As ($p = 0.01$ for both). The Kruskal-Wallis post-hoc test identified significant differences from REF1 with WL5 for Cd ($p = 0.01$) and Cu ($p = 0.007$). The other wetlands were not significantly different from REF1, as seen in Fig. 21. It is important to note that some of the COPC concentrations varied within the wetlands as well. For example, in WL2 Cr was much higher in the deeper water column sediment (61.5 mg/kg) than the shallower sediment (14 mg/kg and 17 mg/kg). The reason for this and its implications will be discussed further in Section 3.4. ANOVA on log-transformed THg revealed no significant differences from the reference wetland ($p = 0.052$) (Fig. 22).

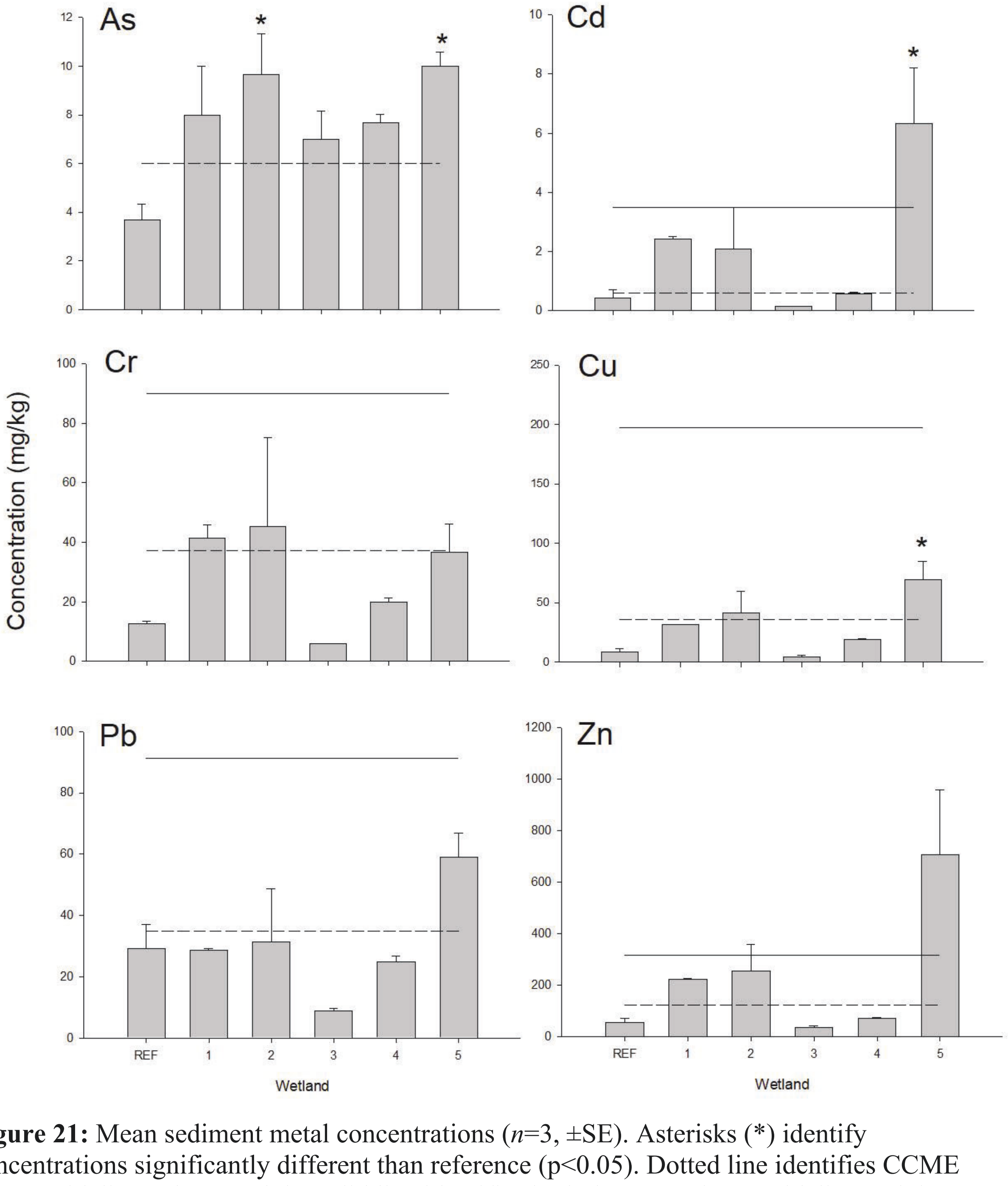

Figure 21: Mean sediment metal concentrations (*n*=3, ±SE). Asterisks (*) identify concentrations significantly different than reference (p<0.05). Dotted line identifies CCME ISQG guideline values, and the solid line identifies both the NSE Tier 1 guideline and the CCME PEL guideline (CCME, 2019; Nova Scotia Minister of the Environment, 2013).

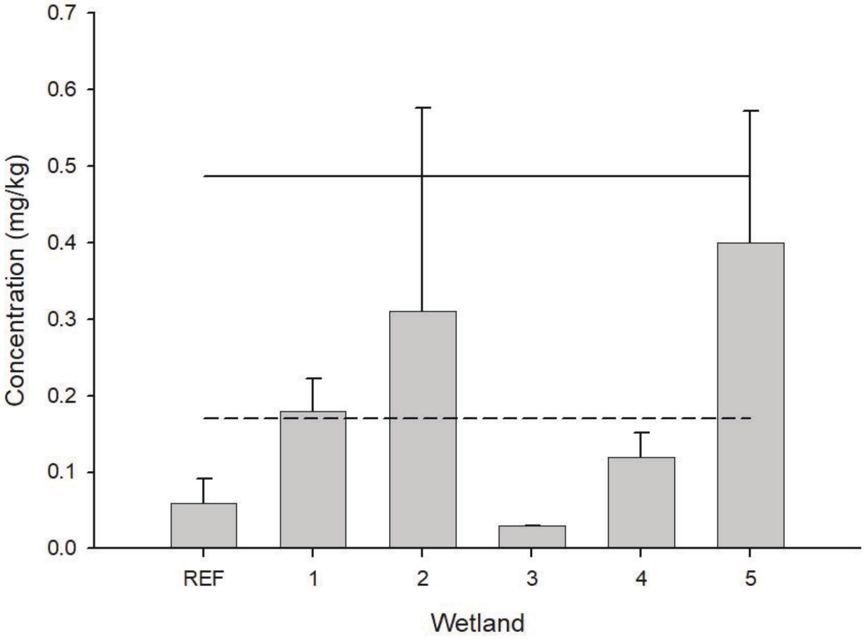

Figure 22: Mean sediment THg concentrations (*n*=3, ±SE). Dotted line identifies CCME ISQG guideline values, and the solid line identifies both the NSE Tier 1 guideline and the CCME PEL guideline (CCME, 2019; Nova Scotia Minister of the Environment, 2013).

When mean samples for PCDD/PCDFs were analyzed, the three studied wetlands (REF1, WL2 and WL4) exceeded the CCME ISQG guideline of 0.85 ng TEQ/kg. The mean sample for WL2 exceeded the NSE Tier 1 and CCME PEL guideline of 21.5 ng TEQ/kg (Fig 23). The Kruskal-Wallis test did not identify significant differences from REF1; this is likely due to the extreme outlier found in WL2 (Fig 24). The highest TEQ value of 594 ng TEQ/kg from WL2 was collected from the deepest surface water location. This was substantially greater than the two other TEQ values (2.0 ng TEQ/kg and 2.6 ng TEQ/kg) from WL2. The cause of this extreme value and its implications will be discussed in Section 3.4.

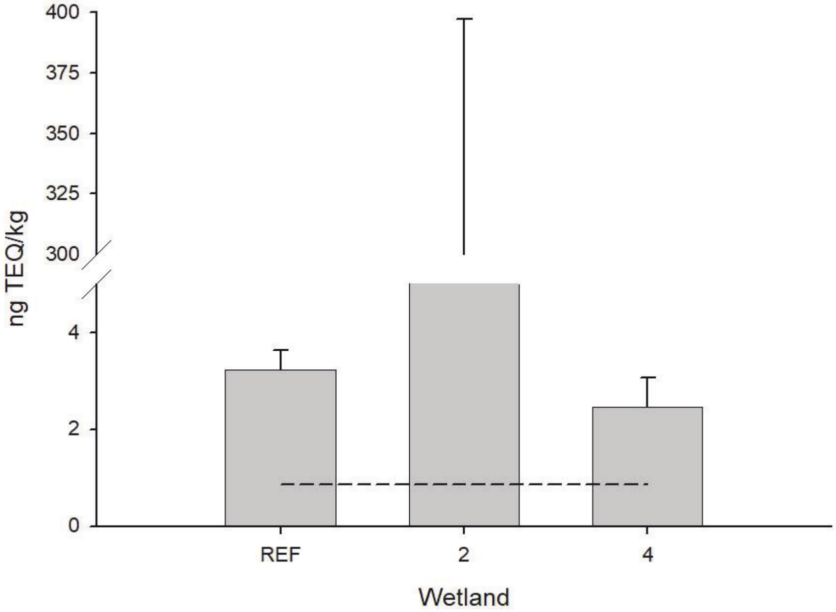

Figure 23: Mean sediment PCDD/PCDF TEQ values (*n*=3, ±SE). Dashed line represents the CCME ISQG guideline of 0.85 ng/kg. The solid line (not pictured here) represents the NSE Tier 1 and CCME PEL guideline of 21.5 ng/kg (CCME, 2019; Nova Scotia Minister of the Environment, 2013).

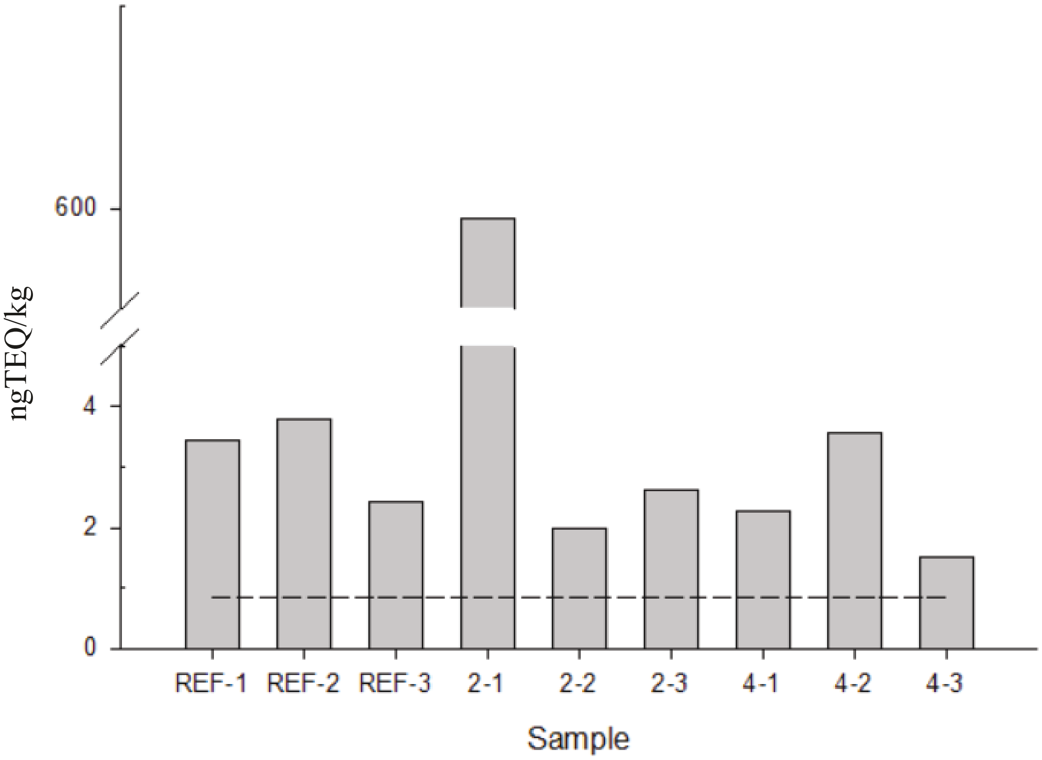

Figure 24: Individual sediment PCDD/PCDF TEQ values measured in sampled wetlands. Dashed line represents the CCME ISQG guideline of 0.85 ng/kg (CCME, 2019).

When comparing results to the GHD HHERA (2019), only WL1 and WL2 were considered, as those were included in the HHERA (Table 1). There are a few notable differences, which reflect common HHERA practices in identifying COPCs. In the HHERA, exceedances of PELs were more common. As well, GHD's decision of COPC status differed from this study. For this study, if contaminants exceeded ISQG guidelines, the wetland was considered moderately contaminated. If contaminants exceeded PEL guidelines, the wetland was considered heavily contaminated. In Table 1, if a contaminant's maximum concentration exceeded ISQG or PEL guidelines but was not significantly different from the reference wetland (NSDB), it was considered a probable contaminant of concern (P). If a contaminant exceeded ISQG or PEL guidelines and was significantly different from the reference wetland (SDB), it was considered a contaminant of concern (Y). If the contaminant did not exceed guidelines and was NSDB, it was not considered a contaminant of concern (N).

For the HHERA, if a contaminant exceeded guidelines but was NSDB, it was not considered to be a contaminant of concern (N). If a contaminant exceeded guidelines and was SDB, it was considered a contaminant of concern (Y). Due to this difference in judgement, Cd, THg and Zn were not considered to be contaminants of concern (N) for the HHERA but were considered probable contaminants of interest (P) for this study. Arsenic was considered a contaminant of concern for this study but was not identified as a contaminant of concern for the HHERA. Maximum concentrations were fairly similar between this study and the HHERA, although the HHERA generally contained greater maximum concentrations. This may be the result of a greater number of samples as the HHERA collected up to 42 samples per contaminant, whereas this study collected 3.

Table 1: Comparison of COPC decisions between the current study and GHD's HHERA (2019). NSDB = No significant difference from background levels; SDB = significant difference from background level.

COPC	CCME guideline		Current study			GHD (2019)	
	ISQG (mg/kg)	PEL (mg/kg)	COPC decision (N/P/Y)	Rationale, (maximum concentration (mg/kg))	Mean concentration (mg/kg)	COPC decision (N/Y)	Rationale (maximum concentration (mg/kg))
As	5.9	17	Y	>ISQG SDB (13)	8.8	N	>PEL, NSDB (26)
Cd	0.6	3.5	P	>PEL NSDB (4.8)	2.26	N	>PEL, NSDB (8.2)
Cr (total)	37.3	90	P	>PEL NSDB (105)	43.3	Y	>PEL, SDB (170)
Cu	35.7	197	P	>ISQG NSDB (66)	43.7	N	>ISQG (69)
Pb	35	91.3	N	>ISQG NSDB (66)	30.1	N	>ISQG (65)
THg	0.17	0.49	P	>ISQG NSDB (0.84)	0.25	N	>IQSG (2.1)
Zn	123	315	P	>PEL NSDB (361)	250	N	>PEL, NSDB (490)
PCDD/PCDF	0.85 ng TEQ.kg	21.5 ng/kg	P	>PEL NSDB (594 ng TEQ/kg)	200	Y	>PEL; SDB (918 ng TEQ/kg)

3.3.2 Surface Water Concentrations

The surface water collected was transparent with a slight yellow-brown tinge. Metal concentrations varied between the sites, with WL3 and WL5 generally exceeding guidelines (Fig. 25). WL3 and WL5 exceeded CCME long-term exposure guidelines for Cd (0.09 µg/L) and CCME Cr(VI)/NSE Cr guideline (1 µg/L) , and CCME short-term exposure and NSE guidelines for Zn (37 and 30 µg/L, respectively). Water hardness for the samples was unknown, so the conservative CCME guidelines for Cu (2 µg/L) and Pb (1 µg/L) were used. Both guideline concentrations are the same in NSE Table 3. WL3 and WL5 exceeded these conservative guidelines. REF1 also exceeded CCME long-term exposure guidelines for Cr(VI) and Zn, as well as the guideline for Pb. WL1, WL2 and REF2 only exceeded the NSE Cd guideline of 0.01 µg/L, however the detection limit used was above this (0.09 µg/L), and therefore it is likely these wetlands contain Cd concentrations below the guideline.

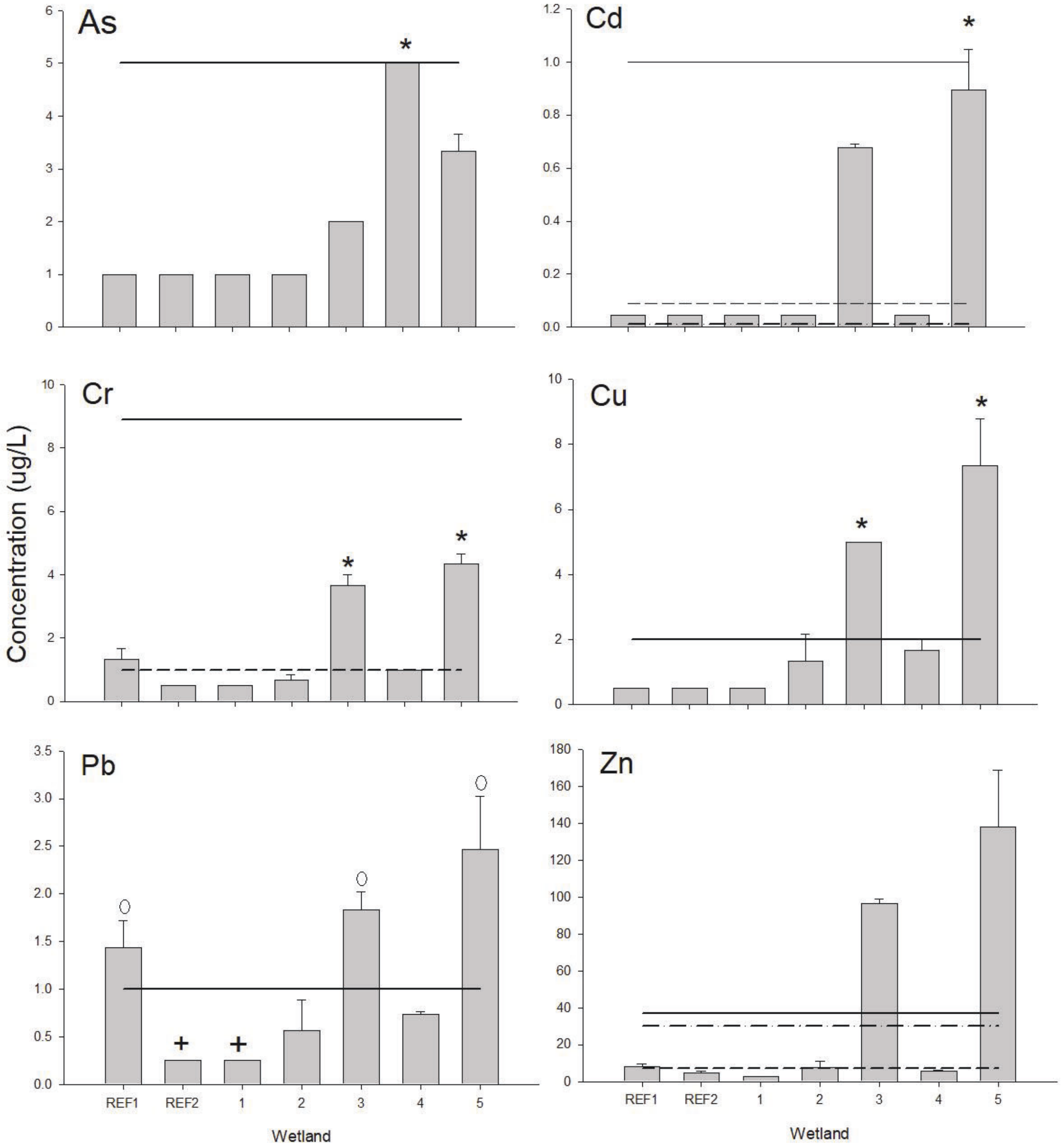

Figure 25: Mean surface water metal concentrations (*n*=3, ±SE). Dotted line represents CCME long-term guideline values. Solid line represents CCME short-term guideline values. Dash-and-dot line lines represent NSE Table 1, Tier 3 guidelines (CCME, 2019; Nova Scotia Minister of the Environment, 2013). In instances where CCME and NSE guidelines were the same, CCME guidelines were shown. Asterisk (*) identifies significant differences from both REF1 and REF2, cross (+) identifies significant differences from REF1 and circle (0) identifies significant differences from REF2 (p<0.05).

Dunnett Test identified significant differences ($p < 0.001$) from REF1 and REF2 to WL3 and WL5 for Cr and Cu. WL5 also differed from REF1 and REF2 for Cd in the Kruskal-Wallis post-hoc test (*p* < 0.001). As in WL4 was significantly higher than REF1 and REF2 (*p* = 0.00). REF1 presented high levels of Pb, whereas REF2 presented low levels, and were significantly different than each other (*p* < 0.001). WL3 and WL5 were also significantly different from the low REF2 Pb level (*p* < 0.001). WL3 was significantly different than the high REF1 Pb level (*p* < 0.001). WL5 was the only site to contain THg concentrations above detection limit and the CCME long-term exposure guideline (Fig. 26). WL5 was significantly different from REF1 and REF2 (*p* < 0.001).

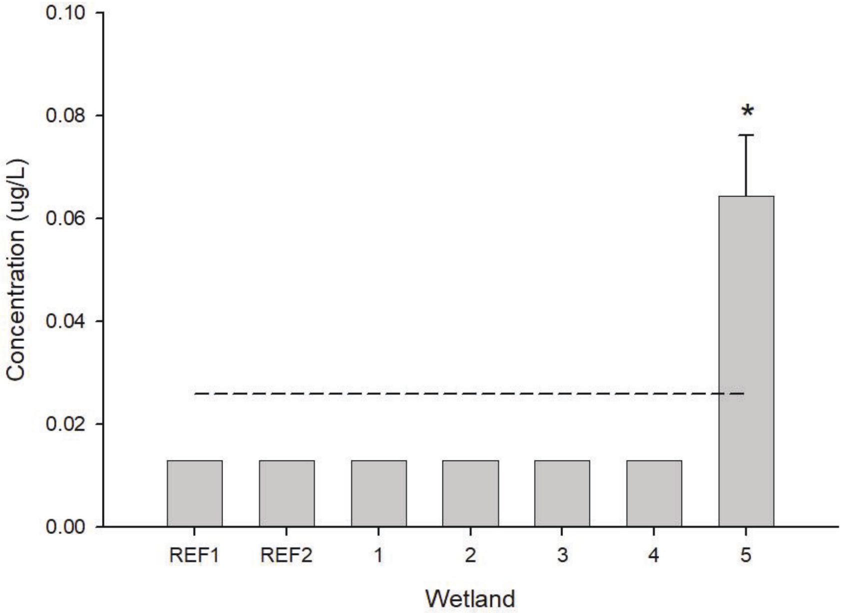

Figure 26: Mean surface water THg concentrations at each site (*n*=3, ±SE). Dashed line represents the CCME long-term exposure guideline (CCME, 2019). Asterisk (*) identifies significant differences from REF1 and REF2 (*p*<0.05).

Surface water contaminant concentrations were compared to the GHD HHERA, similar to the sediment comparison (Table 2). Unlike the sediment concentrations, all the COPC for the HHERA were non-detectable (N.D.), and therefore it was concluded there were no contaminants of concern (GHD, 2019). For this study, Cr, Cu and Pb were detectable in at least one sample which met or exceeded NSE Tier 1, Table 3 guidelines but were NSDB and were therefore considered contaminants of probable concern (P). This difference in detectable metals in surface water samples may be due to differences in sampling times. HHERA samples were collected during the fall, whereas this study collected samples during the summer. Sampling methods were similar.

Table 2: Comparison of COPC decisions between the current study and the HHERA. Asterisks (*) identify instances where a portion of samples had detectable concentrations and other samples had non-detectable concentrations. In these cases, ½ detection limits were used for concentrations below the detection limit.

COPC	CCME Guideline		Current study			GHD, 2019	
	Short term (S.T) (µg/L))	Long term (L.T) µg/L))	COPC decision (N/P/Y)	Rationale, (maximum concentration (µg/L))	Mean concentration (µg/L))	COPC decision (N/Y)	Rationale (maximum concentration (µg/L))
As	-	5	N	<L.T (N.D.)	<2.0	N	<L.T (N.D.)
Cd	1.0	0.09	N	<L.T (N.D.)	<0.09	N	<L.T (N.D.)
Cr (Cr(VI))/Cr(III))	-	1, 8.9	P	=Cr(VI) L.T (1.0), NSDB	0.60*	N	<L.T (N.D.)
Cu	-	2	P	>L.T NSDB (3)	0.92*	N	<L.T (N.D.)
Pb	-	1	P	>L.T, NSDB (1.2)	0.41*	N	<L.T (N.D.)
THg	-	0.026	N	<L.T (N.D.)	<0.026	N	<L.T (N.D.)
Zn	37	7.0	N	>L.T (14)	5.0*	N	<L.T (N.D.)

3.3.3 Tissue Concentrations

Collected Libellulidae organisms were approximately three to four cm long and every organism was intact upon retrieval. Comparison to reference values + 20% presented higher tissue concentrations of As, Cu and Pb in WL1 and WL4 relative to the comparison values (Fig. 27). All the Cd and Cr values were below reportable detection limits (0.3 mg/kg and 2 mg/kg respectively). Reference tissue showed the highest concentration of Zn, albeit slightly.

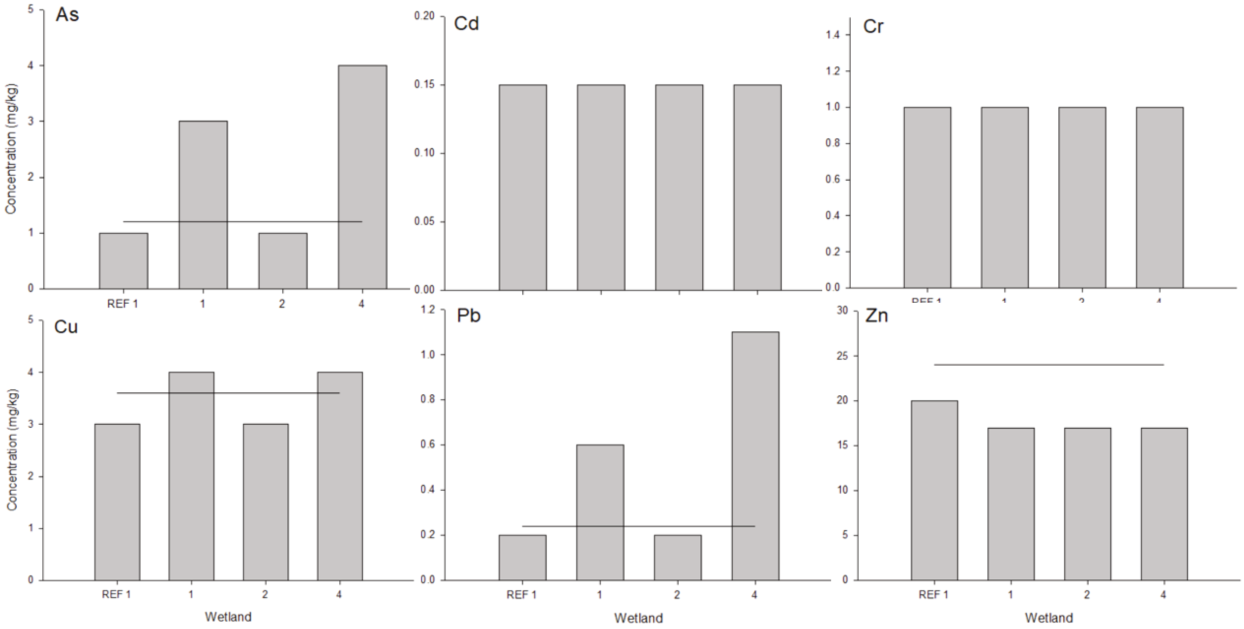

Figure 27: Libellulidae tissue concentrations of 6 COPC. Solid line represents the REF concentration +20%, which the other concentrations are compared against.

REF1 displayed the highest THg concentration compared to WL1 and WL2 (Fig. 28), as well as PCDD/PCDF concentrations (Fig. 26). For PCDD/PCDF, the REF1 tissue concentration was 6.5 times greater than WL4, and 42 times greater than WL2, the hypothesized highly contaminated wetland (Fig. 29).

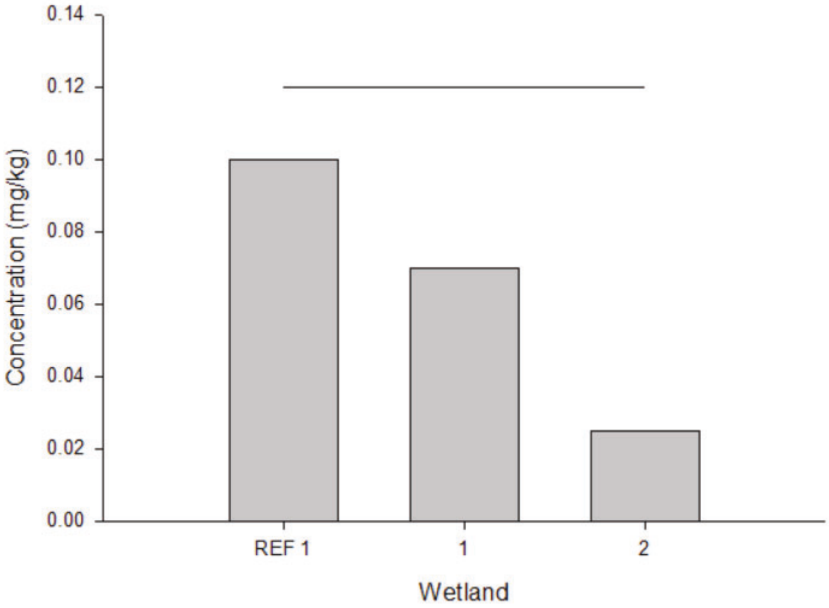

Figure 28: Total Hg tissue concentrations from three sampled wetlands. Solid line represents the REF concentration + 20% to which the other concentrations are compared against.

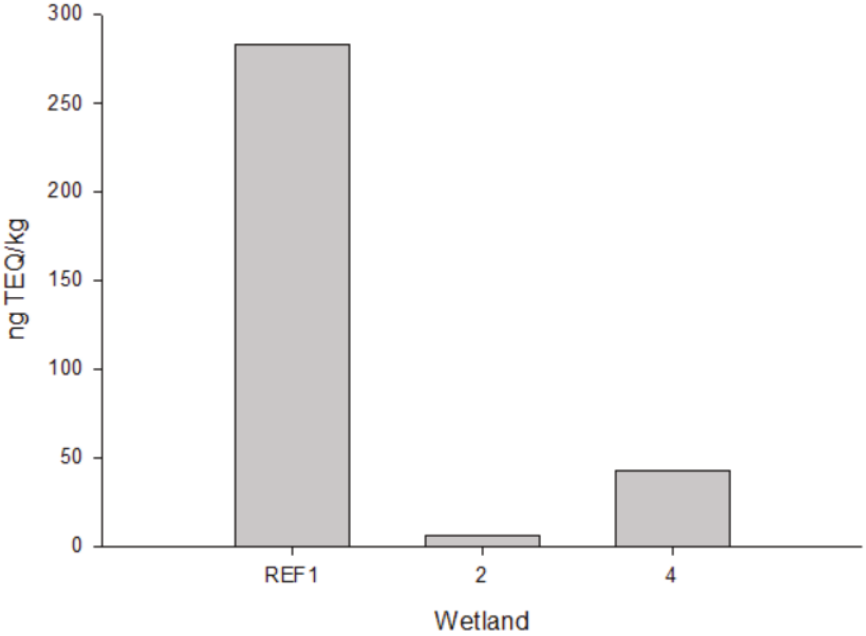

Figure 29: PCDD/PCDF tissue concentrations in three wetlands.

3.3.4 Relationship Between Media

Regression analysis between mean sediment concentrations and mean surface water concentrations detected relationships of varying strength for each COPC (Table 3). Regression graphs can be found in Appendix B. Relationships were generally positive. Linear strength ranged from low (6.5%) to medium (63.6%), and quadratic strength ranged from low (13.7%) to high (92.2%). Regression analysis between mean surface water concentrations and tissue concentrations detected fairly weak relationships (Table 4), and regression analysis between mean sediment concentrations and tissue concentrations detected very weak (0%) to very strong (100%) relationships (Table 5). Due to all Cd and Cr tissue concentrations below detection limits, the regression between sediment, surface water and tissue for the two contaminants could not be calculated. Due to identical THg surface water concentrations, the regression between sediment and surface water and surface water and tissue could not be calculated. Relationships with tissue values has low power as only a few values could be used.

Table 3: Regression results between mean sediment concentrations and mean surface water concentrations for analyzed COPC.

COPC	Linear		Quadratic
	Positive/Negative	R^2	R^2
As	+	6.50	13.7
Cd	+	31.0	73.7
Cr	-	63.6	92.2
Cu	+	23.4	81.7
Pb	+	14.2	78.8
Hg	+	52.8	83.5
Zn	+	38.5	75.0

Table 4: Regression results between mean surface water concentrations and tissue concentrations for analyzed COPC.

COPC	Linear		Quadratic
	Positive/Negative	R^2	R^2
As	+	60.5	60.5
Cu	+	2.60	50.0
Pb	-	10.7	26.9
Zn	+	36.2	71.0

Table 5: Regression analysis between mean sediment concentrations and tissue concentrations for the analyzed COPC.

COPC	Linear		Quadratic
	Positive/Negative	R^2	R^2
As	+	5.80	95.9
Cu		0.00	100
Pb	-	88.0	89.9
Hg	-	99.2	100
Zn	-	40.1	62.5
PCDD/PCDF	-	35.9	-

Spearman rho correlation analysis between sediment, surface water and tissue revealed significant correlations between Pb in sediment and tissue and Hg in sediment and surface water (Table 6). Due to identical Cd and Cr tissue concentrations, the correlation between sediment, surface water and tissue for the two contaminants could not be calculated. Due to identical THg surface water concentrations, the correlation between surface water and tissue could not be calculated.

Table 6: Spearman rho correlation values between sediment, surface water and tissue. "I.D." marks relationships that could not be calculated due to identical concentrations. Asterisk (*) represent *p*<0.05.

COPC	As	Cd	Cr	Cu	Pb	Hg	Zn	PCDD/PCDF
Sediment and surface water	0.21	0.37	-0.20	0.33	0.31	0.54*	0.33	-
Sediment and tissue	-0.11	I.D.	I.D.	0.00	-0.95*	-1.0	-0.78	-0.50
Surface water and tissue	0.82	I.D.	I.D.	0.24	-0.21	I.D.	0.78	-

TOC has been shown to increase the amount of metal concentrations within sediment; therefore, correlation analysis between TOC and the COPC was also run (Table 7). Significant correlations were found between all COPC and sediment TOC, except for As and PCDD/PCDF.

Table 7: Spearman rho correlation analysis between sediment concentrations and TOC values. Asterisk (*) represent *p*<0.05.

	TOC and As	TOC and Cd	TOC and Cr	TOC and Cu	TOC and Pb	TOC and Hg	TOC and Zn	TOC and PCDD/PCDF
Correlation	0.40	0.89*	0.73*	0.75*	0.89*	0.85*	0.79*	0.65

3.3.5 Diffuse Gradient in Thin Film Samplers

DGT disks were successfully retrieved in all four sampling areas. For each sampling area, the minimum and maximum values for the COPC were identified as the range, and the COPC means and standard deviations (SD) were calculated (Table 8). Using this, comparison between the four sampling areas occurred. The DC contained the highest mean concentrations for As, Cr and Pb (1.96 µg/L, 2.42 µg/L and 2.13 µg/L respectively). Surprisingly, the Reference wetland contained the highest mean concentrations for Cd, THg and Zn (0.1 µg/L, 0.05 µg/L and 23.0 µg/L respectively) and was similar to the areas in the BHTF for the other COPC. The BHTF wetlands were marginally higher than the Reference wetland for Cu (1.13 µg/L to 1.10 µg/L respectively). When considering COPC in individual sampling areas, ranges were occasionally quite large. For example, Zn in the Reference wetlands ranged from below detection limit (10 μg/L) to 34 μg/L.

Table 8: DGT porewater results from four sampling areas. Detection limits (DL), range, mean and standard deviations (SD) are reported in μg/L.

	As		**Cd**		**Cr**		**Cu**		**Pb**		**THg**		**Zn**	
Detection Limit	0.2		0.05		1.0		1.0		0.2		0.02		10	
Location	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**
BHTF Wetlands	0.81-3.18	1.78 (0.88)	0.025	0.025 (0)	1.1-1.4	1.28	0.5-2.6	1.13 (0.13)	0.76 - 2.6	1.47 (0.42)	0.01-0.06	0.02 (0.02)	5 - 14	9.83 (3.97)
Reference Wetlands	1.37-2.79	1.94 (0.75)	0.03-0.18	0.1 (0.08)	0.1-1.5	1.3	1.2-1.5	1.1 (0.17)	1.2-1.5	2.05 (0.55)	0.01 - 0.08	0.05 (0.03)	5 - 34	23.0 (15.7)
BH	1.07 - 1.6	1.37 (0.16)	0.025	0.025 (0)	1.2 - 2	1.44 (0.24)	0.5 - 1.3	0.58 (0.25)	0.81 - 1.65	1.14 (0.26)	0.01 - 0.03	0.015(0.01)	5 - 25	11.4 (8.4)
DC	1.42 - 3.4	1.96 (0.66)	0.025 - 0.073	0.03 (0.02)	2.0 - 3.4	2.42 (0.52)	0.5 - 3.5	0.86 (0.95)	1.54 - 3.14	2.13 (0.47)	0.01 - 0.028	0.015 (0.01)	5 - 22	12.5 (5.38)

3.4 Discussion

Given the history of raw pulp mill effluent discharge, as well as results of the GHD Phase Two Environmental Site Assessment (GHD, 2018a), the expectation of this study was that WL1 and WL2 would exceed guidelines more often than the other wetlands. However, WL5 displayed the highest levels of impact, as several ISQGs, Tier 1 and PEL guidelines were exceeded and it was significantly higher than most reference values for sediment and surface water concentrations. Exceedances in this wetland were not unexpected, however, as previous studies have sampled in the neighbouring cove and found exceedances over guidelines for several COPCs (as described in Hoffman et al. [2017b]). Similarly, previous samples in the stabilization lagoon near WL3, which presented several surface water exceedances in this study, have also found guideline exceedances (as described in Hoffman et al. [2017b]). Due to the close connection of lake-connected wetlands (e.g. lacustrine marshes) to lakes through surface and groundwater (Alexander et al., 2015; National Wetlands Working Group, 1997) it is possible that the effluent that has been continuously released into BH has contaminated these wetland areas as well.

In addition, all of the wetlands experienced some degree of drying throughout the summer, as the season was hotter and drier than previous years (Government of Canada, 2019). WL5 and REF1 appeared to have experienced the most amount of drying, as perimeter areas that contained more than 30 cm of standing water were dry by the end of the season. It is possible that the extreme amount of drying concentrated the contaminants in WL5 and exacerbated the contamination. The effect of drying and reflooding on contaminant concentrations in sediment has been shown to increase contaminant mobility and metal release (Lau & Chu, 1999); therefore, this may be the case in surrounding wetlands like WL5.

Another factor influencing sediment metal concentrations was TOC. TOC has been shown to positively correlate with metal concentrations (Remeikaitė-Nikienė et al., 2018; Walker et al., 2015; Yang, Xiong, & Yang, 2010). This correlation was also true in this study, as seen in Table 7. TOC is a sediment toxicity modifying factor as metals have an affinity for organic matter (Remeikaitė-Nikienė et al., 2018; Walker et al., 2015). TOC occasionally increases with depth, as biodiversity and biomass decrease (Soto et al., 2016). TOC was not significantly correlated with PCDD/PCDF, but this could be due to small sample sizes. In a 2013 report by Dr. Ron Russell, sediment samples within BH were collected and tested for various COPC, including PCDD/PCDF. The highest concentration of PCDD/PCDFs were in a mid-settling basin, as opposed to adjacent the ASB outfall. It was concluded that this was due to historic changes in PCDD/PCDF concentrations in effluent, spatially variable sediment deposition, or differences in the bottom profile of sampled locations (Castleden et al., 2016; Russell, 2015). The conclusions from Russell's study may also be applied to the results of the present study.

TOC may also help to explain the high surface water concentrations in WL3. WL3 was a fairly shallow wetland (surface water depth of approximately 0.5 – 0.6 m). As discussed above, previous samples in the connected lagoon revealed sediment contaminant exceedances, but WL3 has a shallower surface water depth than those lagoon samples. With WL1 and WL2, it was shown that the deep surface water samples with high TOC presented higher metal concentrations than shallower samples. With this context, it is likely that the deeper lagoon samples would show higher TOC sediment concentrations, and thus high contamination, than the shallower, low TOC wetlands. Given the affinity of TOC-rich sediments to metals and organic compounds (Gan, Lin, Liang, & Xia, 2013; Kalbitz & Wennrich, 1998), the low TOC concentrations could be why metals and PCDD/PCDF remained in the water column rather than strongly partitioning to the sediment. If the bulk of contaminants are not sequestered in the sediments where they are less bioavailable, uptake by water-based organisms is more likely. However, this could not be tested as insufficient tissue for analysis was collected from WL3. Low TOC in WL3 may be related to shallow depths increasing the effects of water currents and wind-induced wave action on sediment resuspension (Soto et al., 2016). As well, wetland vegetation, litter decomposition and climatic conditions can influence TOC accumulation. Bulk density, salinity and soil composition can cause different types of plant communities and primary production rates, which in turn influence organic carbon stores (Luo, Wang, Dun, Yang, Zhou & Wang, 2014). The macrophyte community in WL3 was not assessed for this study, so the potential effect on TOC can only be speculated.

Microorganisms play a significant role in anaerobic carbon cycling (fermentation and methanogenesis) and may have influenced the contaminant concentrations described above. Microorganisms were not analyzed for this study, and may be low due to changes in pH and land use (Bodelier & Dedysh, 2013; Hartman, Richardson, Vilgalys, & Bruland, 2008). Wetland restoration practices have been shown to negatively impact bacterial communities (Hartman et al., 2008), which should be taken into consideration prior to active remediation efforts.

Grain size can also impact metal concentrations in sediment, as studies have shown finer-grained sediments result in higher metal concentrations (Horowitz, 1986; Maslennikova, Larina, & Larin, 2012; Soto et al., 2016). Finer-grained sediments have higher surface area to grain size ratios, and therefore provide increased area for adsorption of heavy metals (Horowitz, 1986; Lakhan, Cabana & LaValle, 2003). Grain size was not measured for this study; however, GHD calculated grain size for specific samples taken in WL1 and WL2 (as described in 3.3.1). The result of this analysis indicated sediment was generally composed of grain size less than 120 µm (GHD, 2019). Sediment in WL3, WL4, WL5, REF1 and REF2 were visually similar, and therefore it is likely the composition in these wetlands is comparable. Given the inverse correlation between grain size and metal concentrations, it is probable the fine-grain profile of the wetlands influenced the metal concentrations. Further analysis should compare grain size between the deep and shallow vertical water column wetland areas, as differences could explain the metal concentration variances described in this study.

The Dunnett’s and non-parametric post-hoc tests identified several significant differences from the reference values, as described in Section 3.3.1 and 3.3.2. These differences further define the extent of the contamination impact. For example, WL5 exceeds the conservative guidelines for surface water for Cd, Cr and Cu. Due to the conservative nature of these guidelines, the exceedances may be of little importance. However, WL5 was significantly different than reference wetlands that are similar in type and location. Several contaminants, when viewed in a graph (e.g., sediment Zn and Hg) appear to be significantly higher than the reference wetlands. However, the intra-wetland variability made for large standard errors and therefore significant differences were not detected. A greater number of samples could decrease the standard error, and perhaps differences would then become more apparent.

Further, processes within wetlands, such as uptake, sequestration, decomposition and biodegradation, allow wetlands to effectively "self-clean" contaminants that are present in the system (Erin, 2008; Galbrand, 2004; Vymazal & Březinová, 2016). This ability has been applied in natural and constructed wetlands for wastewater treatment purposes. For example, burial of contaminants through natural deposition of cleaner sediments can reduce surface sediment concentrations over time (Magar & Wenning, 2006). The assimilative capacity of wetlands to remove or reduce contaminants may also explain why WL1 and WL2 contained fairly low concentrations of COPC in the shallow areas, as 46 years have passed since the raw effluent release, therefore giving these natural processes time to be effective. In comparison, WL5 has been exposed to effluent more recently and these natural processes may not have had time to be fully successful. Additionally, the process of macrophytes to assimilate contaminants is known as phytoremediation and is commonly used in constructed wetland systems. *Phragmites* spp. have been shown to accumulate heavy metals, which can then be removed from the wetland through harvesting efforts (Lesage et al., 2007). Other plants, including *Typha* spp*.,* have also been used for their ability to reduce bacteria, organic chemicals and inorganic chemicals in wetlands (Ciria, Solano, & Soriano, 2005; Rani, Maheshwari, Kumar, & Vijay, 2011). Lower contaminant concentrations may have been measured in the areas with high concentrations of macrophytes, which could have taken up and incorporated contaminants into tissue. However, phytoremediation would not have completely removed the historic contamination in WL1 and WL2, as macrophytes must be harvested and removed to reduce the contaminant concentrations.

Odonata larvae have been used frequently in assessments of metal-contaminated wetlands. Generally, researchers have found larvae to have increased metal tissue concentrations in metal contaminated areas when compared to reference areas (Azam et al., 2015; Nasirian & Irvine, 2017; Nummelin et al., 2007; Tollett et al., 2009). Partitioning of contaminants to different areas of larvae tissue have been studied, as this could affect trophic transfer of contaminants. For example, Lavilla et al. (2010) found that Cu, Cd and Zn associate with Odonate inner tissues, whereas As, Cr, iron (Fe), manganese (Mn), nickel (Ni) and Zn associated with outer tissues. Similarly, THg and MeHg in different body sections has been studied. Buckland-Nicks (2011) found even partitioning of THg and MeHg within Odonate body parts. LeBlanc (2018) determined Odonate casings accounted for 93% of As lost from the larval to adult stage. Although total body load was measured for this study as oppose to body parts, these studies highlight uptake and assimilation of contaminants into Odonate tissue. Given this, a stronger relationship between sediment concentrations and tissue concentrations was expected. This was not the case, as the only significant relationships found was Pb in sediment and tissue (Table 6). This could be due to metal contaminants sorbing to the finer grained, higher organic sediment in deeper vertical surface water columns, whereas Libellulidae larvae were found in shallow water. Even in the uniform depth wetlands (e.g., WL5), some variation in sediment contamination was still present. The Libellulidae larvae were collected from a larger area than the sediment samples, and therefore the larvae could have been exposed to a variety of contaminant concentrations. The Spearman rho correlation used mean sediment and surface water concentrations to account for this, but additional samples are needed to address this variation.

In addition, several reference tissue samples displayed higher concentrations than the BHTF samples. For example, PCDD/PCDF tissue concentrations for the reference wetland were 6.5 to 42 times higher than WL4 and WL2 respectively. Although this result was not expected, consideration of the sediment PCDD/PCDF concentrations may assist in an explanation. PCDD/PCDF concentrations in REF1 exceeded ISQG guidelines, and individually appear higher than WL2 and WL4 when WL2-1 is removed (Fig. 24). Although REF1 resides on property that is not directly influenced by industries, improper waste disposal, wood and coal burning and forest fires nearby could have increased the PCDD/PCDF concentrations in REF1 (Dyke, Coleman, & James, 1997; Kanan & Samara, 2018) and consequently influenced tissue concentrations. In 2018, Pictou County experienced 23 wildfires, a majority of which occurred just prior to sampling (Department of Lands and Forestry, 2018) and could have impacted these concentrations. Wind rose simulations show wind direction in the area generally blows north-east (Hoffman et al., 2017b), and therefore greater atmospheric deposition from these events may have occurred in REF1 than the BHTF. Although Spearman correlation did not identify a relationship between sediment and tissue PCDD/PCDF concentrations, this may be due to the limited sample size and not a lack of relationship. Additional samples should be taken to further explore this.

THg concentration was higher in REF1 Libellulidae tissue than WL1 and WL2, even though sediment THg was higher in WL1 and WL2. LeBlanc (2018) showed emergent Odonata from Hg-contaminated wetlands can transport Hg out of the wetlands, since a significant amount of Hg is retained in adult Odonates from their larval stage. Odonata can travel outside of their natal area to search for higher habitat quality and mate selection (Crumrine, Switzer, & Crowley, 2008). It is possible that the higher THg concentrations found in the REF tissue was the result of contamination from an outside source that was transported through parental adults. As well, MeHg can account for a high portion of THg (Buckland-Nicks et al., 2014), and since MeHg is highly bioaccumulative, it is also plausible that the Libellulidae larvae, obligate carnivores by nature, display high THg concentrations as the result of high THg or MeHg concentrations in their prey. Libellulidae prey on plankton and smaller invertebrates (Suhling et al., 2015). Phytoplankton and zooplankton have been shown to readily uptake and assimilate MeHg, effectively introducing the contaminant into the food web (Schartup et al., 2018; Stewart et al., 2008). Therefore, it is possible that the plankton within the reference area were either recently impacted by a Hg contamination source, or the plankton community composition and activity resulted in greater mercury uptake. For example, other factors, such as productivity and nutrient content, affect MeHg concentrations in marine plankton (Schartup et al., 2018). pH and selenium (Se) content also affect plankton Hg uptake, with acidic waters increasing uptake and Se providing a protective effect against uptake (Belzile et al., 2006; Le Faucheur, Campbell, Fortin, & Slaveykova, 2014; Yang, Chen, Gunn, & Belzile, 2008). Selenium results were consistently under detection limits (1.0 mg/kg) for the tissue sampled from the wetlands but could have been present at low levels. For example, the Se compound selenite has protective qualities starting at 0.5 mg/kg (Yang et al., 2008). As well, an inverse correlation occurs between algal abundance and Hg concentration in zooplankton through a process called "bloom dilution" (Luengen & Flegal, 2009; Pickhardt et al., 2002). The reference site did not appear to have a high occurrence of algal blooms, which may have resulted in a higher THg concentration for zooplankton uptake and consequently Libellulidae uptake. The tissue metal results are further mirrored in the DGT results, which act as a surrogate for tissue. Reference DGTs displayed higher concentrations when compared to the BHTF wetlands for all except Cu (Table 8), which further demonstrates the possibility of an outside contamination source. As well, ranges in DGT results identify the unevenness of the COPC in each sampling area.

As previously discussed, GHD performed a HHERA from 2017 to 2018 within WL1 and WL2[4]. Table 1 and Table 2 revealed similarities between this study and the HHERA for sediment and surface water contaminant samples. Exceedances were found in the HHERA for contaminants not analyzed as a part of this study, such as volatile organic compounds, semi-volatile organic compounds, and polycyclic aromatic hydrocarbons. On the other hand, this study identified sediment exceedances (Cd, Cu, Pb and Zn) in wetlands that were not studied in the HHERA, specifically WL5. Similarly, this study identified surface water exceedances that were not studied in the HHERA, specifically in WL3 and WL5.

The HHERA also identified receptors, exposure pathways, potential species at risk and valued ecosystem components that are currently at risk and/or could potentially be at risk during remediation. From this, aquatic invertebrates inhabiting the wetlands, such as the Libellulidae in this study, may increase COPC exposure in higher trophic level organisms that consume the odonates, specifically fish, amphibians and benthic and aerial insectivores.

Similarities and differences between the HHERA and this study highlight the value of incorporating scientific studies into consulting projects, as they can complement the HHERA LOEs and help inform remedial decisions. Both this study and the HHERA recommend further sampling and delineation. Sampling should also occur during and after the BHTF remediation as part of an Environmental Effects Monitoring program to assess the effectiveness of remediation, and should include a suite of multimedia monitoring (Walker, 2014).

3.5 Limitations

This study had some limitations that should be considered. First, funding constraints limited the number of samples that could be collected in each wetland. Although triplicate samples were collected, more samples within each wetland would have strengthened the statistical analysis and helped to address the intra-wetland variation. As well, a limited number of wetlands could be sampled. Sampling of additional BHTF wetlands could increase understanding of the extent of the contamination, as well as provide further understanding of the impact range with different wetland types and sizes.

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[4] In the HHERA, WL1 is referred to as FSP2 and WL2 is referred to as FSP3.

Second, difficulties arose in collecting adequate amounts of tissue samples in each wetland due to researcher inexperience, lack of available organisms and limited access to sampler equipment. Samples were collected with a kick net, which was occasionally difficult to maneuver through thicker vegetation. As well, samples were collected by walking through the wetland while sweeping through the vegetation. Due to the ability of Libellulidae to swim through the water column, this type of sampling may have missed some Libellulidae, or allowed for organisms to escape the net before removal. Additional sampling equipment, such as an invertebrate activity trap, could have collected more Libellulidae tissue which would have increased the strength of the statistical analysis.

Third, time constraints restricted sampling to one year. Sampling on an annual basis would help address some of the issues faced in this study, such as wetland drying. This could help explain inter-annual variation in wetland hydrology (e.g. whether the wetlands that dried up (e.g., REF1, WL3 and WL5) dry up annually or if this was due to an unusually hot and dry summer in 2018). Annual sampling could also help to explain and interpret the results presented herein.

3.6 Conclusion

Although WL1 and WL2 directly received raw effluent discharge from 1967 to 1972, this study identified that the ability of the wetlands to self-clean, the effect of TOC concentrations on contaminant binding, as well as other synergistic or antagonistic processes (e.g. selenium) may have reduced the expected COPC concentrations. WL3 and WL5 expressed high COPC concentrations for sediment and/or surface water, likely due to nearby lagoon exceedances and recent effluent discharge. Although wetlands outside of the study area also produced some high COPC concentrations (e.g. REF1), the guideline exceedances of the surrounding BHTF wetlands should be carefully considered with the planning of restoration efforts. Therefore, active remediation activity is likely required in wetlands currently exposed to effluent, as well as deep areas of wetlands historically exposed to effluent. Natural attenuation and monitoring appear to be a feasible remediation option for the shallow areas of WL1 and WL2. Monitored natural recovery (MNR) is a legitimate remediation practice that relies on natural processes to contain, destroy or reduce contaminant concentrations. These processes can include burial, sorption or biological transformations (Magar et al., 2009; Magar & Wenning, 2006). Prior to this, additional sampling within these wetlands, as well as additional BHTF wetlands, should be undertaken to fully understand the contamination extent.

Chapter IV

4.0 LINE OF EVIDENCE TWO: Wetland Macroinvertebrate Community Structures Near an Industrial Wastewater Treatment Facility

Abstract: Macroinvertebrate communities and environmental variables were examined in wetlands surrounding an industrial wastewater treatment facility in order to assess impacts from exposure to effluent. The study includes wetlands that were historically exposed to direct effluent discharge, wetlands that are currently exposed to effluent discharge and reference wetlands. Wetlands were sampled in June, July and September 2018. Environment and Climate Change Canada's "CABIN Wetland" protocol was followed for collection of macroinvertebrates, which were subsequently counted and identified to Family level. Data was visually analyzed using pie charts and nonmetric multidimensional scaling, as well as quantitatively with total abundance, the Shannon Weiner diversity index and the Berger-Parker index. Correlations using Spearman rho were also calculated between the indices and measured environmental variables. Generally, wetlands surrounding the treatment site were not significantly different than the reference sites. Therefore, macroinvertebrate communities surrounding the treatment facility appear to be relatively unaffected by effluent inputs. Given this, monitored natural recovery (MNR) should be implemented in these areas as part of the remediation process. MNR is a remediation tactic that utilizes natural processes to remove or stabilize contaminants.

4.1 Introduction

When evaluating the health of ecosystems impacted by anthropogenic activities, assessing bulk concentrations of contaminants in various ecological media is not always adequate (del Valle & Astorkiza, 2018; Gernes & Helgen, 2002). Incorporating ecological community data, such as diversity, through various biological studies can provide an added assessment lens, as anthropogenic pressures have been shown to affect biological communities (del Valle & Astorkiza, 2018; Gernes & Helgen, 2002; Van Ael, De Cooman, Blust, & Bervoets, 2015). Community assessments can include vegetation (e.g., Boutin & Carpenter, 2016), amphibians (Hopkins, 2007) and fish (Civade, Dejean, Valentini, & Roset, 2016), but more commonly involve assessments of macroinvertebrate communities. In aquatic systems, analyses of macroinvertebrate communities are frequently used to assess impacts of anthropogenic activities, as macroinvertebrates are ubiquitous, are an important link in the food web and have complete or partial life cycles in aquatic systems (Armellin et al., 2017; Baldwin, 2016; Gernes & Helgen, 2002; Merritt et al., 2002). In addition, macroinvertebrate species vary in habitat requirements and sensitivities to contaminants. Therefore different community assemblages occur based on aquatic habitat conditions (Baldwin, 2016). Analysis of the communities can focus on factors such as macroinvertebrate abundance and diversity, or on macroinvertebrates that are known to be tolerant or intolerant to the contaminant(s) of concern (Morris et al., 2014). Assessments through functional groups, instead of taxonomic groups, have also been used (Merritt et al., 2002).

Environment and Climate Change Canada (ECCC) created the "Canadian Aquatic Biomonitoring Network" (CABIN) protocol, which describes a framework for collecting and analyzing macroinvertebrates communities in wadeable streams (ECCC, 2012). This protocol is well used, provides applicable training and an online database for data distribution. Recently, ECCC created another CABIN protocol specifically for wetland use, titled the "CABIN Wetland Macroinvertebrate Protocol" (Armellin et al., 2017). This protocol outlines a framework for collecting and analyzing macroinvertebrates in wetlands, excluding coastal wetlands, and is useful for detecting impacts from anthropogenic stresses. The CABIN Wetland Macroinvertebrate Protocol was implemented for this study to determine whether wetlands surrounding an industrial wastewater treatment facility have been impacted by effluent release.

The treatment facility is located in Boat Harbour[5] (BH), Pictou County, Nova Scotia (Fig. 30). Prior to 1967, BH was a tidal lagoon located on Pictou Landing First Nation (PLFN) land, and was used by the PLFN community for recreational, spiritual and cultural practices (Bennett, 2013; Castleden et al., 2016; Hoffman et al., 2017a). A pulp mill was constructed approximately 4 km southwest of the lagoon at Abercrombie Point and began operation in 1967. BH was chosen as a treatment facility (Boat Harbour Treatment Facility) for the mill's outgoing effluent.

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[5] Boat Harbour is traditionally known as "A'se'K" by the people of Pictou Landing First Nation

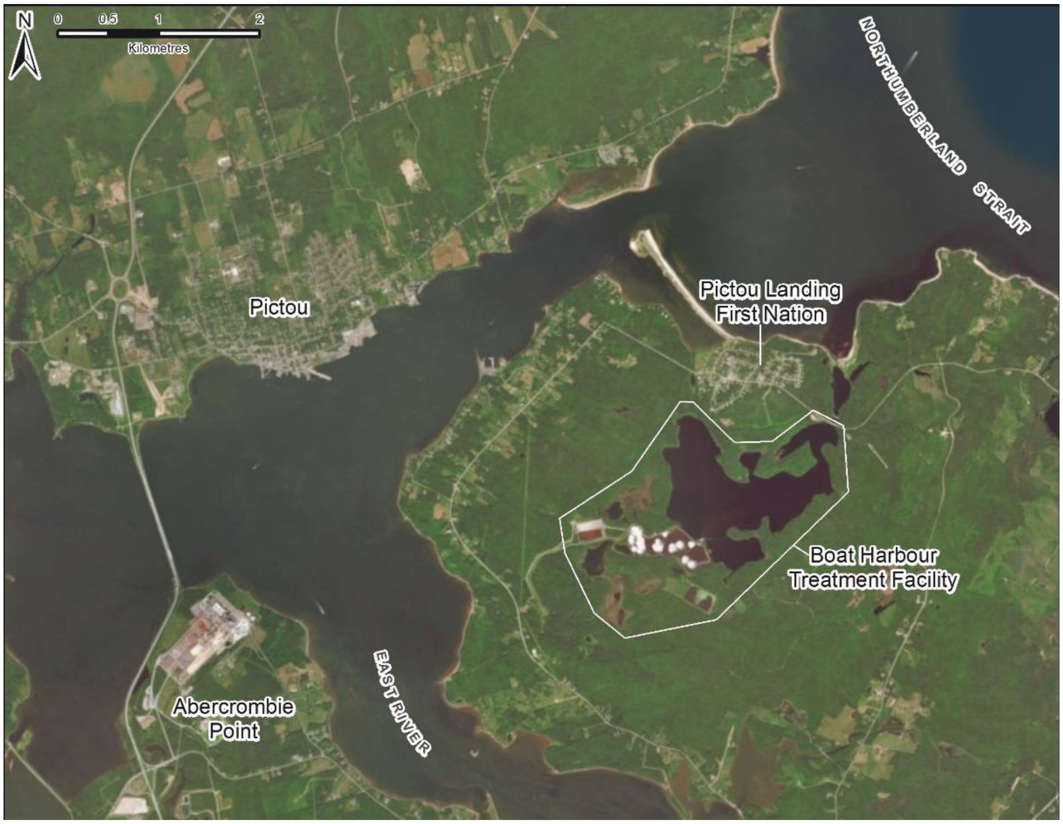

Figure 30: Location of the Boat Harbour Treatment Facility in relation to Abercrombie Point, Pictou Landing First Nation, Pictou and Northumberland Strait. [Map produced using ArcGIS®].

Originally, the treatment framework started at the mill site, where gravity sewers collected and transported raw effluent across East River and into an effluent ditch. The raw effluent was then released into a natural wetland area, where it flowed through the wetland area into a dam called "Settling Pond 2". The effluent was then discharged into the Boat Harbour Treatment Facility (BHTF) and then the Northumberland Strait (GHD, 2018a). The raw effluent contained common pulp contaminants, including metals and polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/PCDF) (GHD, 2018a), which the original treatment process was unable to adequately remove. Because of this, biota within the BHTF was heavily impacted and the surrounding residents experienced strong odours from the area (Baxter, 2017; Castleden et al., 2016). In 1971, effluent from a nearby chlor-alkali plant also began to be discharged into the BHTF, which continued into 1992 (Hoffman et al., 2017b).

In 1972, upgrades were made to the facility, which are currently in use. The effluent is rerouted beyond East River into a lined ditch that bypasses the original wetland discharge area, instead discharging into one of two 50,000 m^3 settling basins (~12-h retention). Effluent subsequently discharges in an aeration settling basin (ASB) (~eight day retention), then into the stabilization lagoon (BH) (20 to 30 d retention) and finally into the Northumberland Strait (Dillon Consulting Limited, 2012, 2019). Additionally, construction of a dam occurred to stop tidal influences into the BHTF, effectively altering the chemistry from saltwater to freshwater (Province of Nova Scotia, n.d.). Elements of both treatment infrastructure are shown in Figure 31.

Figure 31: Components of the Boat Harbour Treatment Facility, including the original infrastructure (1967 - 1972) and the upgraded treatment facility (1972 - present). [Map produced using ArcGIS®].

In total, the fifty years of discharge has deposited more than 570,000 m^3 of unconsolidated sediments containing industrial contamination (Alimohammadi et al., 2019; Hoffman et al., 2015). In 2014, an effluent pipe leak led to the passing of the *Boat Harbour Act* (2015) which mandates the closure of the BHTF by January 31, 2020 with remediation following hereafter. Prior to remediation, baseline assessments must be completed. GHD was retained by Nova Scotia Lands to perform a Phase I and II Environmental Site Assessment, as well as a Human Health and Environmental Risk Assessment (HHERA) to inform the remediation (GHD, 2018a, 2019).

Approximately 25 wetland areas surround the BHTF (WSP, 2018). Each wetland area is expected to have been impacted to some degree by the effluent, either by the historical effluent inputs or the current effluent discharges. Although studies have been done on biota within the lagoon (as described in Dillon Consulting Limited [2012]), wetland biota studies are lacking. This study addresses this data gap using the CABIN Wetland Macroinvertebrate protocol. This protocol will provide insight into how the wetland macroinvertebrate community is responding to the anthropogenic pressure of the BHTF. It will also provide additional information on the health of the wetland ecosystems, which can be utilized for remediation planning.

4.2 Methods

4.2.1 Location of Sample Sites

Five wetlands surrounding the BHTF were sampled, as well as two far-field reference wetlands (Fig. 32). Wetlands were either marshes or swamp-marsh complexes. If a wetland was a complex, the marsh area was selectively sampled. Two wetlands (WL1, WL2) were chosen based on the historic direct discharge point into these wetlands and were *a priori* assumed to contain the highest degree of contamination. Three wetlands (WL3, WL4, WL5) located around the BHTF were chosen based on similar wetland type to WL1 and WL2, as well as accessibility. WL4 was of interest due to its proximity to the sludge disposal cell. Due to their connection to BH and current effluent inputs, these wetlands were considered to have moderate contamination potential. Two reference wetlands (REF1, REF2) were chosen using the Provincial Landscape Viewer (Nova Scotia Department of Natural Resources, 2015) based on similarity in size and wetland type to the BHTF wetlands. REF2 was not sampled in the spring due to lack of permission.

Figure 32: Study area and sampling sites. [Map produced in ArcGIS®].

Previous assessments were completed in these wetlands by WSP (2018), where the dominant vegetation and hydric soils were described. Cattails (*Typha* spp.) were the dominant herbaceous species in all the BHTF wetlands. Hydric soils were classified using hydric soil indicators, and identified soils as Thin, Dark Surface (WL1), Histosols (WL3), Depleted Matrix (WL2, WL4, WL5) and Hydrogen Sulphide odour (WL1, WL4) (WSP, 2018).

4.2.2 Macroinvertebrate Community Sampling

Aquatic macroinvertebrates were collected during the spring (June 4-7, 2018), summer (July 23-27, 2018) and fall (September 15-18, 2018) to evaluate community composition throughout the growing season. The federal ECCC "CABIN Wetland Macroinvertebrate Protocol" (Armellin et al., 2017) was followed for each sampling event. To ensure consistent collection across the different wetlands, a triangle dip net (Fig. 33) was utilized by one person at each wetland. An example of a completed CABIN Wetland worksheet is shown in Appendix E.

Figure 33: Triangular dipnet utilized for this study (Shelton, n.d.).

Dipnetting is a frequently used technique for sampling macroinvertebrates in lentic habitats (Merritt et al., 2002; Tarr, Babar & Babbitt, 2005). Triplicate sweeps, each for a duration of two minutes, were taken by walking forward in a zig-zag pattern through the emergent and submergent vegetation. The net was swept up and down the water column during sweeps. Gentle tapping on the sediment surface was included to displace macroinvertebrates in the sediment. Following the sweep, the outside of the net was carefully splashed with wetland surface water to transfer material to the collection cup in the net. The collection cup was then removed, and contents were placed into 1-L wide mouth plastic jars. Any remaining material in the nets, as well as biota clinging to large vegetation in the net, were carefully sprayed into the jugs using a wash bottle and wetland surface water. Formalin (10% buffered) was added to each jar at a 1:3 Formalin to sample ratio. The jar was then capped and gently swirled to distribute the preservative.

During sampling, pH, electrical conductivity (µS), water temperature (ºC) and dissolved oxygen (mg/L) were recorded three times during the spring sampling and once during the summer and fall sampling at each wetland between approximately 8:00 am and 4:00 pm, using a YSI® 600 Series sonde. These parameters were measured to determine if physical environment differences existed between wetlands which could influence composition, abundance and diversity of macroinvertebrate communities.

Once collected, samples were transported back to the laboratory. Within a week of collection, samples were transferred to 70% ethanol. To identify and count samples, a small portion of sample was poured into a gridded petri dish, and organisms were counted systematically following the grid pattern. After the entire dish was counted, the sample was replaced with another portion of the entire sample. This occurred until the entire sample was counted. Sample examination was conducted using a Wild® M4A dissecting microscope at 8 to 20 magnification power. Simultaneously, each counted organism was identified to Family level using standardized identification keys from Batzer, Rader and Wissinger (1999), Peckarsky et al. (1990), and from the Learning to See, Seeing to Learn project (Learning to See Seeing to Learn, n.d.), with assistance from Thorp and Covich (2010). Identifications were verified through consultation with iNaturalist® (iNaturalist, n.d.) and ResearchGate® (ResearchGate, 2019).

4.2.3 Community Analysis

First, total abundance of each sweep was counted and comparisons to reference wetlands were made to assess general productivity. Then, the diversity and community composition was analyzed to further assess impacts. Community composition at the order level was evaluated with pie charts. Visual results of these charts were used to determine whether known pollution sensitive orders, such as Ephemeroptera, were present in the wetlands. Finer taxonomic resolution of family level was utilized in a nonmetric multi-dimensional scaling (NMDS) analysis in RStudio® (RStudio Team, 2015) using the *metaMDS()* function from the Vegan package. Bray-Curtis distances were applied, and the number of axes was limited to three. To examine the differences in community composition, polygons were fitted using the ordiellipse function. NMDS is commonly used for biological community analysis as it does not assume a linear relationship (Holland, 2008; Oksanen, 2015, 2019).

Following visual analysis, quantitative diversity indices with Family level identifications were analyzed. The Shannon Weiner diversity index (H’) (Equation 2) was calculated for diversity analysis:

$$H' = -\sum_{i}^{k}(p_i * ln(p_i)) \qquad \text{(Eq. 2)}$$

Where:

p_i= proportion of individuals in one species in population k

In addition to abundance and H', the Berger-Parker (BP) index was calculated. BP calculates the percent of the dominant family of the sweep in the total sweep community. BP is calculated using Equation 3:

$$\mathrm{BP} = \frac{N_f}{N_t} \qquad \text{(Eq. 3)}$$

Where:

N_f is the abundance of the dominant family,

N_t is the total community abundance in the sample.

BP has been used in numerous studies to discriminate between disturbed and undisturbed sites (Berger & Parker, 1970; Caruso, Pigino, Bernini, Bargagli, & Migliorini, 2007; Morris et al., 2014). Although typically used for species level, this index was implemented here for family level. Because oligochaetes were not identified beyond class level, they occasionally dominated sweeps. For this reason, it was noted when oligochaetes dominated but their numbers were not included in this analysis.

To confirm parametric assumptions, normality and equal variances of group abundance, H' and BP were tested in *Minitab® 18.1* (Minitab Inc., 2017). The normality test Ryan-Joiner was used to test normality at a significance value of 0.05. If the resulting p-value was below 0.05, the data were deemed non-normal. If the significance value was above 0.05 for Ryan-Joiner the data were deemed normal and tested for equal variance using a formal test in *Minitab® 18.1*. If the significance value for equal variances was below 0.05, the data were deemed non-normal; if above 0.05, the data were deemed normal. Data that were deemed non-normal were then log-transformed and retested for normality using the above framework. If log-transformed data failed normality testing, data were analyzed non-parametrically. If log-transformed or original data passed normality testing, data were analyzed parametrically. Abundance was deemed of normal distribution in the spring, but log-transformation was necessary for summer and fall values. H' was normal for the three seasons. BP was normal for the spring and summer, but log-transformation was necessary for the fall values. Data were analyzed with a one-way ANOVA, followed by a Dunnett's Test using the reference wetlands as a comparison. Mean values ±SE are depicted in the following figures and are reported throughout.

4.3 Results

4.3.1. Abiotic Factors

Environmental variables of wetlands are presented in Table 9. All wetlands were considered to have a neutral to slightly acidic pH. Equipment issues arose which impeded specific conductance measurements. Percent dissolved oxygen was calculated using the measured temperature and mg/L reading in an oxygen nomogram (“Dissolved Oxygen”, n.d.; Hart, 1967) . Triplicate readings in each wetland were collected during the spring event, but single readings were collected during summer and fall. Because of this, significant differences using a Dunnett’s test could only be calculated in the spring. In the spring, only pH showed significant differences (F = 6.65, p=0.03) from the reference wetland (Table 9).

Table 9: Environmental variables at each site throughout the sampling season. Statistical differences could only be calculated in the spring, where asterisks identify significant differences from the reference site ($p<0.05$).

Wetland	Time of sampling	Water temperature	pH	Dissolved oxygen (1/3 total depth)		Dissolved oxygen (5cm from sediment bottom)	
				mg/L	%	mg/L	%
Spring							
REF	2:00pm	11.2	5.84	15.4	141	16.5	150
1	9:45am	11.8	6.83*	10.6	96	8.49	75
2	10:35am	11.6	6.73*	8.24	77	7.80	74
3	11:00am	12.1	6.8*	9.76	90	9.75	90
4	1:30pm	10.0	6.61	7.1	64	7.92	70
5	11:35am	10.9	7.12*	4.43	41	4.03	37
Summer							
REF1	9:30am	25.2	6.22	5.5	65	2.16	25
REF2	10:30am	25.7	7.50	1.67	18	0.95	11
1	2:00pm	29.4	7.34	3.01	37	5.68	70
2	2:45pm	28.9	7.2	7.85	74	8.55	105
3	9:38am	23.0	6.88	2.24	25	2.30	27
4	4:14pm	30.1	6.80	14.97	>140	14.5	>140
Fall							
REF2	2:30pm	16.0	8.38	6.00	60	5.66	57
1	10:05am	16.4	6.83	3.50	41	2.95	30
2	11:50am	16.6	6.49	3.36	36	2.62	27
3	1:33pm	16.4	6.57	3.70	39	3.50	38
4	3:30pm	15.7	6.21	4.30	43	4.22	42

4.3.2 Abundance Analysis

A total of 1005 invertebrates were captured during the spring sweep, 1908 invertebrates were captured during the summer sweep, and 244 invertebrates were captured during the fall sweep. Thirty-one families were identified in spring, 33 families in summer, and 17 in fall (Table 10). Examples of organisms collected, identified and counted can be seen in Fig. 34.

Figure 34: Examples of macroinvertebrates collected during this study, viewed under magnification.

Table 10: Macroinvertebrate identified during each sampling period. Oligochaetes and Hirudinea were not identified beyond class level.

	ORDER	FAMILY
SPRING		
	Amphipoda	Hylellidae
	Araneae	Dictynidae
		Pisauridae
	Cladocera	Daphniidae
	Coleoptera	Dytiscae
		Elmidae
		Gyrinidae
		Haliplidae
	Cyclopoida	Cyclopidae
	Diptera	Chaoboridae
		Chironomidae
		Culicidae
		Muscidae
		Tabanidae
	Ephemeroptera	Baetidae
		Caenidae
		Siphlonuridae
	Hemiptera	Corixidae
		Gerridae
		Notonectidae
		Veliidae
	Littorinimorpha	Hydrobiidae
	Megaloptera	Sialidae
	Odonata	Aeshnidae
		Coenagrionidae
		Lestidae
		Libelullidae
		Siphlonuridae
	Oligochaete	
	Trichoptera	Hydropsychidae
	Veneroida	Sphaeriidae
SUMMER		
	Amphipoda	Hylellidae
	Araneae	Dictynidae
		Pisauridae
		Pisauridae
	Cladocera	Daphniidae
	Coleoptera	Dytiscae
		Elmidae
		Gyrinidae
		Haliplidae
	Cyclopoida	Cyclopidae
	Diptera	Chaoboridae
		Chironomidae
		Culicidae
		Muscidae
		Tabanidae
		Tipulidae
	Ephemeroptera	Baetidae
		Caenidae
		Siphlonuridae
	Hemiptera	Belostomatidae
		Corixidae
		Gerridae
		Notonectidae
		Veliidae
	Littorinimorpha	Hydrobiidae
	Megaloptera	Sialidae
	Odonata	Aeshnidae
		Coenagrionidae
		Lestidae
		Libelullidae
		Siphlonuridae
SUMMER CON'T		
	Oligochaete	
	Trichoptera	Hydropsychidae
	Veneroida	Sphaeriidae
FALL		
	Cladocera	Daphniidae
	Coleoptera	Dytiscae
		Haliplidae
	Cyclopoida	Cyclopidae
	Diptera	Chaoboridae
		Chironomidae
		Culicidae
		Muscidae
	Ephemeroptera	Baetidae
		Siphlonuridae
	Hemiptera	Corixidae
		Gerridae
		Notonectidae
	Hirudinae	
	Littorinimorpha	Hydrobiidae
	Odonata	Aeshnidae
		Lestidae
	Oligochaete	
	Veneroida	Sphaeriidae

Macroinvertebrate abundance within the wetlands varied between wetlands and between sampling events (Fig. 35). In the spring, abundance ranged from 9 to 154 with REF1 garnering the greatest mean abundance of 98.7 ±29.7. Abundances in the summer were generally higher, ranging from 19 to 393. Again, REF1 contained the highest mean abundance of 245.7 ±83.2. In the fall, abundances noticeably decreased to a range of 7 to 42 individuals, with WL4 containing the highest mean abundance of 26 ±2.3. Not included in summer and fall counts is WL5, as the wetland lost most of its standing water and could not be properly sampled during these events. The reference wetland REF1 is also absent from the fall counts, as it too lost a considerable amount of standing water and could not be effectively sampled. As these wetlands have never been sampled in this way before, it is unclear as to whether this is a yearly occurrence where WL5 and REF1 have shorter hydroperiods, or was a result of hotter, drier weather than typically occurs. REF1 and WL5 contained families that are generally considered "perennial stream obligate", such as Aeshnidae (Chadwick & Huryn, 2007; Mazzacano & Black, 2012), so it is possible this was an unexpected event. Other families have characteristics that resist drying, such as laying desiccate-resistant eggs or burying into substrate (Batzer & Wissinger, 1996) which is why a lack of macroinvertebrates would not determine a seasonally flooded wetland. Additionally, different areas of WL4 had to be sampled during the fall, as the original area had lost significant water due to the presence of a nearby beaver dam. Abundance in WL4 was significantly lower than REF1 in the spring (T = - 2.93, p=0.048) and significantly higher than REF2 in the fall (T = 3.06, p=0.038). No other significant differences were detected.

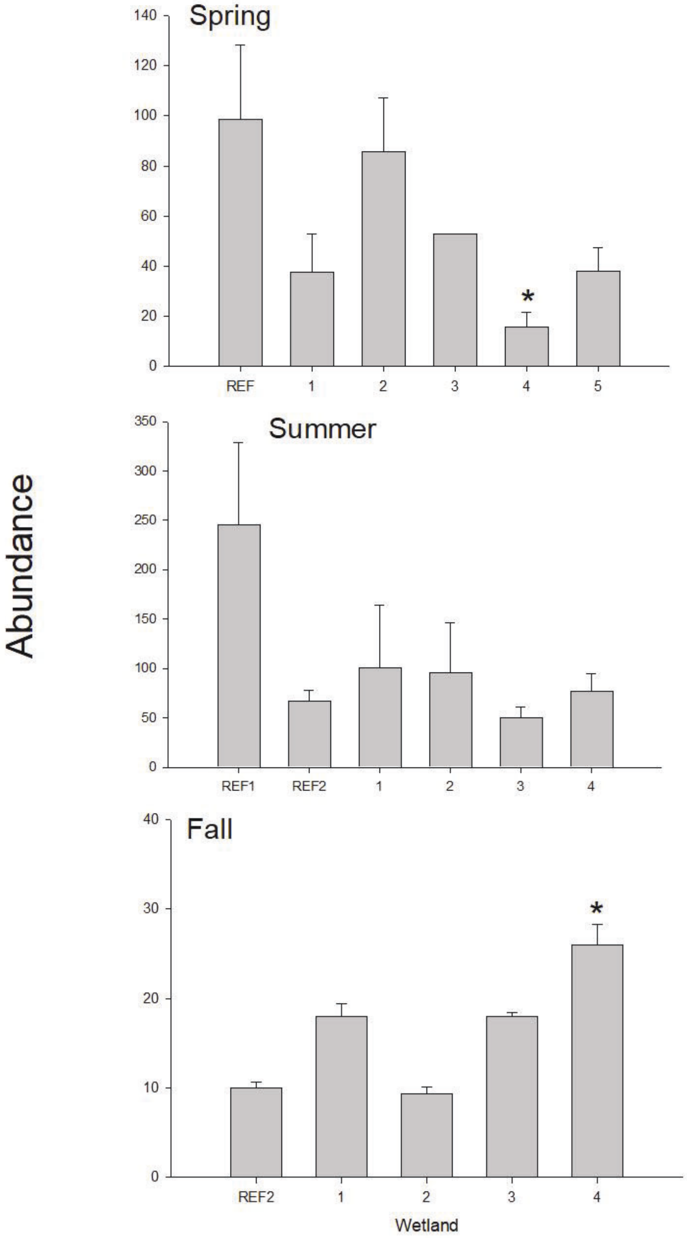

Figure 35: Mean abundance values for each studied wetland throughout the 2018 field season (*n*=3, ±SE). Asterisks identify significant differences from the available reference wetland ($p<0.05$).

4.3.2 Diversity Analysis

Mean relative abundance by Order was first used to visually identify any differences that occur between the wetland sites (Figs. 36-38). From this, it is apparent that community compositions change from wetland to wetland, and between sampling events. In the spring, Cladocera, Coleoptera, Diptera and Ephermeroptera dominated one or multiple wetlands (Fig. 36). In the summer, the dominant Orders change, with Amphipoda, Cladocera, Diptera, Hemiptera and Oligochaeta (identified only to sub-class) dominating one or multiple wetlands (Fig. 37). This shifts again in the fall, with Cladocera, Diptera and Oligochaeta (identified only to sub-class) dominating (Fig. 38).

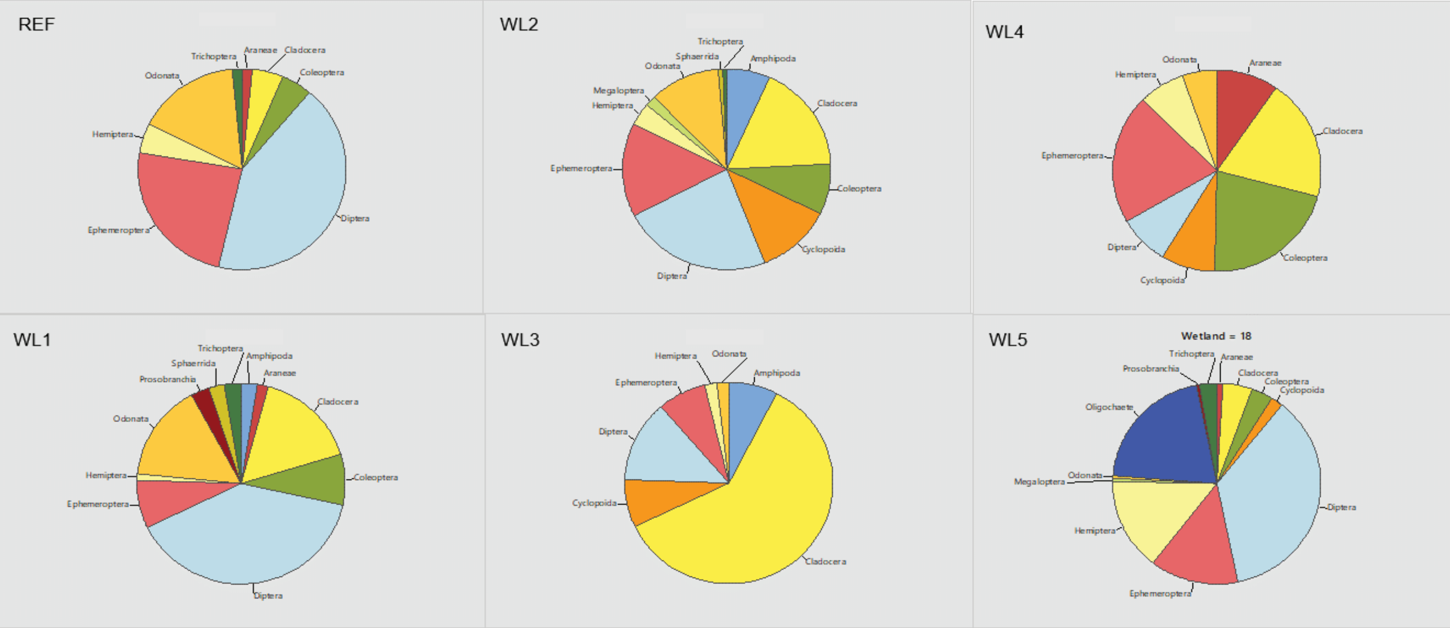

Figure 36: Mean order composition of macroinvertebrate communities in each wetland during Spring sampling.

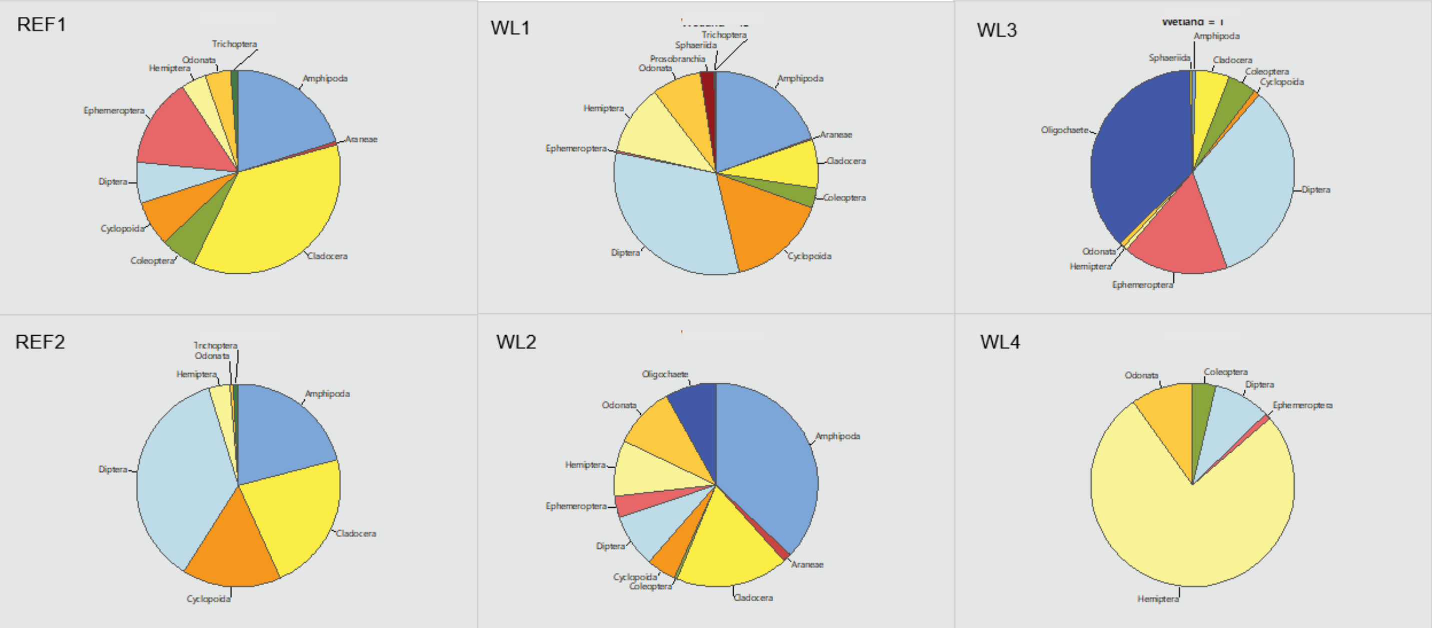

Figure 37: Mean order composition of macroinvertebrate communities in each wetland during Summer sampling.

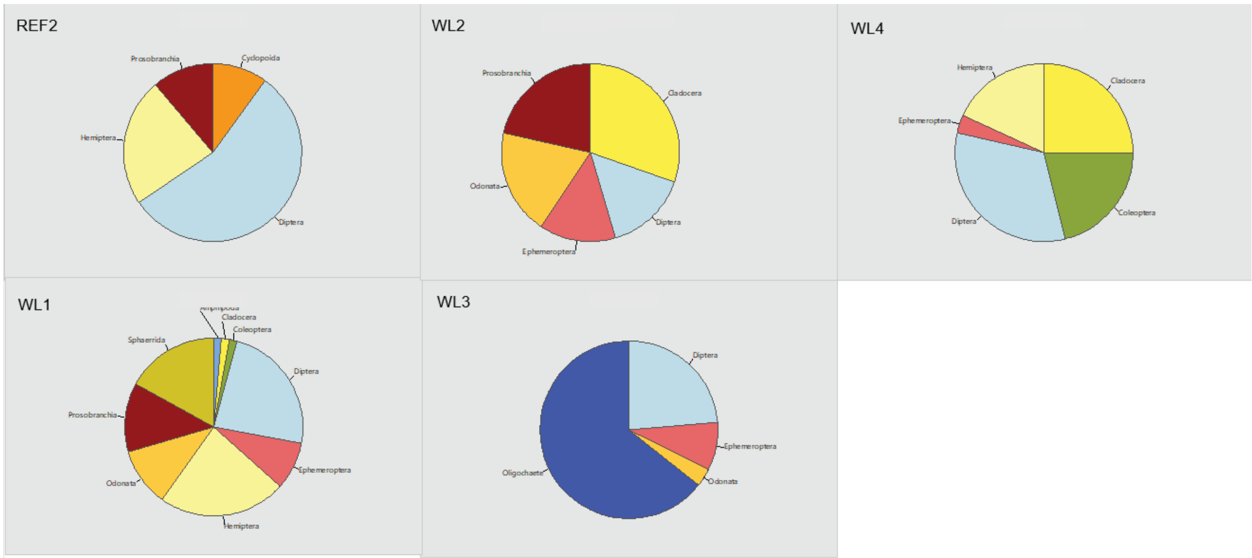

Figure 38: Mean order composition of macroinvertebrate communities in each wetland during Fall sampling.

To further assess diversity differences between communities visually, NMDS using finer taxonomic resolution of Family was applied. The NMDS ordination produced reasonable stress levels at 0.12 (Spring), 0.10 (Summer) and 0.08 (Fall) at three axes (Fig. 39 to 41). Community composition appeared relatively similar to the reference wetland in the spring (Fig. 39). No clear overlap occurred with REF1 in the summer, albeit the only wetland clearly different than REF1 and REF2 was WL4 (Fig. 40). There was no clear overlap between any wetland in the fall (Fig.41).

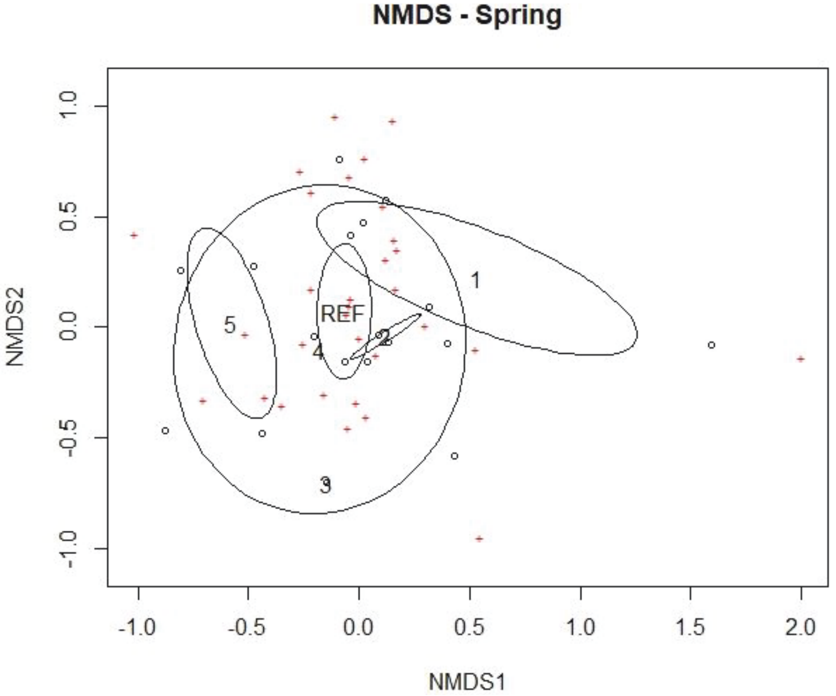

Figure 39: NMDS results for the spring sampling (stress = 0.12).

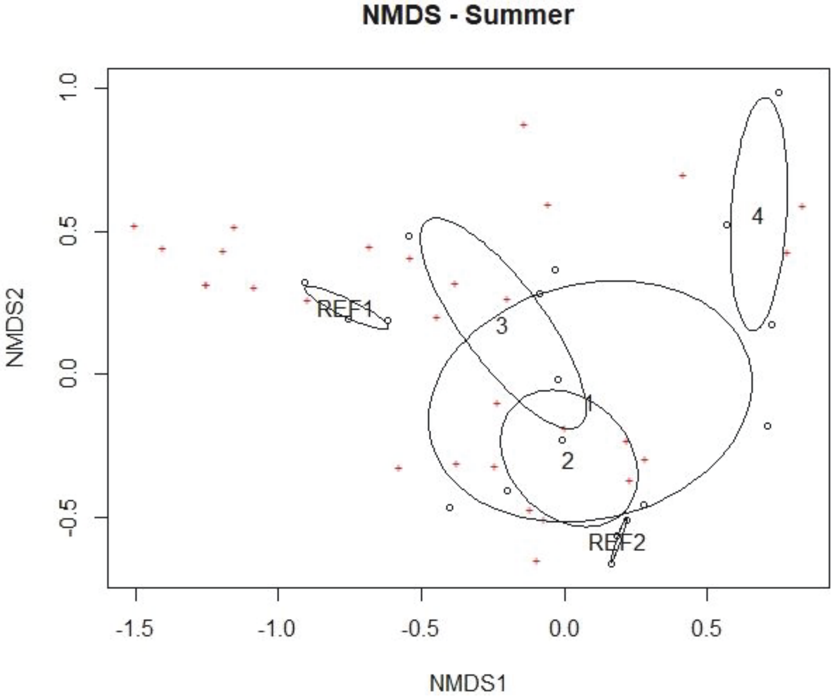

Figure 40: NMDS results for the summer sampling (stress = 0.10).

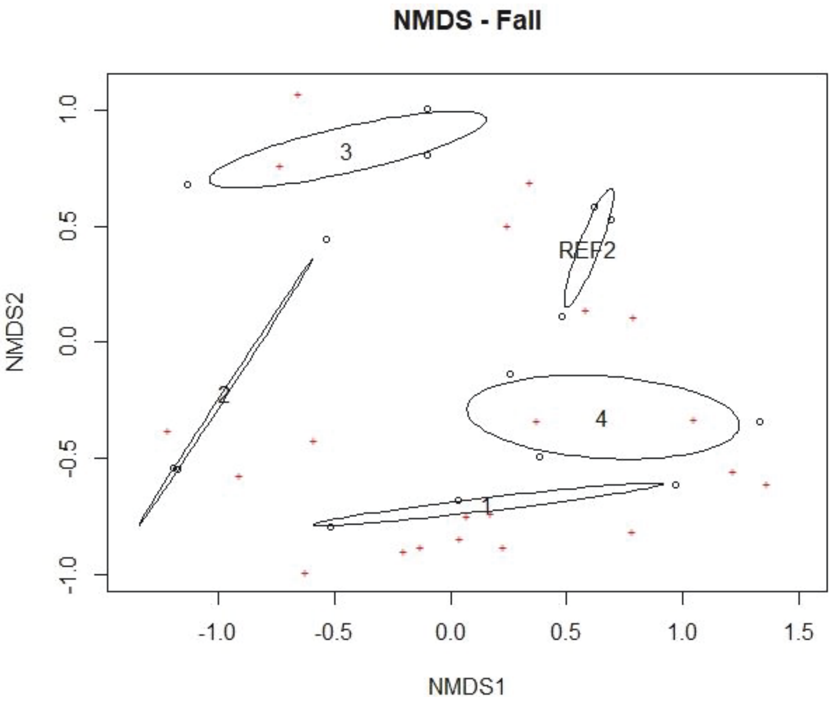

Figure 41: NDMS results for the fall sampling (stress = 0.08).

H’ (using the taxonomic resolution of Family) ranged from 0.75 to 2.1 throughout the sampling season. Only two significant differences from the reference diversities were observed (Fig. 42). In the summer, WL4 was significantly lower than REF1 and REF2 (T = -6.64, *p* = 0.00) and in the fall, WL1 was significantly higher than REF2 (T = 3.39, *p*=0.022). WL2 displayed the highest H’ throughout the entire sampling event during the spring at 2.18 ±0.05. In the summer, REF1 displayed the highest index at 2.14 ±0.17. H’ dropped slightly in the fall, ranging from 0.85 – 1.81. WL1 displayed the highest H’ at 1.81 ±0.13.

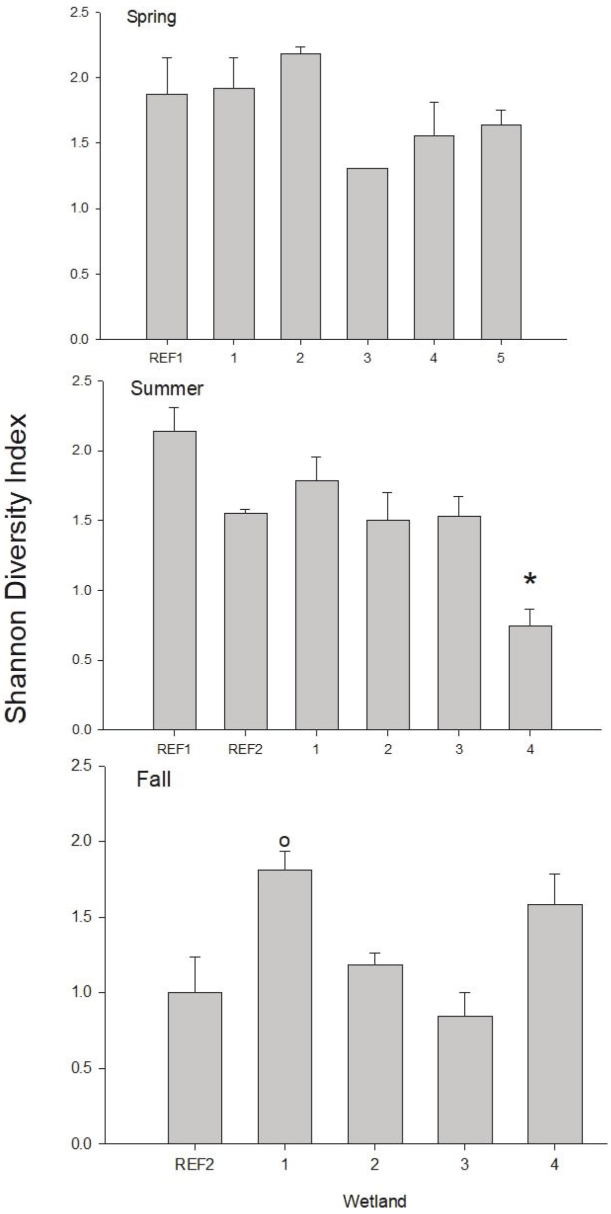

Figure 42: Mean Shannon Weiner diversity indices throughout the sampling season (*n*=3, ±SE). Asterisks (*) represent significant differences to both REF1 and REF2, whereas circles (o) represent significant differences to REF2 ($p<0.05$).

The dominant family differed between sweeps, wetlands and sampling events (Table 11). BP varied between sites and sampling events, ranging from 0.23 (WL2, Spring) to 0.81 (WL4, Summer) (Fig. 43). In summer, WL2 and WL4 differed significantly from reference wetlands (F = 17.46, $p < 0.01$).

Table 11: Dominant families in each wetland throughout the sampling season. Numbers in brackets identify whether a family was dominant more than once, and how many times. Asterisks beside oligochaetes denote dominance in sweeps but were not included in Berger-Parker calculations as oligochaetes were not identified to family level.

Wetland	Dominant Families
Spring	
REF	Chironomidae (2)
	Culicidae
1	Aeshnidae
	Chironomidae
	Culicidae (2)
	Daphniidae (2)
2	Baetidae
	Cyclopoidae
	Daphniidae (2)
	Elmeridae
3	Daphniidae
4	Baetidae
	Daphniidae
	Dytiscae
	Hydrachnidae
5	Culicidae
	Muscidae
	Oligochaete*
	Siphlonuridae

Wetland	Dominant Families
Summer	
REF1	Daphniidae (3)
REF2	Chironomidae (3)
	Daphniidae
1	Chaoboridae
	Cyclopoidae
	Hylellidae
2	Daphniidae
	Hylellidae (2)
3	Baetidae
	Chironomidae
	Oligochaete*
4	Notonectidae (3)
Fall	
REF2	Chironomidae (3)
	Cyclopoidae
1	Hydrobiidae
	Notonectidae
	Sphaeriidae
2	Chironomiidae
	Daphniidae
	Sphaeriidae
3	Baetidae
	Chironomidae (2)
	Oligochaete (3)*
4	Daphniidae (2)
	Dytiscae

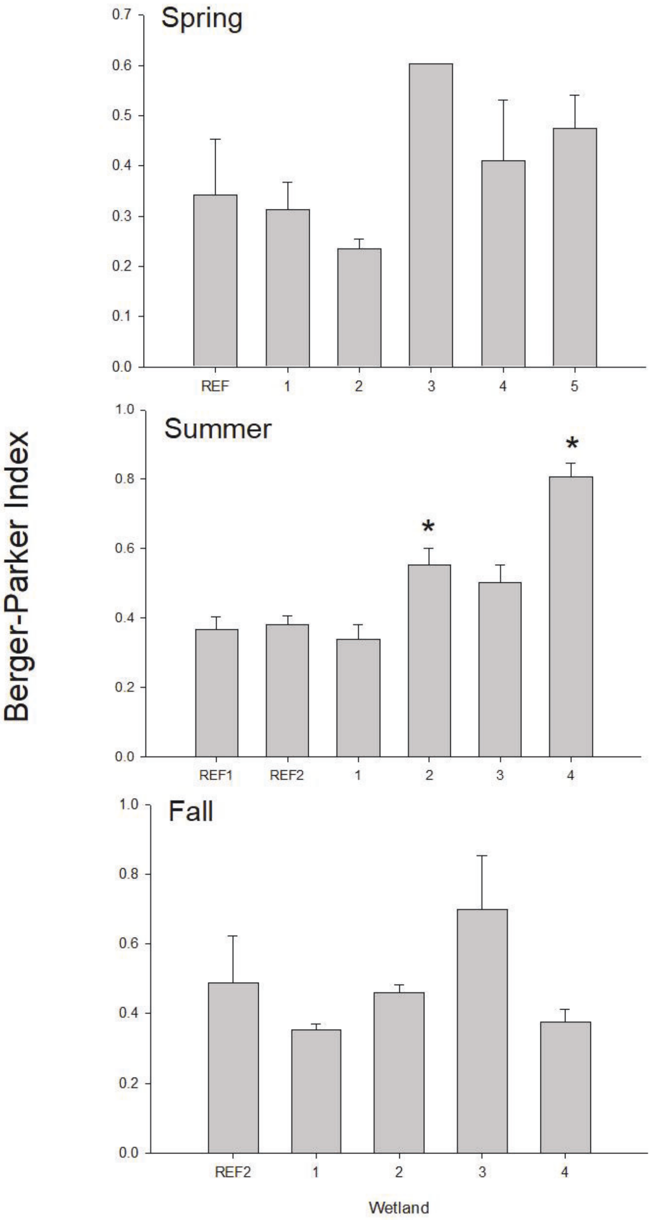

Figure 43: Mean Berger-Parker index in all sampling events, excluding sub-class Oligochaete. Asterisks (*) indicate significant difference from REF1 and REF2 (*n*=3, ±SE) ($p<0.05$).

For the GHD HHERA, the CABIN Wetland protocol was used to assess macroinvertebrate communities in the former settling ponds, similar to WL1 and WL2 in this study (GHD, 2019). Following collection, GHD retained professional taxonomists to enumerate and identify specimens collected to species level. The data were then used to calculate various benthic community metrics, including abundance and H'. As the HHERA samples were collected in similar locations to WL1 and WL2 between this study's summer and fall sampling, comparison of the HHERA results to the two sampling events is tabulated in Table 12. For the HHERA, a greater number of specimens were collected. As the sampling occurred during a similar time period and using identical protocols, this difference could be due to lack of experience during this study's sampling attempts. H' was similar between the studies, with the present study finding slightly higher H' than the HHERA. H' has been shown to be more robust than abundance (Caruso et al., 2007; Morris et al., 2014), and therefore difference in experience between researchers is less apparent. H' in the HHERA used genus and species-level counts, whereas this study used family-level counts, which may explain the difference between the studies.

Table 12: Comparison of macroinvertebrate community metrics between GHD's HHERA and the present study.

Metric	HHERA - Fall			Present study - Summer			Present study - Fall		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Abundance	655	0	130	225	19	98	11	3	6
H'	2.17	0	1.29	2.11	1.12	1.65	2.06	1.03	1.50

The HHERA also focused on other metrics, including the Pielou's Evenness, Hilsenhoff Index, Percent Oligochaetes and Percent Chironomidae. As the HHERA identified specimens to a finer taxonomic resolution (genus and species), these metrics, as well as H', were likely more accurate than this study (Bailey, Norris, & Reynoldson, 2001; Chessman, Trayler, & Davis, 2002; Feio, Reynoldson, & Graça, 2004). On the other hand, this study measured community metrics throughout the growing season, whereas the HHERA only measured once. Therefore, this study adds to the understanding of the BHTF wetlands by identifying seasonal changes in communities. As well, this study identified communities in additional wetlands not included in the HHERA. The HHERA concluded limited risk to benthic macroinvertebrate communities was present (GHD, 2019).

4.3.3. Correlation

Spearman rho correlation analysis revealed no significant correlations between environmental variables and abundance, H’ and BP in spring and fall. In summer, dissolved oxygen at both 1/3 total depth and 5 cm from sediment surface and showed significant correlation with H’ (Table 13).

Table 13: Correlation analysis between mean environmental variables and mean community indices. Asterisks (*) mark significant correlations ($p<0.05$).

	Temperature (ºC)	pH	Dissolved oxygen (1/3 of total depth)	Dissolved oxygen (5 cm from surface sediment)	Wetland size (ha)
SPRING					
Abundance	0.43	-0.63	0.650	0.66	0.148
H’	0.1	0.68	0.218	0.11	0.393
BP	0.23	0.69	-0.09	-0.02	-0.317
SUMMER					
Abundance	-0.10	-0.73	0.03	-0.22	0.003
H’	0.46	-0.17	0.91*	0.87*	0.586*
BP	-0.46	-0.21	-0.72	-0.78	-0.455
FALL					
Abundance	-0.56	-0.59	-0.22	-0.04	-0.131
H’	-0.22	-0.34	-0.31	-0.31	0.164
BP	0.35	0.06	-0.00	0.06	-0.005

4.4 Discussion

This line of evidence was used to investigate macroinvertebrate community responses to historic and current industrial effluent inputs. Results indicated that invertebrate responses to effluent inputs did not align with what was hypothesized. WL1 and WL2, the proposed “high contamination potential” wetlands, were expected to show different macroinvertebrate communities from reference, low macroinvertebrate abundance and diversity, as this was observed in previous studies of metal-contaminated aquatic systems (e.g. Clements, Carlisle, Lazorchak & Johnson, 2000). However, WL1 and WL2 did not differ significantly from the reference areas, except for WL1 during fall sampling, which showed significantly higher H’ than REF2. However, higher H’ typically depicts healthier communities. Commonly known pollution intolerant orders, such as Ephemeroptera (Capitulo, Tangorra, & Ocon, 2001; Clements et al.,

2000) and families, such as Daphniidae (Tomasik & Warren, 1996), were present in WL1 and WL2, occasionally dominating the sweep composition. If these wetlands were contaminated, these families would likely not be present. WL1 and WL2 did not appear to differ much from the reference wetlands in the NMDS analysis. Large spatial wetland intra-variation in community compositions are visible in the NMDS analysis as large polygons. Additionally, the HHERA drew similar conclusions, which adds confidence to this conclusion.

Higher than expected abundance and diversity is likely because sweeps occurred within shallower, vegetated portions of the wetlands as opposed to the deeper areas. As described in Chapter 3, contaminants accumulate in deeper areas of WL1 and WL2. Therefore, shallower areas that provide habitat for macroinvertebrates contain a lower concentration of contaminants, which is a potential reason why these communities appeared healthy. From this, WL1 and WL2, at least in the littoral areas where the sweeps occurred, are likely not as contaminated as expected.

Wetlands surrounding the BHTF (WL1 – 5) do not show a consistent pattern of impact. Wetlands that appear to be impacted when considering one index are not impacted when considering another. For example, WL4 had a significantly lower abundance than the reference wetland in the spring. However, in that same sampling event, H’ for WL4 did not significantly differ from the reference, and the dominant families in WL4 included pollution sensitive families such as Baetidae. As well, wetlands that appeared impacted by an index do not appear impacted when considering the same index during a different sampling event. For example, H’ for WL4 in the spring was not significantly different from the reference wetland. However, WL4 H’ was significantly lower in the summer. This drop was likely due to the dominance of Notonectidae in WL4 in the summer, which was not the situation in the spring.

These dissimilarities highlight the need to test more than one index, as impacts are generally not clear when considering only one index (Purvis & Hector, 2000). Each index has strengths and weaknesses that must be considered (Morris et al., 2014). Abundance can be useful in cases where only biota presence is useful, such as some conservation biology applications (Purvis & Hector, 2000). However, a system can contain high abundance but could also be dominated by one or two species. This system would appear un-impacted if only abundance was analyzed. Species richness and abundance are dependent on sampling effort (Magurran, 2004), whereas H’ and BP are more robust (Caruso et al., 2007; Morris et al., 2014).

However, as was evident in this study, each measure can be useful in identifying various effects. Again, WL4 can highlight this, as this wetland showed significantly different abundance from the reference wetlands twice, but abundance was never significantly correlated with environmental variables and did not follow a *priori* assumptions of contamination potential.

Additionally, WL4 presented significantly higher abundance in the fall. Sampling during this event occurred in a different area, as previously described. Therefore, the decreased abundance in the spring may have been due to intra-wetland differences, such as macrophyte composition, as macrophytes are a key factor in macroinvertebrate community composition (Batzer & Wissinger, 1996). Macrophytes provide shelter from vertebrate predators, as well as providing additional habitat for macroinvertebrate prey (Gosselain et al., 2005; Khudhair, Yan, Liu, & Yu, 2019). As well, submerged plants with similar morphologies but different life cycles will support different macroinvertebrate communities (Hargeby, 1990). Macrophyte composition was not thoroughly analyzed in this study, but instead visually analyzed and wetlands were deemed to be generally similar. It is therefore possible subtle variances may have existed, thus affecting abundance in portions of WL4. This line of thought can also be extended to the other wetlands, as well as H' and BP, as these indices varied between wetlands and seasons. A vegetation survey was completed for the HHERA in WL1 and WL2. *Typha angustifolia* was the dominant macrophyte, and the macrophyte community was deemed healthy with no evidence of phytotoxicity (GHD, 2019). However, these wetlands had reduced macrophyte species richness and diversity when compared to HHERA reference wetlands. Detailed vegetation surveys did not occur in WL3, 4, 5, REF1 and REF2, and consequently further macrophyte differences may be influencing the macroinvertebrate communities.

Correlations between environmental variables and community metrics were only significant in the summer for H'. More samples are required and may identify influences from environmental variables. As well, environmental variables can be influenced by outside factors. For example, in this study environmental variables were not measured at a consistent time of day. In the spring, WL1 was sampled at 9:45 am, whereas REF was sampled at 2:00 pm. This sampling discrepancy may be the reason why REF displayed a higher dissolved oxygen content than WL1. Dissolved oxygen has been shown to fluctuate throughout the day due to photosynthesis and respiration activities, with peak oxygen release from plants generally occurring after peak light intensity (Dong, Zhu, Zhao, & Gao, 2011). Daily stratification of dissolved oxygen can occur in shallow water columns (<0.6 m), such as the wetlands studied here, followed by nocturnal convection mixing aerobic surface waters with anaerobic bottom waters resulting in high dissolved oxygen content in the latter half of the afternoon but lower oxygen content in the morning (Andersen, Kragh, & Sand-Jensen, 2017). Therefore, the variations in dissolved oxygen may have been caused by these processes and the differences in sampling time between wetlands instead of environmental contamination or impacted biological communities. Future studies should sample these variables be consistent with sampling times to avoid these confounding factors.

There are several advances in bioassessment that could be employed in future wetland assessments, including the use of environmental DNA (eDNA). eDNA is the collection of genetic material directly from environmental samples (Thomsen & Willerslev, 2015). The eDNA is then coupled with high-throughput sequencing (HTS) platforms and known taxonomic sequences (Deiner et al., 2017; Deiner, Fronhofer, Mächler, Walser, & Altermatt, 2016). Detection of present families, and even species, can be achieved using this technology (Deiner et al., 2016). eDNA has been shown to identify a greater number of families, incorporate a wider scale for biodiversity, and require less time and sampling than the conventional morphological identification method (Fernández et al., 2018). Still, eDNA is more expensive than conventional methods (Fernández et al., 2018), which could be a serious limitation for community monitoring groups.

4.5 Limitations

This study has potential limitations that should be considered. First, although efforts were made to ensure consistent sampling effort between the three sampling events, slight differences exist. WL3 could only be sampled once in the spring but was sampled three times in the summer and fall, affecting statistical analysis during the spring. As well, environmental variables were measured three times at each site in the spring but were sampled once in the summer and fall. This decision was made as little variation was present in the spring readings. However, statistical analysis was then impeded. Future tests should continue measuring environmental variables to provide additional data. With this, further statistical analysis could be completed to determine whether correlations between environmental variables and community indices are present.

Second, there were no wetlands of similar size to WL1 and WL2 surrounding the BHTF. WL3, WL4 and WL5 were chosen based on similarities in wetland type to WL1 and WL2;

however, they were upwards of 30 times smaller. WL3 and WL5 border the BH waterbody, which creates a similar wetland edge to WL1 and WL2. The differences in size were not correlated to the indices measured (barring summer H'); however, the size may have impacted other factors, such as present macrophytes or wind strength and speed. These factors have been showed to impact macroinvertebrate communities (Cai, Gong, & Qin, 2011; Hargeby, 1990). In-depth macrophyte community analysis should be completed in future studies to determine whether macrophyte communities are impacted by the BHTF effluent inputs. As well, examination of hydroperiod and nutrient loading should also occur, to identify whether these are impacting the macroinvertebrate communities.

Lastly, lack of experience and precise equipment limited the taxonomic resolution. Effects of the effluent or environmental variables may only be apparent with genus or species level analysis (Bailey et al., 2001; Feio et al., 2004). A dipnet was solely used for collection purposes. Other techniques, such as the Quadrat-Column-Core method (Meyer, Davis, & Bidwell, 2013) or a funnel trap (Turner & Trexler, 1997) could have been used to mitigate the downfalls of dipnetting and collect more individuals. Therefore, further investigation should employ identification specialists or eDNA for more accurate and finer resolution identification.

4.6 Conclusion

Results of this study suggest that macroinvertebrate communities vary slightly among the BHTF wetlands and the surrounding reference wetlands. However, it is unclear what factors are regulating these communities. A *prior* expectations of contamination potential were not reflected in these results, as WL1 and WL2 did not differ significantly from REF1. This could be partly due to contaminant partitioning in deeper areas that were not sampled for communities (as described in Chapter III). From this study, none of the BHTF wetlands appear to require active remediation action, as no heavily impacted macroinvertebrate communities are present. Instead, allowing for natural attenuation and monitoring of the wetlands through monitored natural recovery (MNR) should occur throughout the remediation process. MNR is a legitimate practice that utilizes natural processes, such as biological processes and metal precipitation. Lines of evidence should include monitoring long-term recovery of sediment, surface water and biota communities (Magar et al., 2009; Magar & Wenning, 2006). MNR should occur following remediation, as the BHTF will return to its tidal state. This will likely impact wetland communities, as they are currently composed of freshwater macroinvertebrates.

Chapter V

5.0 Conclusions: Management Implications for Contaminants of Potential Concern in the Boat Harbour Treatment Facility Wetlands

5.1 Summary of Research

The objective of this research was to assess and delineate contaminants of potential concern (COPC) in the wetlands surrounding the Boat Harbour Treatment Facility (BHTF). Three research objectives were followed to support this objective:

1. Determine the contaminant concentration present in select wetland media around the BHTF to provide a delineation of impact on wetland areas for remediation (described in Chapter III),
2. Identify the macroinvertebrate community composition in the representative wetlands around the BHTF, and compare to reference wetlands to determine effects of historical and current effluent inputs on the biota (described in Chapter IV),
3. Provide a baseline of the BHTF wetlands against which future monitoring studies can be compared to during and after remediation of impacted sites in the BHTF.

To achieve the first objective, sediment, surface water and Libellulidae (Odonata) tissue was collected from select wetlands surrounding the BHTF, as well as two reference wetlands. Samples were analyzed for COPC and compared to provincial/federal guidelines and reference concentrations. For the second objective, Environment and Climate Change Canada's CABIN Wetland protocol was followed. Samples were then enumerated, identified, and data was run through several community metrics. Both objectives were used to achieve the third objective, as data from both studies were added to current baseline assessments. This work further solidified the importance of using multiple lines of evidence (LOE) when performing an environmental assessment, as one LOE cannot provide a comprehensive view.

This chapter provides a summary of the key findings of this research, management-specific recommendations, the study limitations, and opportunities for future research.

5.2 Key Findings

This study resulted in four key findings:

1. The proposed "high contamination potential" wetlands generally contained low concentrations of COPC and were rarely significantly different from reference wetlands in terms of COPC and macroinvertebrate community metrics, except for deeper wetland samples.
2. Wetlands surrounding the BHTF, specifically WL3 and WL5, frequently differed from the reference wetlands for COPC in sediment and surface water.
3. Community metrics in wetlands surrounding the BHTF rarely differed from reference wetlands.
4. Wetlands outside of the study area have been impacted by certain COPC, including select metals, total mercury (THg), polychlorinated dibenzo-p-furans and polychlorinated dibenzofurans (PCDD/PCDF).

Recommendations for managing the BHTF wetlands through future remediation activities given these findings are discussed below.

5.3 Management Implications and Recommendations

5.3.1 Assessment of Contaminants of Potential Concern

The majority of sediments and surface water collected in the *a priori* assumed "high contamination potential" wetlands (WL1 and WL2) were considered uncontaminated to moderately contaminated, with the highest sediment concentrations generally occurring in the deepest water samples. This finding suggests the historical contamination has selectively sorbed or mobilized to finer grained, high organic sediment in deep surface water column areas. As well, shallow areas with macrophyte presence may have attenuated contaminants through processes such as uptake, sequestration and biodegradation.

Three wetlands (WL3, WL4, WL5) surrounding the BHTF were analyzed as well. *A priori* assumptions were that these wetlands would be of moderate contamination, as historic direct effluent discharge did not occur in those areas. However, WL3 and WL5 displayed high concentrations of the COPC in sediment and/or surface water media and were considered heavily contaminated as provincial and national guidelines were frequently exceeded. This finding suggests that attention should be paid to the surrounding wetlands, instead of solely sampling the historic discharge areas.

Recommendation*: Pre-remediation assessments should include the surrounding wetlands to further delineate contamination extent.*

5.3.2 Monitored Natural Recovery

As shallow WL1/WL2 and overall WL4 displayed COPC concentrations below guidelines and does not appear to be impacting the aquatic macroinvertebrate or macrophyte community, it would appear natural attenuation is successful in these areas. Natural attenuation and monitored natural recovery (MNR) is a process where a combination of physical, chemical and biological processes reduce contamination without human intervention (Bekins, Rittmann, & MacDonald, 2001; Magar & Wenning, 2006). In wetlands, natural attenuation processes can involve burial, adsorption, biodegradation, cation and anion exchange processes, and binding of hydrophobic organic chemicals to the rich organic carbon soil (GHD, 2018b). Additionally, wetland macrophytes can be very efficient in the uptake and removal of contaminants (An et al., 2011). These processes have been used in numerous wetland remediation projects, such as with acid mine drainage (Humphries, McCarthy, & Pillay, 2017), arsenic (An et al., 2011), trichloroethene (Qin, Struckhoff, Agrawal, Shelley, & Dong, 2015) and hexavalent chromium (Hellerich, Nikolaidis, & Dobbs, 2008) contamination.

WL3 displayed high surface water concentrations, but low sediment concentrations. This may be the result of resuspension of contaminants in the nearby remediation test cove, with the inability of sediments to mobilize contaminants due to low TOC concentrations. Macroinvertebrate communities within WL3 rarely differed from the reference wetlands and contained pollutant sensitive organisms such as Ephemeroptera (Lock, Asenova, & Goethals, 2011; Mandaville, 2002). Therefore, natural attenuation may have occurred here prior to remediation testing, and may be a plausible remediation strategy. However, this spike in surface water COPC could settle in the sediments, so careful monitoring of this area should occur. If sediment shows an increase in COPC, more action may be required. Additionally, WL2 and WL4 displayed PCDD/PCDF concentrations above ISQG guidelines, suggesting moderate contamination. When analyzing the Odonata tissue data from this study and the HHERA, PCDD/PCDF does not appear to be heavily impacting the food web.

Active remediation processes can cause many adverse impacts to wetlands, such as vegetation and hydric soil removal, changes to hydrology and displacement of wildlife (GHD, 2018b). Therefore, natural attenuation is an option that would be minimally intrusive and allow the present communities to continue to flourish.

Recommendation: *During the BHTF remediation process, areas that are deemed uncontaminated and support a fairly healthy ecosystem should be left undisturbed for natural attenuation to continue. Use of MNR processes should occur to monitor these areas to determine whether recovery is occurring, and if nearby active remediation efforts are negatively affecting these areas.*

5.3.3 Active Remediation

The deep vertical surface water areas of WL1 and WL2, as well as the entirety of WL5 displayed relatively high concentrations of COPC in the sediment. As the goal of the BHTF remediation is to return the area to pre-1967 tidal status (Province of Nova Scotia, n.d.) for recreation and fishing use, and these contaminants are potentially at concentrations too high for natural attenuation, active remediation activities could be considered. As well, these areas could be risk managed, such as restricting access, hunting and fishing. Planting of common wetland macrophytes that are known to uptake and remove contaminants, such as *Typha,* could speed up natural remediation processes (Mitsch & Gosselink, 2015). Following uptake, macrophytes should be harvested to fully remove contaminants. However, if the PLFN community wishes to use these areas within a short time frame post-remediation, active remediation may be necessary. GHD has suggested two active remediation tactics: *ex-situ* remediation and *in-situ* remediation (2018). *Ex-situ* remediation would involve dewatering the wetlands and excavating impacted sediments. The sediments would then be dewatered and placed in a sludge disposal cell. For *in-situ* remediation, various techniques can be implemented to augment natural wetland processes, such as encapsulation of contaminants with chemical binding agents, and injection of colloidal organic carbon to enhance binding of contaminants to sediments. *In-situ* remediation techniques should be prioritized as they are less destructive than *ex-situ*.

Recommendation: *When necessary, active remediation techniques should be implemented, with in-situ remediation being prioritized.*

5.3.4 Assessment of Outside Contaminant Sources

REF1 wetland displayed concentrations of sediment PCDD/PCDF above ISQG levels, as well as higher concentrations of tissue THg and PCDD/PCDF. As this wetland resides on land not impacted by the study effluent, it is likely other contaminating sources are present. Aerial deposition of PCDD/PCDF from forest and campfires, as well as nearby coal burning operations may be the cause of this increase (Dyke et al., 1997). Unsanctioned dumping may also have occurred. Finally, this may highlight movement of these contaminants in aerial invertebrates, as parental Libellulidae may have transferred THg and PCDD/PCDF from outside of the wetland. As well, WL5 is located downhill from PLFN, and therefore may be experiencing urban impacts, such as runoff.

Recommendation: *During BHTF remediation, awareness should be paid to outside contamination sources. Removal of contaminated sediments and discontinued effluent inputs may not completely stop aerial and outside contaminant inputs. Therefore, monitoring should continue so PLFN are properly informed of contaminant concentrations.*

5.3.5 Temporal and Yearly Macroinvertebrate Community Assessments

This study identified changes in wetland macroinvertebrate communities throughout the growing season. However, the sampling season occurred during a hotter, drier season than typically occurs, and a few of the wetlands lost a significant amount of surface water. It is unclear whether the loss of water occurred due to the climate or if a shorter hydroperiod is usual for these wetlands. In order to understand whether communities are impacted by contaminants or the hydroperiod, sampling should continue on a multi-year basis. Remediation, especially active remediation, may impact wetland processes, which will impact macrophytes and in turn, wetland macroinvertebrates.

Recommendation: *As shown with this study, macroinvertebrate communities change throughout the growing season. Therefore, monitoring these communities to assess potential remediation impacts (both positive and negative) should occur throughout the growing season. Monitoring should also occur on a yearly basis to rule out impacts of changing weather and climate.*

5.3.6 Importance of Multiple Lines of Evidence

This study highlighted the importance of including multiple lines of evidence, as chemical analysis can be a poor indicator of long-term environmental effects or non-chemical sources/stressors. Including chemical analysis with biological analysis, can provide a more holistic understanding of ecosystem health. As well, incorporating university studies with consulting studies can add value to assessment conclusions. Consulting studies typically follow regimented protocols frequently used in environmental assessments that are robust and well tested. University studies can offer focus on specific areas that standard protocols cannot. Additionally, university lab studies can control variables that modify study conclusions. The partnering of both types of studies therefore adds breadth to the types of information and data collected and may help develop LOE that further the understanding of potential remediation requirements.

Recommendation: *Continue to include academic studies throughout the BHTF remediation process.*

5.4 Study Limitations

This thesis demonstrated various limitations that can be organized into two categories: monetary/time restrictions, and insufficient biota collection.

5.4.1 Monetary/Time Restrictions

Funding constraints limited the number of collected samples. The purpose of the research was to sample wetlands along an *a priori* proposed contamination potential, and therefore the allowed total number of samples had to be distributed evenly among more than one wetland. Although triplicate samples were taken per wetland, a greater number of samples would have increased the strength of the statistical analysis. As seen in Chapter III, there was a great deal of intra-wetland variation, especially between deep and shallow areas. A greater number of samples are then necessary to further delineate the contamination magnitude and extent. As well, the three community sweeps taken in each wetland displayed high temporal and spatial intra-wetland variation. More samples could reduce the large standard errors and give a clearer picture of the community composition. Additionally, as this research was done as a part of a 2-year graduate project, data collection could only occur for one research season. This presented some challenges for the results in both Chapter III and IV. The significant loss of surface water in some wetlands may have impacted contaminant concentrations (as discussed in Chapter III), and affected macroinvertebrate community sampling (as discussed in Chapter IV). If this research had continued for several years, these impacts could have been compared to a cooler, wetter research season. Comparison could then deem whether the climate affected these results, or the contaminant inputs.

5.4.2 Insufficient Biota Collection

Tissue for Chapter III and community sweeps for Chapter IV was collected with a triangular dipnet. Given the mobility of the collected species, researcher inexperience, difficulties maneuvering and limited equipment access, insufficient tissue for Chapter III and insufficient abundance data for Chapter IV was collected. For Chapter III, insufficient tissue for triplicate samples resulted in inabilities to perform robust statistical analysis. In WL3 and WL5, insufficient tissue was collected to garner a single contaminant concentration. This was unfortunate, as WL3 and WL5 showed high contamination potential. For Chapter IV, ECCC Wetland CABIN protocol states identifying and enumerating collected communities should stop at 300 individuals (Armellin et al., 2017). However, the counts in the study rarely reached 300 individuals, suggesting that noticeably fewer individuals were collected than usual for a wetland study. Initially, an attempt was made to avoid this limitation. Hester Dendy samplers were made and deployed in May 2018. When collected a month later, no individuals were collected. Other options, such as the Quadrat-Column-Core method (Meyer et al., 2013) or funnel traps (Turner & Trexler, 1997) have been shown to complement dipnetting, and could be employed in future studies to increase the number of collected individuals.

5.5 Concluding Comments

This research has gathered information that supports contaminant characterization efforts in the BHTF wetlands. The evidence provided demonstrates both the ability of a wetland and the biological communities within to attenuate and recover from a contamination event, as well as contaminant concentrations that exceed this ability. As the BHTF remediation efforts progress, attention should be paid to the current state of each wetland. If natural attenuation appears to be succeeding, MNR should be implemented to avoid further harm. If contamination is too great (such as potentially in WL5), further action should be taken in order to meet remediation goals. Given the high cost, public awareness and sensitivity to PLFN needs, the BHTF remediation plan should consider these recommendations to ensure effective use of funding and labor. Hopefully, this research can help to return A'se'K back to the people of PLFN.

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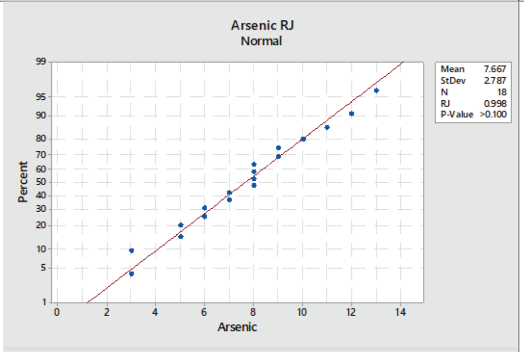
Appendix A

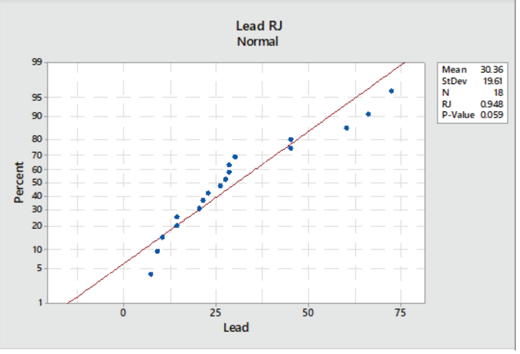
Statistical test examples

Normality and Equal Variance example - Sediment

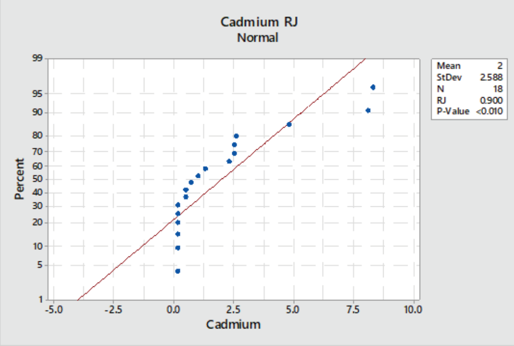
Ryan-Joiner Normality Tests

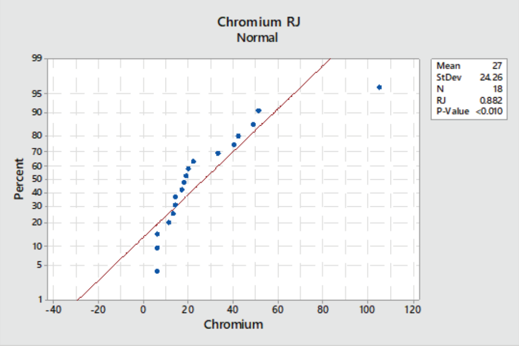
P-VALUE>0.05

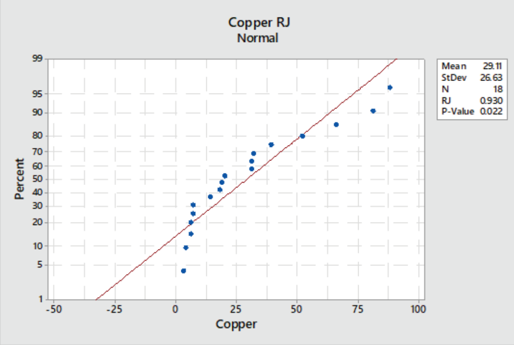


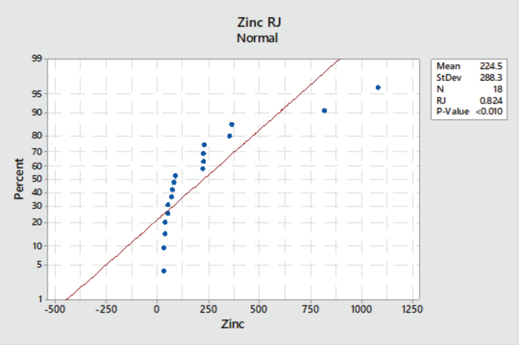


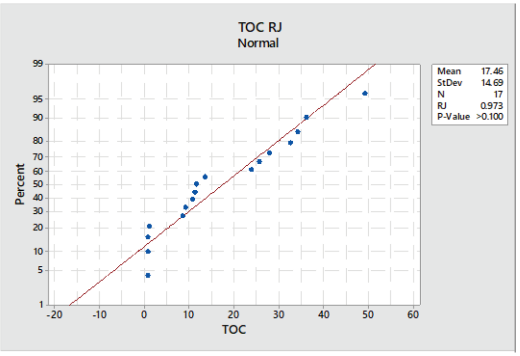
P-VALUE<0.05

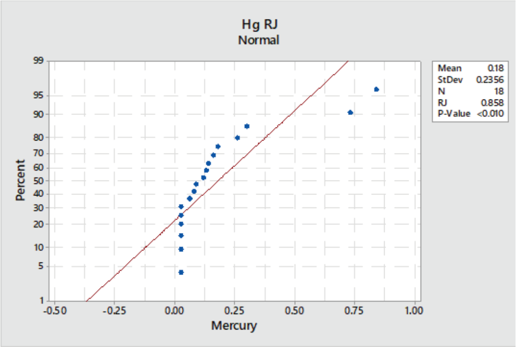


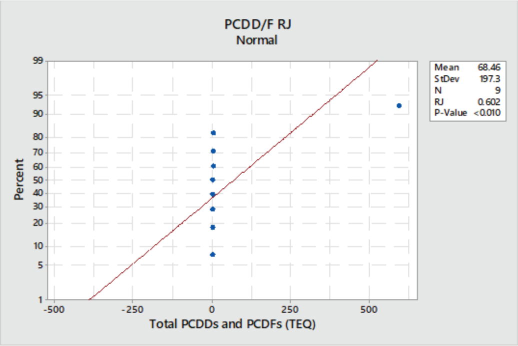






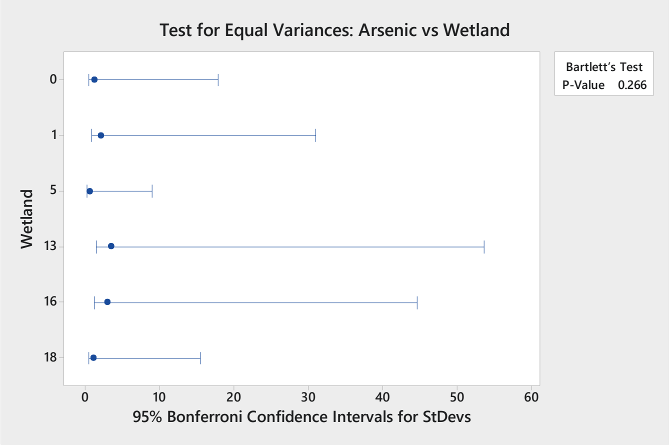

TOC RJ
Normal
99
95
90
80
70
60
50
40
30
20
10
5
1
Percent
-20
-10
0
10
20
30
40
50
60
TOC
Mean 17.46
StDev 14.69
N 17
RJ 0.973
P-Value >0.100


Hg RJ
Normal
99
95
90
80
70
60
50
40
30
20
10
5
1
Percent
-0.50
-0.25
0.00
0.25
0.50
0.75
1.00
Mercury
Mean 0.18
StDev 0.2356
N 18
RJ 0.858
P-Value <0.010

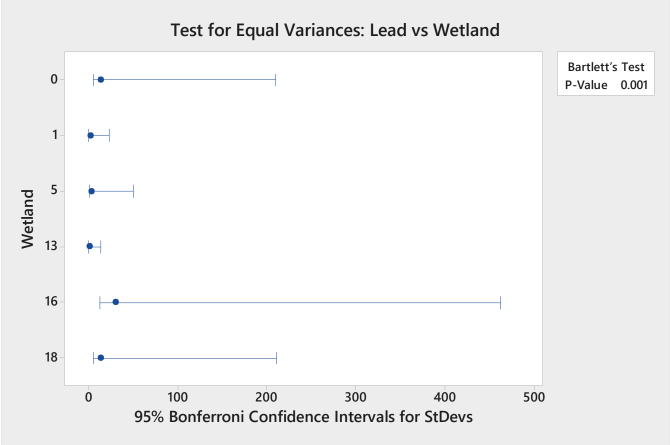

PCDD/F RJ
Normal
99
95
90
80
70
60
50
40
30
20
10
5
1
Percent
-500
-250
0
250
500
Total PCDDs and PCDFs (TEQ)
Mean 68.46
StDev 197.3
N 9
RJ 0.602
P-Value <0.010

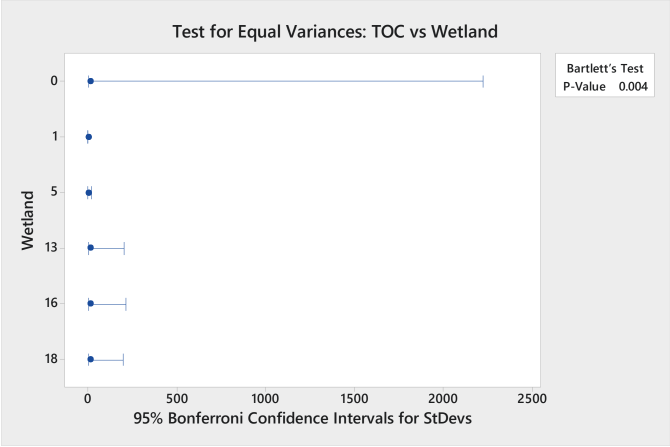
Equal Variance Tests using Bartlett's Test

P-VALUE > 0.05



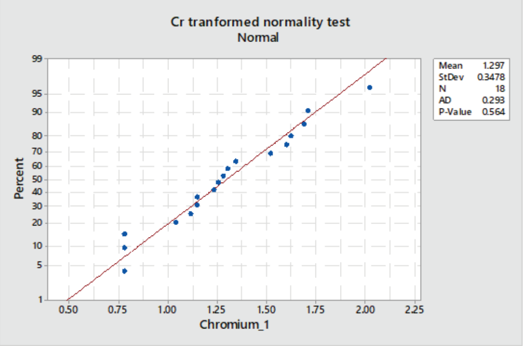
P-VALUE <0.05

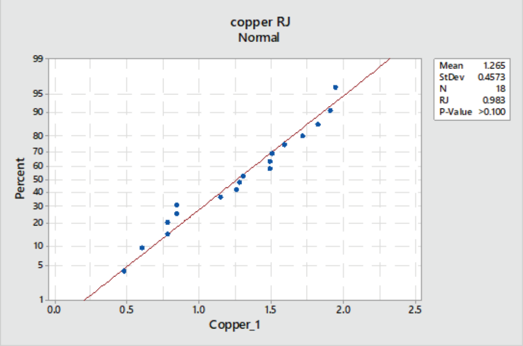


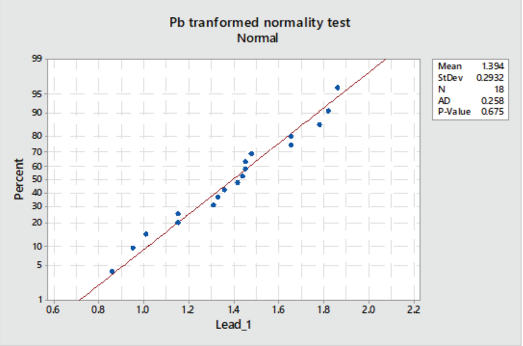


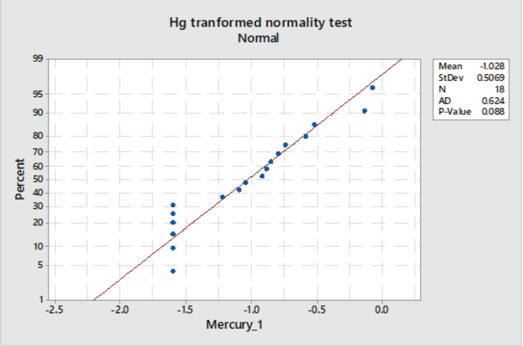
Log-transformed Ryan-Joiner Normality Testing

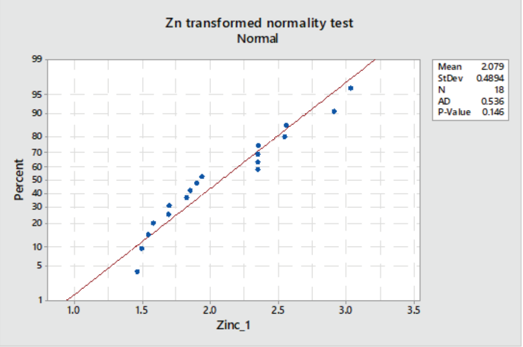
P-VALUE >0.05



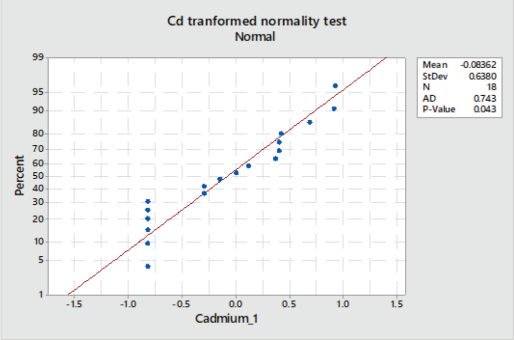






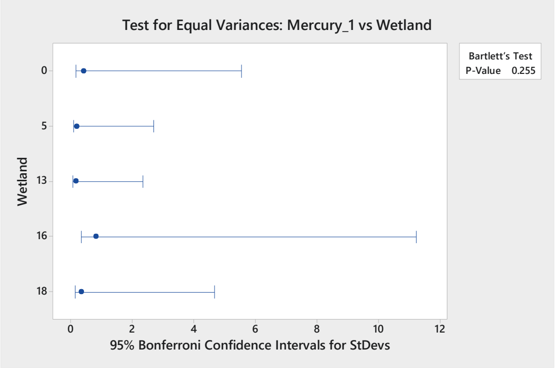


P-VALUE < 0.05

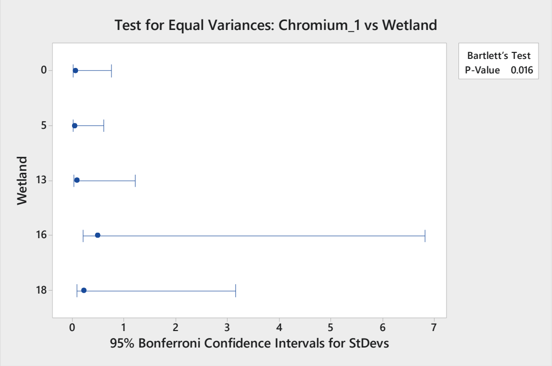


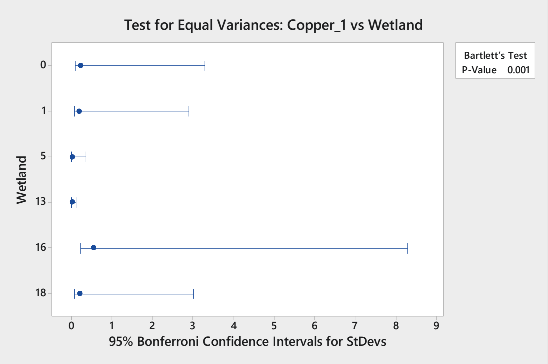
Log-transformed Bartlett's Test

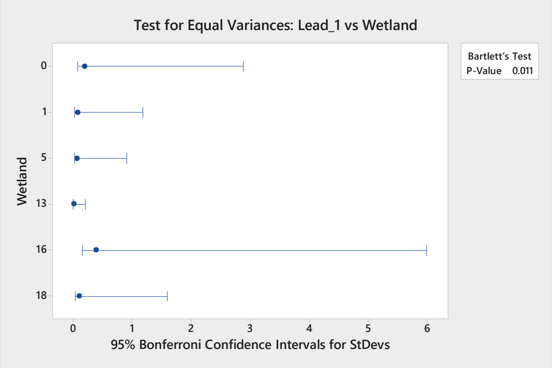
P-VALUE >0.05

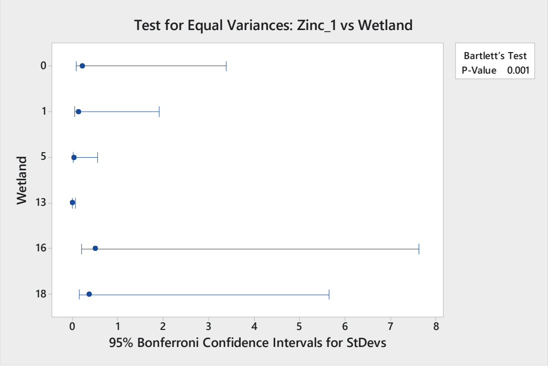


P-VALUE <0.05









One-Way ANOVA + Dunnett Test example

One-way ANOVA: Arsenic versus Wetland

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Wetland	6	0, 1, 2, 3, 4, 5

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Wetland	5	78.00	15.600	3.47	0.036
Error	12	54.00	4.500		
Total	17	132.00			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.12132	59.09%	42.05%	7.95%

Means

Wetland	N	Mean	StDev	95% CI
0	3	3.667	1.155	(0.998, 6.335)
1	3	8.00	3.46	(5.33, 10.67)
2	3	9.67	2.89	(7.00, 12.34)
3	3	7.00	2.00	(4.33, 9.67)
4	3	7.667	0.577	(4.998, 10.335)
5	3	10.000	1.000	(7.332, 12.668)

Pooled StDev = 2.12132

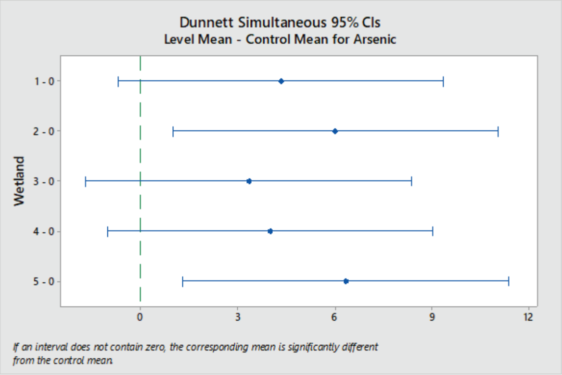
Dunnett Multiple Comparisons with a Control

Grouping Information Using the Dunnett Method and 95% Confidence

Wetland	N	Mean	Grouping
0 (control)	3	3.667	A
5	3	10.000	
2	3	9.67	
1	3	8.00	A
4	3	7.667	A
3	3	7.00	A

Means not labeled with the letter A are significantly different from the control level mean.

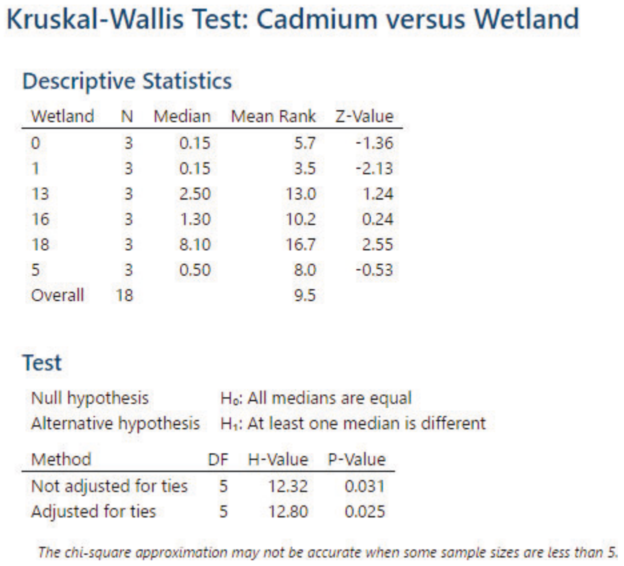
Dunnett Simultaneous 95% Cis



Dunnett Simultaneous 95% CIs
Level Mean - Control Mean for Arsenic

If an interval does not contain zero, the corresponding mean is significantly different from the control mean.

Kruskal Wallis and Post-hoc test example



Kruskal-Wallis Test: Cadmium versus Wetland

Descriptive Statistics

Wetland	N	Median	Mean Rank	Z-Value
0	3	0.15	5.7	-1.36
1	3	0.15	3.5	-2.13
13	3	2.50	13.0	1.24
16	3	1.30	10.2	0.24
18	3	8.10	16.7	2.55
5	3	0.50	8.0	-0.53
Overall	18		9.5	

Test

Null hypothesis H₀: All medians are equal
Alternative hypothesis H₁: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	5	12.32	0.031
Adjusted for ties	5	12.80	0.025

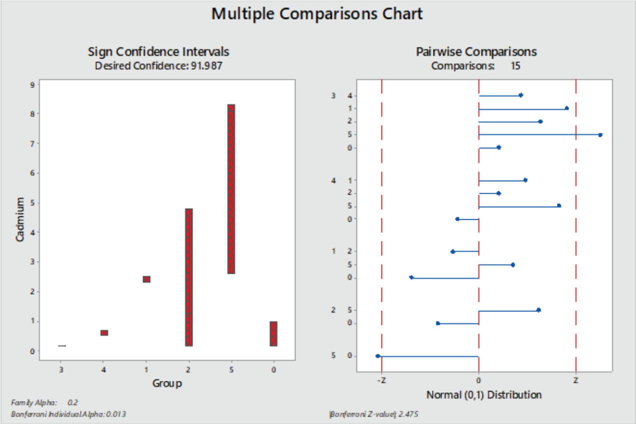
The chi-square approximation may not be accurate when some sample sizes are less than 5.

Kruskal-Wallis: Conclusions

The following groups showed significant differences (adjusted for ties):

Data

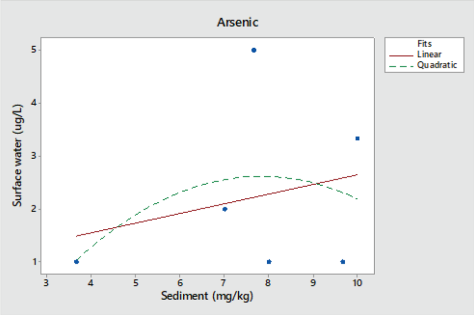
Groups	Z vs. Critical value	P-value
3 vs. 5	3.08002 >= 2.475	0.0021
5 vs. 0	2.57318 >= 2.475	0.0101

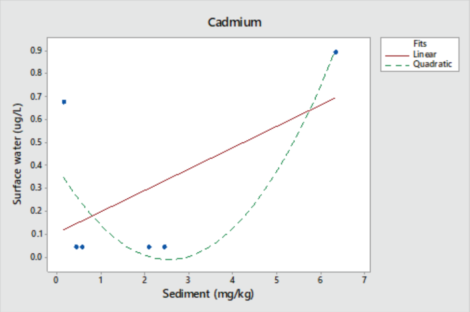


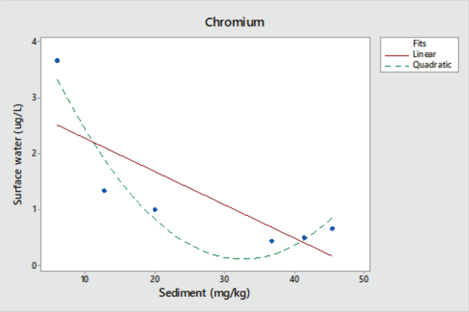
Appendix B

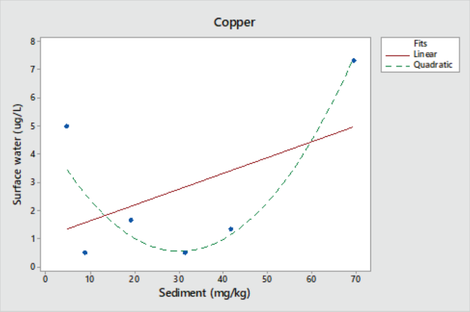
Regression Graphs

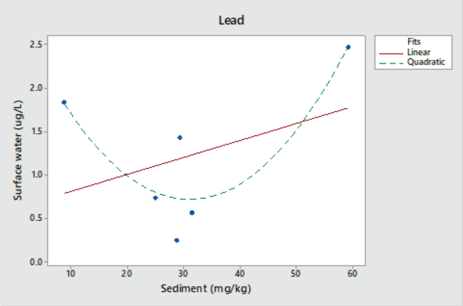
Sediment and Surface Water

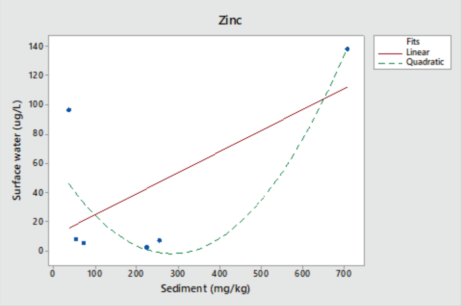




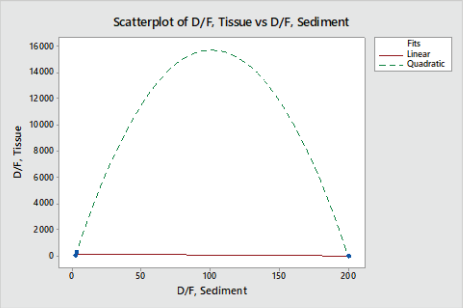


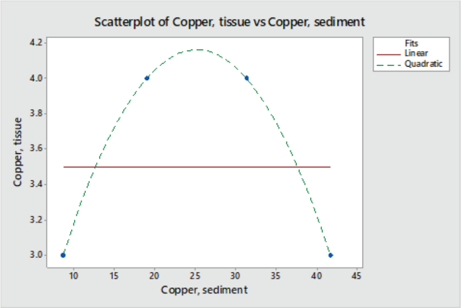


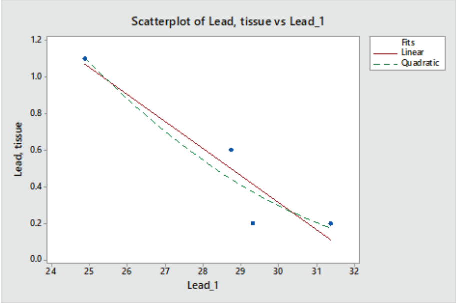


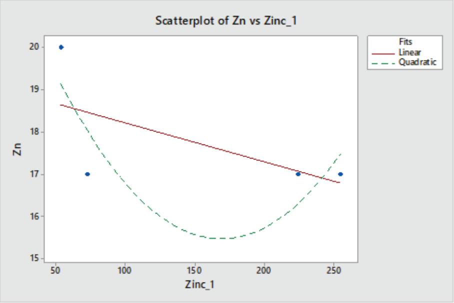


Sediment and Tissue

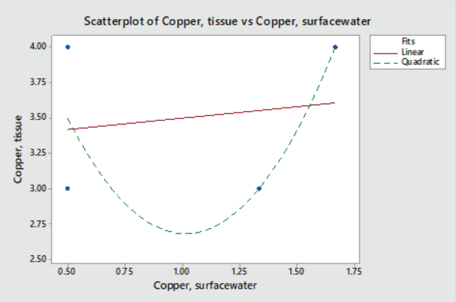


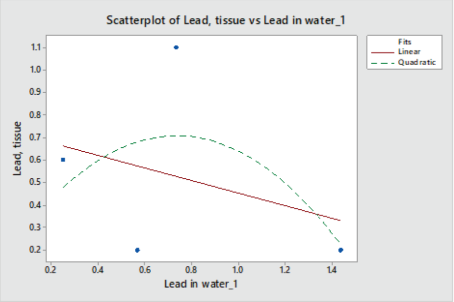


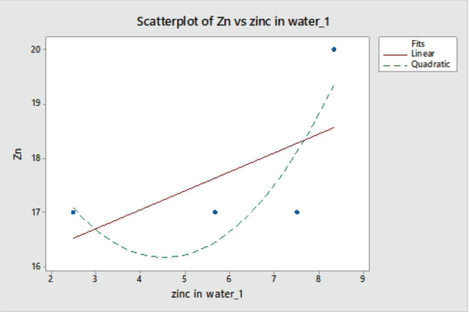




Surface Water and Tissue







Appendix C

AGAT Certificate of Analysis and Chain of Custody forms

AGAT Laboratories

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924 http://www.agatlabs.com

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES
5793 University Ave. PO Box 15000,
HALIFAX, NS B3H4R2
902-494-1717

ATTENTION TO: Meghan Quanz

PROJECT:

AGAT WORK ORDER: 18X367355

SOIL ANALYSIS REVIEWED BY: Laura Baker, Inorganics Data Reporter

ULTRA TRACE REVIEWED BY: Philippe Morneau, chimiste

DATE REPORTED: Aug 28, 2018

PAGES (INCLUDING COVER): 43

VERSION*: 1

Should you require any information regarding this analysis please contact your client services representative at (902) 468-8718

**NOTES*

AGAT Laboratories (V1)

AGAT Laboratories

11 Morris Drive, Unit 122

Certificate of Analysis

CANADA B3B 1M2

AGAT WORK ORDER: 18X367355

Dartmouth, Nova Scotia

TEL (902)468-8718
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http://www.agatlabs.com

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Available Metals in Soil

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-02

			SAMPLE DESCRIPTION:	WL 1-1	WL 1-2	WL 1-3	WL 5-1	WL 5-2	WL 5-3	WL 13-1	WL 13-2
			SAMPLE TYPE:	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
			DATE SAMPLED:	2018-07-25	2018-07-25	2018-07-25	2018-07-23	2018-07-23	2018-07-23	2018-07-24	2018-07-24
Parameter	**Unit**	**G / S**	**RDL**	**9430633**	**9430640**	**9430641**	**9430645**	**9430652**	**9430653**	**9430660**	**9430661**
Aluminum	mg/kg		10	4360	4470	3720	18000	14700	12400	6520	4790
Antimony	mg/kg		1	<1	<1	<1	<1	<1	<1	<1	<1
Arsenic	mg/kg		1	7	9	5	8	8	7	12	6
Barium	mg/kg		5	15	20	47	735	575	596	390	465
Beryllium	mg/kg		2	<2	<2	<2	<2	<2	<2	<2	<2
Boron	mg/kg		2	3	<2	<2	4	4	4	12	8
Cadmium	mg/kg		0.3	<0.3	<0.3	<0.3	0.5	0.7	0.5	2.5	2.5
Chromium	mg/kg		2	6	6	6	20	22	18	49	33
Cobalt	mg/kg		1	4	4	3	10	13	10	14	7
Copper	mg/kg		2	3	4	7	18	20	19	32	31
Iron	mg/kg		50	7700	9150	7260	13700	17100	13700	22000	21000
Lead	mg/kg		0.5	8.9	10.2	7.2	27.4	26.0	21.2	29.8	28.2
Lithium	mg/kg		5	14	16	11	35	33	31	13	6
Manganese	mg/kg		2	345	548	246	644	608	314	6460	5620

Molybdenum	mg/kg		2	<2	<2	<2	<2	<2	<2	<2	<2
Nickel	mg/kg		2	7	7	7	24	30	25	27	25
Selenium	mg/kg		1	<1	<1	<1	<1	<1	<1	<1	<1
Silver	mg/kg		0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.8	1.2
Strontium	mg/kg		5	<5	<5	<5	21	21	17	36	39
Thallium	mg/kg		0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	0.2	0.2
Tin	mg/kg		2	3	3	3	2	2	2	3	3
Uranium	mg/kg		0.1	0.3	0.4	0.3	9.0	4.0	4.2	5.1	0.8
Vanadium	mg/kg		2	9	9	10	19	22	21	50	47
Zinc	mg/kg		5	29	31	49	67	79	71	223	227

Available Metals in Soil

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-02

			SAMPLE DESCRIPTION:	WL 13-3	WL 16-1	WL 16-2	WL 16-3	WL 18-1	WL 18-2	WL 18-3	REF 1-1
			SAMPLE TYPE:	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
			DATE SAMPLED:	2018-07-24	2018-07-26	2018-07-26	2018-07-26	2018-07-25	2018-07-25	2018-07-25	2018-07-25
Parameter	**Unit**	**G / S**	**RDL**	**9430662**	**9430671**	**9430673**	**9430674**	**9430693**	**9430699**	**9430700**	**9430713**
Aluminum	mg/kg		10	5750	16700	9450	7890	6460	6440	7050	8150
Antimony	mg/kg		1	<1	<1	<1	<1	2	1	<1	<1
Arsenic	mg/kg		1	6	13	8	8	10	9	11	3
Barium	mg/kg		5	344	288	53	258	499	399	556	91

Beryllium	mg/kg	2	<2	<2	<2	<2	<2	<2	<2	<2
Boron	mg/kg	2	8	6	<2	4	15	14	33	2
Cadmium	mg/kg	0.3	2.3	4.8	<0.3	1.3	8.3	8.1	2.6	<0.3
Chromium	mg/kg	2	42	105	14	17	19	40	51	13
Cobalt	mg/kg	1	8	16	8	20	5	6	7	5
Copper	mg/kg	2	31	52	7	66	88	81	39	6
Iron	mg/kg	50	18700	32900	15900	17400	8940	15600	19400	7960
Lead	mg/kg	0.5	28.2	65.9	14.1	14.1	45.0	72.2	60.1	22.7
Lithium	mg/kg	5	10	38	21	26	7	10	13	14
Manganese	mg/kg	2	2520	1120	310	594	1650	1110	1660	106
Molybdenum	mg/kg	2	<2	3	<2	<2	16	12	8	<2
Nickel	mg/kg	2	24	39	13	23	23	30	24	10
Selenium	mg/kg	1	<1	<1	<1	<1	2	<1	2	<1
Silver	mg/kg	0.5	1.1	0.8	<0.5	<0.5	3.3	3.0	0.8	<0.5
Strontium	mg/kg	5	20	26	<5	14	65	65	82	9
Thallium	mg/kg	0.1	0.2	0.3	<0.1	<0.1	0.5	0.3	0.2	<0.1
Tin	mg/kg	2	2	3	3	3	7	6	3	3
Uranium	mg/kg	0.1	1.0	2.0	0.6	2.4	2.7	3.2	11.2	0.7
Vanadium	mg/kg	2	43	55	16	21	49	85	69	27
Zinc	mg/kg	5	222	353	50	361	1080	816	223	35

Available Metals in Soil

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Certificate of Analysis

AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-02

			SAMPLE DESCRIPTION:	REF 1-2	REF 1-3
			SAMPLE TYPE:	Soil	Soil
			DATE SAMPLED:	2018-07-25	2018-07-25
Parameter	**Unit**	**G / S**	**RDL**	**9430717**	**9430720**
Aluminum	mg/kg		10	9550	7460
Antimony	mg/kg		1	<1	<1
Arsenic	mg/kg		1	5	3
Barium	mg/kg		5	200	97
Beryllium	mg/kg		2	<2	<2
Boron	mg/kg		2	4	<2
Cadmium	mg/kg		0.3	1.0	<0.3
Chromium	mg/kg		2	14	11
Cobalt	mg/kg		1	9	4
Copper	mg/kg		2	14	6
Iron	mg/kg		50	12400	7340
Lead	mg/kg		0.5	44.9	20.3
Lithium	mg/kg		5	16	13
Manganese	mg/kg		2	400	109
Molybdenum	mg/kg		2	<2	<2
Nickel	mg/kg		2	13	9

Certificate of Analysis

AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Selenium	mg/kg	1	<1	<1
Silver	mg/kg	0.5	<0.5	<0.5
Strontium	mg/kg	5	33	9
Thallium	mg/kg	0.1	<0.1	<0.1
Tin	mg/kg	2	3	3
Uranium	mg/kg	0.1	1.1	0.6
Vanadium	mg/kg	2	42	24
Zinc	mg/kg	5	87	38

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard **9430633-9430720** Results are based on the dry weight of the sample.

Inorganics

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-07-31

						SAMPLE DESCRIPTION:	**WL 1-1**	**WL 1-2**	**WL 1-3**	**WL 5-1**	**WL 5-2**
						SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
						DATE SAMPLED:	**2018-07-25**	**2018-07-25**	**2018-07-25**	**2018-07-23**	**2018-07-23**
Parameter	**Unit**	**G / S: A**	**G / S: B**	**G / S: C**	**G / S: D**	**RDL**	**9430633**	**9430640**	**9430641**	**9430645**	**9430652**
Total Organic Carbon	%					0.3	0.8	0.8	1.1	13.5	11.2
						SAMPLE DESCRIPTION:	**WL 5-3**	**WL 13-1**	**WL 13-2**	**WL 13-3**	**WL 16-1**
						SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
						DATE SAMPLED:	**2018-07-23**	**2018-07-24**	**2018-07-24**	**2018-07-24**	**2018-07-26**

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES **ATTENTION TO: Meghan Quanz**

SAMPLING SITE: **SAMPLED BY:**

Parameter	Unit	G / S: A	G / S: B	G / S: C	G / S: D	RDL	9430653	9430660	9430661	9430662	9430671
Total Organic Carbon	%					0.3	10.7	36.1	32.5	11.6	27.8

						SAMPLE DESCRIPTION:	**WL 16-2**	**WL 16-3**	**WL 18-1**	**WL 18-2**	**WL 18-3**
						SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
						DATE SAMPLED:	**2018-07-26**	**2018-07-26**	**2018-07-25**	**2018-07-25**	**2018-07-25**
Parameter	**Unit**	**G / S: A**	**G / S: B**	**G / S: C**	**G / S: D**	**RDL**	**9430673**	**9430674**	**9430693**	**9430699**	**9430700**
Total Organic Carbon	%					0.3	0.8	8.4	49.1	34.1	23.8

						SAMPLE DESCRIPTION:	**REF 1-2**	**REF 1-3**
						SAMPLE TYPE:	**Soil**	**Soil**
						DATE SAMPLED:	**2018-07-25**	**2018-07-25**
Parameter	**Unit**	**G / S: A**	**G / S: B**	**G / S: C**	**G / S: D**	**RDL**	**9430717**	**9430720**
Total Organic Carbon	%					0.3	25.5	9.1

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard: A Refers to Basses-Terres du St-Laurent, B Refers to QC PTC 2016 B, C Refers to QC PTC 2016 C, D Refers to QC RESC (Annexe 1) Guideline values are for general reference only. The guidelines provided may or may not be relevant for the intended use. Refer directly to the applicable standard for regulatory interpretation.

9430633-9430720 Une LDR plus élevée indique qu’une dilution a été effectuée afin de réduire la concentration des analytes ou de réduire l’interférence de la matrice.

Mercury Analysis in Soil

DATE RECEIVED: 2018-07-27 **DATE REPORTED: 2018-08-01**

SAMPLE DESCRIPTION:	**WL 1-1**	**WL 1-2**	**WL 1-3**	**WL 5-1**	**WL 5-2**	**WL 5-3**	**WL 13-1**	**WL 13-2**
SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**

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Certificate of Analysis

AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

SAMPLING SITE:

ATTENTION TO: Meghan Quanz

SAMPLED BY:

Mercury Analysis in

			DATE SAMPLED:	**2018-07-25**	**2018-07-25**	**2018-07-25**	**2018-07-23**	**2018-07-23**	**2018-07-23**	**2018-07-24**	**2018-07-24**
Parameter	**Unit**	**G / S**	**RDL**	**9430633**	**9430640**	**9430641**	**9430645**	**9430652**	**9430653**	**9430660**	**9430661**
Mercury	mg/kg		0.05	<0.05	<0.05	<0.05	0.18	0.09	0.08	0.26	0.13

			SAMPLE DESCRIPTION:	**WL 13-3**	**WL 16-1**	**WL 16-2**	**WL 16-3**	**WL 18-1**	**WL 18-2**	**WL 18-3**	**REF 1-1**
			SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
			DATE SAMPLED:	**2018-07-24**	**2018-07-26**	**2018-07-26**	**2018-07-26**	**2018-07-25**	**2018-07-25**	**2018-07-25**	**2018-07-25**
Parameter	**Unit**	**G / S**	**RDL**	**9430662**	**9430671**	**9430673**	**9430674**	**9430693**	**9430699**	**9430700**	**9430713**
Mercury	mg/kg		0.05	0.14	0.84	<0.05	0.06	0.16	0.30	0.73	<0.05

			SAMPLE DESCRIPTION:	**REF 1-2**	**REF 1-3**
			SAMPLE TYPE:	**Soil**	**Soil**
			DATE SAMPLED:	**2018-07-25**	**2018-07-25**
Parameter	**Unit**	**G / S**	**RDL**	**9430717**	**9430720**
Mercury	mg/kg		0.05	0.12	<0.05

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard **9430633-9430720** Results are based on the dry weight of the soil.

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AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Tissue

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-02

			SAMPLE DESCRIPTION:	WL 13-1	WL 16-D	WL 16-S	REF 1-D
			SAMPLE TYPE:	Tissue	Tissue	Tissue	Tissue
			DATE SAMPLED:	2018-07-24	2018-07-26	2018-07-26	2018-07-23
Parameter	**Unit**	**G / S**	**RDL**	**9430663**	**9430679**	**9430680**	**9430764**
Mercury in Tissue	mg/kg		0.05	0.07	<0.05	<0.05	0.10

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard **9430663-9430764** Results are based on the wet weight of the sample.

Certificate of Analysis

AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Metals in Tissue

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-02

			SAMPLE DESCRIPTION:	WL 5-D	WL 13-1	WL 13-D	WL 16-D	WL 16-S	REF 1-D
			SAMPLE TYPE:	Tissue	Tissue	Tissue	Tissue	Tissue	Tissue
			DATE SAMPLED:	2018-07-23	2018-07-24	2018-07-26	2018-07-26	2018-07-26	2018-07-23
Parameter	Unit	G / S	RDL	9430655	9430663	9430670	9430679	9430680	9430764
Aluminum	mg/kg		10	524	92	252	33	<10	76
Antimony	mg/kg		2	<2	<2	<2	<2	<2	<2
Arsenic	mg/kg		2	4	<2	3	<2	<2	<2
Barium	mg/kg		5	42	43	195	21	<5	<5
Beryllium	mg/kg		2	<2	<2	<2	<2	<2	<2
Bismuth	mg/kg		5	<5	<5	<5	<5	<5	<5
Boron	mg/kg		2	<2	3	87	<2	<2	<2
Cadmium	mg/kg		0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Chromium	mg/kg		2	<2	<2	<2	<2	<2	<2
Cobalt	mg/kg		1	2	<1	<1	<1	<1	<1
Copper	mg/kg		2	4	<2	4	3	<2	3
Iron	mg/kg		50	1450	311	1110	213	112	427
Lead	mg/kg		0.4	1.1	<0.4	0.6	<0.4	<0.4	<0.4
Manganese	mg/kg		2	422	257	2590	372	15	168
Molybdenum	mg/kg		2	<2	<2	<2	<2	<2	<2

AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

Tissue Prep

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

DATE RECEIVED: 2018-07-27

DATE REPORTED:

	SAMPLE DESCRIPTION:		**WL 13-1**	**WL 13-D**	**WL 16-D**	**WL 16-S**	**REF 1-D**	
Nickel	mg/kg	2	<2	<2	<2	<2	<2	<2
Selenium	mg/kg	1	<1	<1	<1	<1	<1	<1
Silver	mg/kg	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Strontium	mg/kg	5	<5	5	<5	<5	<5	<5
Thallium	mg/kg	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tin	mg/kg	2	4	<2	6	3	2	3
Uranium	mg/kg	0.1	0.2	<0.1	0.1	<0.1	<0.1	<0.1
Vanadium	mg/kg	2	7	<2	6	3	4	4
Zinc	mg/kg	5	17	67	17	17	17	20

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard **9430655-9430764** Results are based on the wet weight of the sample.

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

			SAMPLE TYPE:	**Tissue**	**Tissue**	**Tissue**	**Tissue**	**Tissue**
			DATE SAMPLED:	**2018-07-24**	**2018-07-26**	**2018-07-26**	**2018-07-26**	**2018-07-23**
Parameter	**Unit**	**G / S**	**RDL**	**9430663**	**9430670**	**9430679**	**9430680**	**9430764**
Prep Complete				Y	Y	Y	Y	Y

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

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PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-22

			SAMPLE DESCRIPTION:	WL 5-1		WL 5-2		WL 5-3		WL 16-1
			SAMPLE TYPE:	Soil		Soil		Soil		Soil
			DATE SAMPLED:	2018-07-23		2018-07-23		2018-07-23		2018-07-26
Parameter	**Unit**	**G / S**	**RDL**	**9430645**	**RDL**	**9430652**	**RDL**	**9430653**	**RDL**	**9430671**
2,3,7,8-Tetra CDD	ng/kg		0.6	<0.6	1	<1	0.4	<0.4	4	41
1,2,3,7,8-Penta CDD	ng/kg		2	<2	2	<2	1	<1	5	<5
1,2,3,4,7,8-Hexa CDD	ng/kg		2	<2	3	<3	2	<2	5	<5
1,2,3,6,7,8-Hexa CDD	ng/kg		2	<2	3	<3	2	<2	5	5
1,2,3,7,8,9-Hexa CDD	ng/kg		2	<2	3	<3	2	<2	5	<5
1,2,3,4,6,7,8-Hepta CDD	ng/kg		4	8	6	10	4	<4	10	36
Octa CDD	ng/kg		20	329	20	331	20	154	100	591
2,3,7,8-Tetra CDF	ng/kg		0.6	<0.6	2	<2	0.9	<0.9	20	5310
1,2,3,7,8-Penta CDF	ng/kg		1	<1	2	<2	0.8	<0.8	5	34
2,3,4,7,8-Penta CDF	ng/kg		1	<1	2	2	0.8	<0.8	5	52
1,2,3,4,7,8-Hexa CDF	ng/kg		0.8	1.1	2	3	1	<1	10	<10
1,2,3,6,7,8-Hexa CDF	ng/kg		0.7	<0.7	2	<2	1	<1	10	<10
2,3,4,6,7,8-Hexa CDF	ng/kg		0.8	<0.8	2	<2	2	<2	6	<6
1,2,3,7,8,9-Hexa CDF	ng/kg		2	<2	4	<4	1	<1	8	<8
1,2,3,4,6,7,8-Hepta CDF	ng/kg		1	<1	2	4	2	2	5	18
1,2,3,4,7,8,9-Hepta CDF	ng/kg		3	<3	4	<4	3	<3	10	<10
Octa CDF	ng/kg		9	<9	10	<10	5	<5	20	26
Total Tetrachlorodibenzodioxins	ng/kg		0.6	3.6	1	9	0.4	3.4	4	111

Total Pentachlorodibenzodioxins	ng/kg		2	125	2	10	1	5	5	21
Total Hexachlorodibenzodioxins	ng/kg		2	36	3	464	2	16	5	76
Total Heptachlorodibenzodioxins	ng/kg		4	28	6	27	4	4	10	86
Total PCDDs	ng/kg		20	521	20	841	20	182	100	886
Total Tetrachlorodibenzofurans	ng/kg		0.6	4.3	2	31	0.9	4.9	20	9420
Total Pentachlorodibenzofurans	ng/kg		1	7	2	15	0.8	5.2	6	247
Total Hexachlorodibenzofurans	ng/kg		2	2	4	8	2	<2	10	18
Total Heptachlorodibenzofurans	ng/kg		3	3	4	7	3	4	10	30
Total PCDFs	ng/kg		9	16	10	60	5	14	20	9740
2,3,7,8-Tetra CDD (TEF 1.0)	TEQ			0		0		0		40.8
1,2,3,7,8-Penta CDD (TEF 1.0)	TEQ			0		0		0		0
1,2,3,4,7,8-Hexa CDD (TEF 0.1)	TEQ			0		0		0		0

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-22

			SAMPLE DESCRIPTION:	WL 5-1		WL 5-2		WL 5-3		WL 16-1
			SAMPLE TYPE:	Soil		Soil		Soil		Soil
			DATE SAMPLED:	2018-07-23		2018-07-23		2018-07-23		2018-07-26
Parameter	**Unit**	**G / S**	**RDL**	**9430645**	**RDL**	**9430652**	**RDL**	**9430653**	**RDL**	**9430671**
1,2,3,6,7,8-Hexa CDD (TEF 0.1)	TEQ			0		0		0		0.487
1,2,3,7,8,9-Hexa CDD (TEF 0.1)	TEQ			0		0		0		0
1,2,3,4,6,7,8-Hepta CDD (TEF 0.01)	TEQ			0.0775		0.0987		0		0.360
Octa CDD (TEF 0.0003)	TEQ			0.0986		0.0993		0.0461		0.177
2,3,7,8-Tetra CDF (TEF 0.1)	TEQ			0		0		0		531
1,2,3,7,8-Penta CDF (TEF 0.03)	TEQ			0		0		0		1.03

2,3,4,7,8-Penta CDF (TEF 0.3)	TEQ	0	0.530	0	15.7
1,2,3,4,7,8-Hexa CDF (TEF 0.1)	TEQ	0.115	0.312	0	0
1,2,3,6,7,8-Hexa CDF (TEF 0.1)	TEQ	0	0	0	0
2,3,4,6,7,8-Hexa CDF (TEF 0.1)	TEQ	0	0	0	0
1,2,3,7,8,9-Hexa CDF (TEF 0.1)	TEQ	0	0	0	0
1,2,3,4,6,7,8-Hepta CDF (TEF 0.01)	TEQ	0	0.0377	0.0163	0.177
1,2,3,4,7,8,9-Hepta CDF (TEF 0.01)	TEQ	0	0	0	0
Octa CDF (TEF 0.0003)	TEQ	0	0	0	0.00775
Total PCDDs and PCDFs (TEQ)	TEQ	0.291	1.08	0.0624	590

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-22

		SAMPLE DESCRIPTION:	WL 5-1	WL 5-2	WL 5-3	WL 16-1
		SAMPLE TYPE:	Soil	Soil	Soil	Soil
		DATE SAMPLED:	2018-07-23	2018-07-23	2018-07-23	2018-07-26
Surrogate	Unit	Acceptable Limits	9430645	9430652	9430653	9430671
13C-2378-TCDF	%	30-140	60	46	66	66
13C-12378-PeCDF	%	30-140	49	39	53	50
13C-23478-PeCDF	%	30-140	63	51	55	51
13C-123478-HxCDF	%	30-140	67	61	36	53
13C-123678-HxCDF	%	30-140	96	79	73	50
13C-234678-HxCDF	%	30-140	95	67	58	59
13C-123789-HxCDF	%	30-140	69	55	50	58
13C-1234678-HpCDF	%	30-140	49	39	39	38
13C-1234789-HpCDF	%	30-140	41	31	32	30
13C-2378-TCDD	%	30-140	75	57	81	79
13C-12378-PeCDD	%	30-140	62	48	60	55

13C-123478-HxCDD	%	30-140		80		59		75		94
13C-123678-HxCDD	%	30-140		115		75		63		68
13C-1234678-HpCDD	%	30-140		43		33		36		32
13C-OCDD	%	30-140		44		38		31		**23**

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-22

			SAMPLE DESCRIPTION:	**WL 16-2**		**WL 16-3**		**REF 3**		**REF 1**
			SAMPLE TYPE:	**Soil**		**Soil**		**Soil**		**Soil**
			DATE SAMPLED:	**2018-07-26**		**2018-07-26**				
Parameter	**Unit**	**G / S**	**RDL**	**9430673**	**RDL**	**9430674**	**RDL**	**9430770**	**RDL**	**9430777**
2,3,7,8-Tetra CDD	ng/kg		0.2	<0.2	0.5	<0.5	0.6	<0.6	0.5	<0.5
1,2,3,7,8-Penta CDD	ng/kg		0.8	<0.8	2	<2	2	<2	2	<2
1,2,3,4,7,8-Hexa CDD	ng/kg		0.6	<0.6	2	<2	2	<2	2	<2
1,2,3,6,7,8-Hexa CDD	ng/kg		0.5	<0.5	2	<2	1	<1	2	<2
1,2,3,7,8,9-Hexa CDD	ng/kg		0.6	<0.6	2	<2	2	<2	2	<2
1,2,3,4,6,7,8-Hepta CDD	ng/kg		0.8	2.5	2	3	5	19	8	22
Octa CDD	ng/kg		9	274	10	28	20	192	20	210
2,3,7,8-Tetra CDF	ng/kg		0.3	10.0	0.5	1.4	0.8	<0.8	0.6	<0.6
1,2,3,7,8-Penta CDF	ng/kg		0.5	<0.5	1	<1	1	<1	1	<1
2,3,4,7,8-Penta CDF	ng/kg		1	<1	3	<3	0.8	<0.8	2	<2
1,2,3,4,7,8-Hexa CDF	ng/kg		0.4	0.4	1	<1	1	<1	1	<1
1,2,3,6,7,8-Hexa CDF	ng/kg		0.4	<0.4	1	<1	1	<1	0.9	<0.9
2,3,4,6,7,8-Hexa CDF	ng/kg		0.5	<0.5	2	<2	2	<2	1	<1

Parameter	Unit	G / S	RDL	9430673	RDL	9430674	RDL	9430770	RDL	9430777
1,2,3,7,8,9-Hexa CDF	ng/kg		0.8	<0.8	4	<4	3	<3	2	<2
1,2,3,4,6,7,8-Hepta CDF	ng/kg		1	<1	1	<1	3	6	3	10
1,2,3,4,7,8,9-Hepta CDF	ng/kg		3	<3	2	<2	7	<7	6	<6
Octa CDF	ng/kg		2	<2	10	<10	8	21	8	17
Total Tetrachlorodibenzodioxins	ng/kg		0.2	2.4	0.5	3.2	0.6	3.6	0.5	3.1
Total Pentachlorodibenzodioxins	ng/kg		0.8	1.2	2	9	2	6	2	8
Total Hexachlorodibenzodioxins	ng/kg		0.6	2.8	2	5	2	10	2	11
Total Heptachlorodibenzodioxins	ng/kg		0.8	6.1	2	8	5	43	8	34
Total PCDDs	ng/kg		9	286	10	52	20	255	20	266
Total Tetrachlorodibenzofurans	ng/kg		0.3	16.7	0.5	5.9	0.8	6.9	0.6	6.4
Total Pentachlorodibenzofurans	ng/kg		1	2	3	<3	1	5	2	4
Total Hexachlorodibenzofurans	ng/kg		0.8	2.0	4	<4	3	16	2	10
Total Heptachlorodibenzofurans	ng/kg		3	<3	2	3	7	34	6	28
Total PCDFs	ng/kg		3	21	10	12	8	83	8	66
2,3,7,8-Tetra CDD (TEF 1.0)	TEQ			0		0		0		0
1,2,3,7,8-Penta CDD (TEF 1.0)	TEQ			0		0		0		0
1,2,3,4,7,8-Hexa CDD (TEF 0.1)	TEQ			0		0		0		0

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-22

			SAMPLE DESCRIPTION:	WL 16-2		WL 16-3		REF 3		REF 1
			SAMPLE TYPE:	Soil		Soil		Soil		Soil
			DATE SAMPLED:	2018-07-26		2018-07-26				
Parameter	**Unit**	**G / S**	**RDL**	**9430673**	**RDL**	**9430674**	**RDL**	**9430770**	**RDL**	**9430777**
1,2,3,6,7,8-Hexa CDD (TEF 0.1)	TEQ			0		0		0		0

1,2,3,7,8,9-Hexa CDD (TEF 0.1)	TEQ	0	0	0	0
1,2,3,4,6,7,8-Hepta CDD (TEF 0.01)	TEQ	0.0251	0.0326	0.190	0.218
Octa CDD (TEF 0.0003)	TEQ	0.0821	0.00827	0.0577	0.0629
2,3,7,8-Tetra CDF (TEF 0.1)	TEQ	1.00	0.140	0	0
1,2,3,7,8-Penta CDF (TEF 0.03)	TEQ	0	0	0	0
2,3,4,7,8-Penta CDF (TEF 0.3)	TEQ	0	0	0	0
1,2,3,4,7,8-Hexa CDF (TEF 0.1)	TEQ	0.0441	0	0	0
1,2,3,6,7,8-Hexa CDF (TEF 0.1)	TEQ	0	0	0	0
2,3,4,6,7,8-Hexa CDF (TEF 0.1)	TEQ	0	0	0	0
1,2,3,7,8,9-Hexa CDF (TEF 0.1)	TEQ	0	0	0	0
1,2,3,4,6,7,8-Hepta CDF (TEF 0.01)	TEQ	0	0	0.0623	0.993
1,2,3,4,7,8,9-Hepta CDF (TEF 0.01)	TEQ	0	0	0	0
Octa CDF (TEF 0.0003)	TEQ	0	0	0.00631	0.00505
Total PCDDs and PCDFs (TEQ)	TEQ	1.15	0.181	0.317	0.385

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-22

		SAMPLE DESCRIPTION:	**WL 16-2**	**WL 16-3**	**REF 3**	**REF 1**
		SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**
		DATE SAMPLED:	**2018-07-26**	**2018-07-26**		
Surrogate	**Unit**	**Acceptable Limits**	**9430673**	**9430674**	**9430770**	**9430777**
13C-2378-TCDF	%	30-140	58	58	67	61
13C-12378-PeCDF	%	30-140	48	49	58	53
13C-23478-PeCDF	%	30-140	59	55	65	61
13C-123478-HxCDF	%	30-140	61	70	66	58
13C-123678-HxCDF	%	30-140	74	81	83	73

13C-234678-HxCDF	%	30-140	66	61	77	66
13C-123789-HxCDF	%	30-140	50	36	59	54
13C-1234678-HpCDF	%	30-140	36	55	44	38
13C-1234789-HpCDF	%	30-140	30	38	34	31
13C-2378-TCDD	%	30-140	71	73	86	75
13C-12378-PeCDD	%	30-140	60	59	69	63
13C-123478-HxCDD	%	30-140	64	47	64	59
13C-123678-HxCDD	%	30-140	78	86	91	78
13C-1234678-HpCDD	%	30-140	31	41	35	31
13C-OCDD	%	30-140	33	38	**13**	**18**

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-22

			SAMPLE DESCRIPTION:	Ref 2
			SAMPLE TYPE: DATE SAMPLED:	Soil
Parameter	**Unit**	**G / S**	**RDL**	**9430783**
2,3,7,8-Tetra CDD	ng/kg		0.5	<0.5
1,2,3,7,8-Penta CDD	ng/kg		3	<3
1,2,3,4,7,8-Hexa CDD	ng/kg		2	<2
1,2,3,6,7,8-Hexa CDD	ng/kg		2	<2
1,2,3,7,8,9-Hexa CDD	ng/kg		2	<2
1,2,3,4,6,7,8-Hepta CDD	ng/kg		8	36
Octa CDD	ng/kg		30	266
2,3,7,8-Tetra CDF	ng/kg		1	<1
1,2,3,7,8-Penta CDF	ng/kg		2	<2

2,3,4,7,8-Penta CDF	ng/kg	2	<2
1,2,3,4,7,8-Hexa CDF	ng/kg	3	<3
1,2,3,6,7,8-Hexa CDF	ng/kg	2	<2
2,3,4,6,7,8-Hexa CDF	ng/kg	3	<3
1,2,3,7,8,9-Hexa CDF	ng/kg	6	<6
1,2,3,4,6,7,8-Hepta CDF	ng/kg	6	16
1,2,3,4,7,8,9-Hepta CDF	ng/kg	10	<10
Octa CDF	ng/kg	10	14
Total Tetrachlorodibenzodioxins	ng/kg	0.5	4.9
Total Pentachlorodibenzodioxins	ng/kg	3	12
Total Hexachlorodibenzodioxins	ng/kg	2	13
Total Heptachlorodibenzodioxins	ng/kg	8	70
Total PCDDs	ng/kg	30	366
Total Tetrachlorodibenzofurans	ng/kg	1	11
Total Pentachlorodibenzofurans	ng/kg	2	6
Total Hexachlorodibenzofurans	ng/kg	6	25
Total Heptachlorodibenzofurans	ng/kg	10	46
Total PCDFs	ng/kg	10	102
2,3,7,8-Tetra CDD (TEF 1.0)	TEQ		0
1,2,3,7,8-Penta CDD (TEF 1.0)	TEQ		0
1,2,3,4,7,8-Hexa CDD (TEF 0.1)	TEQ		0

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27
DATE REPORTED: 2018-08-22

AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

			SAMPLE DESCRIPTION:	Ref 2
			SAMPLE TYPE:	Soil
			DATE SAMPLED:	
Parameter	**Unit**	**G / S**	**RDL**	**9430783**
1,2,3,6,7,8-Hexa CDD (TEF 0.1)	TEQ			0
1,2,3,7,8,9-Hexa CDD (TEF 0.1)	TEQ			0
1,2,3,4,6,7,8-Hepta CDD (TEF 0.01)	TEQ			0.359
Octa CDD (TEF 0.0003)	TEQ			0.0797
2,3,7,8-Tetra CDF (TEF 0.1)	TEQ			0
1,2,3,7,8-Penta CDF (TEF 0.03)	TEQ			0
2,3,4,7,8-Penta CDF (TEF 0.3)	TEQ			0
1,2,3,4,7,8-Hexa CDF (TEF 0.1)	TEQ			0
1,2,3,6,7,8-Hexa CDF (TEF 0.1)	TEQ			0
2,3,4,6,7,8-Hexa CDF (TEF 0.1)	TEQ			0
1,2,3,7,8,9-Hexa CDF (TEF 0.1)	TEQ			0
1,2,3,4,6,7,8-Hepta CDF (TEF 0.01)	TEQ			0.158
1,2,3,4,7,8,9-Hepta CDF (TEF 0.01)	TEQ			0
Octa CDF (TEF 0.0003)	TEQ			0.00419
Total PCDDs and PCDFs (TEQ)	TEQ			0.602

Dioxins and Furans (Soil, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-22

		SAMPLE DESCRIPTION:	Ref 2
		SAMPLE TYPE:	Soil
		DATE SAMPLED:	
Surrogate	**Unit**	**Acceptable Limits**	**9430783**

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CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES
ATTENTION TO: Meghan Quanz
SAMPLING SITE:
SAMPLED BY:

13C-2378-TCDF	%	30-140	61
13C-12378-PeCDF	%	30-140	52
13C-23478-PeCDF	%	30-140	54
13C-123478-HxCDF	%	30-140	65
13C-123678-HxCDF	%	30-140	85
13C-234678-HxCDF	%	30-140	80
13C-123789-HxCDF	%	30-140	60
13C-1234678-HpCDF	%	30-140	46
13C-1234789-HpCDF	%	30-140	36
13C-2378-TCDD	%	30-140	74
13C-12378-PeCDD	%	30-140	58
13C-123478-HxCDD	%	30-140	70
13C-123678-HxCDD	%	30-140	99
13C-1234678-HpCDD	%	30-140	35
13C-OCDD	%	30-140	37

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

9430645-9430653 The results were corrected based on the surrogate percent recoveries.

9430671 The results were corrected based on the surrogate percent recoveries.
The percent recovery for 13C-OCDD is outside of acceptable range due to matrix interferences. The percent recoveries are respected for more than 90% of the compounds, the results are acceptable.

9430673-9430674 The results were corrected based on the surrogate percent recoveries.

9430770-9430777 The results were corrected based on the surrogate percent recoveries.
The percent recovery for 13C-OCDD is outside of acceptable range due to matrix interferences. The percent recoveries are respected for more than 90% of the compounds, the results are acceptable.

9430783 The results were corrected based on the surrogate percent recoveries.

Dioxins and Furans (Tissue, WHO 2005)

DATE RECEIVED: 2018-07-27
DATE REPORTED: 2018-08-21

11 Morris Drive, Unit 122

Certificate of Analysis

CANADA B3B 1M2

Dartmouth, Nova Scotia

AGAT WORK ORDER: 18X367355

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PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

				SAMPLE DESCRIPTION:	WL 1-M		WL 5-D		WL 16-D		WL 16-S
				SAMPLE TYPE:	Tissue		Tissue		Tissue		Tissue
				DATE SAMPLED:	2018-07-25		2018-07-23		2018-07-26		2018-07-26
Parameter	**Unit**	**G / S**	**RDL**		**9430644**	**RDL**	**9430655**	**RDL**	**9430679**	**RDL**	**9430680**
2,3,7,8-Tetra CDD	ng/kg		50		<50	9	<9	2	<2	0.4	<0.4
1,2,3,7,8-Penta CDD	ng/kg		90		<90	30	<30	5	<5	0.8	<0.8
1,2,3,4,7,8-Hexa CDD	ng/kg		100		<100	30	<30	5	<5	1	<1
1,2,3,6,7,8-Hexa CDD	ng/kg		100		<100	30	<30	5	<5	1	<1
1,2,3,7,8,9-Hexa CDD	ng/kg		100		<100	30	<30	5	<5	1	<1
1,2,3,4,6,7,8-Hepta CDD	ng/kg		100		198	30	<30	8	<8	2	<2
Octa CDD	ng/kg		800		872	100	<100	20	27	7	<7
2,3,7,8-Tetra CDF	ng/kg		70		<70	40	76	4	4	0.8	3.5
1,2,3,7,8-Penta CDF	ng/kg		100		<100	20	23	3	4	1	2
2,3,4,7,8-Penta CDF	ng/kg		80		<80	20	21	3	<3	1	<1
1,2,3,4,7,8-Hexa CDF	ng/kg		100		148	20	<20	2	5	2	2
1,2,3,6,7,8-Hexa CDF	ng/kg		100		<100	10	<10	2	<2	1	2
2,3,4,6,7,8-Hexa CDF	ng/kg		200		<200	20	<20	2	<2	2	<2
1,2,3,7,8,9-Hexa CDF	ng/kg		200		<200	30	<30	4	5	3	<3
1,2,3,4,6,7,8-Hepta CDF	ng/kg		200		436	20	<20	6	7	3	<3
1,2,3,4,7,8,9-Hepta CDF	ng/kg		300		<300	30	<30	10	<10	6	<6
Octa CDF	ng/kg		900		966	200	<200	40	<40	9	<9
Total Tetrachlorodibenzodioxins	ng/kg		50		148	9	9	2	4	0.4	1.4
Total Pentachlorodibenzodioxins	ng/kg		90		196	30	44	5	18	0.8	<0.8
Total Hexachlorodibenzodioxins	ng/kg		100		<100	30	<30	5	15	1	<1
Total Heptachlorodibenzodioxins	ng/kg		100		198	20	82	8	<8	2	<2

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Total PCDDs	ng/kg		800	1410	100	135	20	65	7	<7
Total Tetrachlorodibenzofurans	ng/kg		70	228	40	485	4	13	0.8	8.9
Total Pentachlorodibenzofurans	ng/kg		100	308	20	122	3	6	1	5
Total Hexachlorodibenzofurans	ng/kg		200	512	30	<30	4	12	3	5
Total Heptachlorodibenzofurans	ng/kg		300	614	30	37	10	<10	6	<6
Total PCDFs	ng/kg		900	2630	200	645	40	<40	9	19
2,3,7,8-Tetra CDD (TEF 1.0)	TEQ			0		0		0		0
1,2,3,7,8-Penta CDD (TEF 1.0)	TEQ			0		0		0		0
1,2,3,4,7,8-Hexa CDD (TEF 0.1)	TEQ			0		0		0		0

Dioxins and Furans (Tissue, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-21

			SAMPLE DESCRIPTION:	WL 1-M		WL 5-D		WL 16-D		WL 16-S
			SAMPLE TYPE:	Tissue		Tissue		Tissue		Tissue
			DATE SAMPLED:	2018-07-25		2018-07-23		2018-07-26		2018-07-26
Parameter	**Unit**	**G / S**	**RDL**	**9430644**	**RDL**	**9430655**	**RDL**	**9430679**	**RDL**	**9430680**
1,2,3,6,7,8-Hexa CDD (TEF 0.1)	TEQ			0		0		0		0
1,2,3,7,8,9-Hexa CDD (TEF 0.1)	TEQ			0		0		0		0
1,2,3,4,6,7,8-Hepta CDD (TEF 0.01)	TEQ			1.98		0		0		0
Octa CDD (TEF 0.0003)	TEQ			0.262		0		0.00816		0
2,3,7,8-Tetra CDF (TEF 0.1)	TEQ			0		7.6		0.408		0.348
1,2,3,7,8-Penta CDF (TEF 0.03)	TEQ			0		0.7		0.113		0.0545
2,3,4,7,8-Penta CDF (TEF 0.3)	TEQ			0		6.3		0		0
1,2,3,4,7,8-Hexa CDF (TEF 0.1)	TEQ			14.8		0		0.504		0.212
1,2,3,6,7,8-Hexa CDF (TEF 0.1)	TEQ			0		0		0		0.169

2,3,4,6,7,8-Hexa CDF (TEF 0.1)	TEQ	0	0	0	0
1,2,3,7,8,9-Hexa CDF (TEF 0.1)	TEQ	0	0	0.504	0
1,2,3,4,6,7,8-Hepta CDF (TEF 0.01)	TEQ	4.36	0	0.0720	0
1,2,3,4,7,8,9-Hepta CDF (TEF 0.01)	TEQ	0	0	0	0
Octa CDF (TEF 0.0003)	TEQ	0.290	0	0	0
Total PCDDs and PCDFs (TEQ)	TEQ	21.7	14.6	1.61	0.784

Dioxins and Furans (Tissue, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-21

		SAMPLE DESCRIPTION:	WL 1-M	WL 5-D	WL 16-D	WL 16-S
		SAMPLE TYPE:	Tissue	Tissue	Tissue	Tissue
		DATE SAMPLED:	2018-07-25	2018-07-23	2018-07-26	2018-07-26
Surrogate	**Unit**	**Acceptable Limits**	**9430644**	**9430655**	**9430679**	**9430680**
13C-2378-TCDF	%	30-140	61	45	58	45
13C-12378-PeCDF	%	30-140	44	39	47	36
13C-23478-PeCDF	%	30-140	48	35	47	39
13C-123478-HxCDF	%	30-140	76	64	87	72
13C-123678-HxCDF	%	30-140	76	69	87	75
13C-234678-HxCDF	%	30-140	73	69	77	68
13C-123789-HxCDF	%	30-140	59	52	61	55
13C-1234678-HpCDF	%	30-140	46	45	50	39
13C-1234789-HpCDF	%	30-140	40	37	37	31
13C-2378-TCDD	%	30-140	69	50	65	53
13C-12378-PeCDD	%	30-140	48	34	45	40
13C-123478-HxCDD	%	30-140	48	66	75	69
13C-123678-HxCDD	%	30-140	72	65	80	75
13C-1234678-HpCDD	%	30-140	76	40	40	34
13C-OCDD	%	30-140	44	41	71	33

AGAT Laboratories

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AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Dioxins and Furans (Tissue, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-21

			SAMPLE DESCRIPTION:	Ref 2
			SAMPLE TYPE:	Tissue
			DATE SAMPLED:	
Parameter	**Unit**	**G / S**	**RDL**	**9430784**
2,3,7,8-Tetra CDD	ng/kg		40	<40
1,2,3,7,8-Penta CDD	ng/kg		80	<80
1,2,3,4,7,8-Hexa CDD	ng/kg		100	<100
1,2,3,6,7,8-Hexa CDD	ng/kg		100	<100
1,2,3,7,8,9-Hexa CDD	ng/kg		100	<100
1,2,3,4,6,7,8-Hepta CDD	ng/kg		200	254
Octa CDD	ng/kg		700	<700
2,3,7,8-Tetra CDF	ng/kg		50	1020
1,2,3,7,8-Penta CDF	ng/kg		90	204
2,3,4,7,8-Penta CDF	ng/kg		80	158
1,2,3,4,7,8-Hexa CDF	ng/kg		100	168
1,2,3,6,7,8-Hexa CDF	ng/kg		100	148
2,3,4,6,7,8-Hexa CDF	ng/kg		100	<100
1,2,3,7,8,9-Hexa CDF	ng/kg		200	<200
1,2,3,4,6,7,8-Hepta CDF	ng/kg		200	<200
1,2,3,4,7,8,9-Hepta CDF	ng/kg		400	<400
Octa CDF	ng/kg		1000	<1000

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES
ATTENTION TO: Meghan Quanz
SAMPLING SITE:
SAMPLED BY:

Total Tetrachlorodibenzodioxins	ng/kg		40	84
Total Pentachlorodibenzodioxins	ng/kg		80	334
Total Hexachlorodibenzodioxins	ng/kg		100	380
Total Heptachlorodibenzodioxins	ng/kg		200	254
Total PCDDs	ng/kg		700	1050
Total Tetrachlorodibenzofurans	ng/kg		50	3140
Total Pentachlorodibenzofurans	ng/kg		90	864
Total Hexachlorodibenzofurans	ng/kg		200	372
Total Heptachlorodibenzofurans	ng/kg		400	<400
Total PCDFs	ng/kg		1000	4380
2,3,7,8-Tetra CDD (TEF 1.0)	TEQ			0
1,2,3,7,8-Penta CDD (TEF 1.0)	TEQ			0
1,2,3,4,7,8-Hexa CDD (TEF 0.1)	TEQ			0

Dioxins and Furans (Tissue, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-21

			SAMPLE DESCRIPTION:	**Ref 2**
			SAMPLE TYPE:	**Tissue**
			DATE SAMPLED:	
Parameter	**Unit**	**G / S**	**RDL**	**9430784**
1,2,3,6,7,8-Hexa CDD (TEF 0.1)	TEQ			0
1,2,3,7,8,9-Hexa CDD (TEF 0.1)	TEQ			0
1,2,3,4,6,7,8-Hepta CDD (TEF 0.01)	TEQ			2.54
Octa CDD (TEF 0.0003)	TEQ			0
2,3,7,8-Tetra CDF (TEF 0.1)	TEQ			102

1,2,3,7,8-Penta CDF (TEF 0.03)	TEQ	6.12
2,3,4,7,8-Penta CDF (TEF 0.3)	TEQ	47.4
1,2,3,4,7,8-Hexa CDF (TEF 0.1)	TEQ	16.8
1,2,3,6,7,8-Hexa CDF (TEF 0.1)	TEQ	14.8
2,3,4,6,7,8-Hexa CDF (TEF 0.1)	TEQ	0
1,2,3,7,8,9-Hexa CDF (TEF 0.1)	TEQ	0
1,2,3,4,6,7,8-Hepta CDF (TEF 0.01)	TEQ	0
1,2,3,4,7,8,9-Hepta CDF (TEF 0.01)	TEQ	0
Octa CDF (TEF 0.0003)	TEQ	0
Total PCDDs and PCDFs (TEQ)	TEQ	190

Dioxins and Furans (Tissue, WHO 2005)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-21

		SAMPLE DESCRIPTION:	Ref 2
		SAMPLE TYPE:	Tissue
		DATE SAMPLED:	
Surrogate	**Unit**	**Acceptable Limits**	**9430784**
13C-2378-TCDF	%	30-140	54
13C-12378-PeCDF	%	30-140	42
13C-23478-PeCDF	%	30-140	42
13C-123478-HxCDF	%	30-140	77
13C-123678-HxCDF	%	30-140	83
13C-234678-HxCDF	%	30-140	74
13C-123789-HxCDF	%	30-140	55
13C-1234678-HpCDF	%	30-140	48
13C-1234789-HpCDF	%	30-140	35

13C-2378-TCDD	%	30-140	58
13C-12378-PeCDD	%	30-140	70
13C-123478-HxCDD	%	30-140	73
13C-123678-HxCDD	%	30-140	73
13C-1234678-HpCDD	%	30-140	73
13C-OCDD	%	30-140	37

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

9430644-9430784 The results were corrected based on the surrogate percent recoveries.

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AGAT WORK ORDER: 18X367355

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PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Mercury Analysis in Water (Total)

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-01

			SAMPLE DESCRIPTION:	WL 1	WL 5	WL 13	WL 16	WL 18	REF 1	REF 2	WL 1(2)
			SAMPLE TYPE:	Water	Water	Water	Water	Water	Water	Water	Water
			DATE SAMPLED:	2018-07-25	2018-07-23	2018-07-24	2018-07-26	2018-07-25	2018-07-23	2018-07-26	2018-07-25
Parameter	**Unit**	**G / S**	**RDL**	**9430726**	**9430729**	**9430730**	**9430731**	**9430732**	**9430733**	**9430734**	**9437980**
Total Mercury	ug/L		0.026	<0.026	<0.026	<0.026	<0.026	0.051	<0.026	<0.026	<0.026

			SAMPLE DESCRIPTION:	WL 1(3)	WL 5(2)	WL 5(3)	WL 13(2)	WL 13(3)	WL 16(2)	WL 16(3)	WL 18(2)
			SAMPLE TYPE:	Water	Water	Water	Water	Water	Water	Water	Water
			DATE SAMPLED:	2018-07-25	2018-07-23	2018-07-23	2018-07-24	2018-07-24	2018-07-26	2018-07-26	2018-07-25
Parameter	**Unit**	**G / S**	**RDL**	**9437981**	**9437982**	**9437983**	**9437984**	**9437985**	**9437986**	**9437987**	**9437988**
Total Mercury	ug/L		0.026	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026	0.054

			SAMPLE DESCRIPTION:	WL 18(3)	REF 1(2)	REF 1(3)	REF 2(2)	REF 2(3)
			SAMPLE TYPE:	Water	Water	Water	Water	Water
			DATE SAMPLED:	2018-07-25	2018-07-23	2018-07-23	2018-07-26	2018-07-26
Parameter	**Unit**	**G / S**	**RDL**	**9437989**	**9437990**	**9437991**	**9437992**	**9437993**
Total Mercury	ug/L		0.026	0.088	<0.026	<0.026	<0.026	<0.026

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

Total Metals

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-03

			SAMPLE DESCRIPTION:	WL 1	WL 5	WL 13	WL 16	WL 18	REF 1	REF 2	WL 1(2)

AGAT Laboratories

11 Morris Drive, Unit 122

Certificate of Analysis

CANADA B3B 1M2

Dartmouth, Nova Scotia

AGAT WORK ORDER: 18X367355

TEL (902)468-8718
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PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

			SAMPLE TYPE:	Water	Water	Water	Water	Water	Water	Water	Water
			DATE SAMPLED:	2018-07-25	2018-07-23	2018-07-24	2018-07-26	2018-07-25	2018-07-23	2018-07-26	2018-07-25
Parameter	**Unit**	**G / S**	**RDL**	**9430726**	**9430729**	**9430730**	**9430731**	**9430732**	**9430733**	**9430734**	**9437980**
Total Aluminum	ug/L		5	1670	179	10	8	1600	346	63	1610
Total Antimony	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Arsenic	ug/L		2	2	5	<2	<2	3	<2	<2	2
Total Barium	ug/L		5	332	417	141	140	295	69	263	307
Total Beryllium	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Bismuth	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Boron	ug/L		5	76	18	11	10	101	12	11	75
Total Cadmium	ug/L		0.09	0.70	<0.09	<0.09	<0.09	0.61	<0.09	<0.09	0.65
Total Chromium	ug/L		1	3	1	<1	<1	4	1	<1	4
Total Cobalt	ug/L		1	<1	3	<1	<1	1	6	<1	<1
Total Copper	ug/L		1	5	2	<1	<1	5	<1	<1	5
Total Iron	ug/L		50	543	3100	308	404	1230	5730	817	521
Total Lead	ug/L		0.5	1.7	0.7	<0.5	<0.5	1.4	1.1	<0.5	1.6
Total Manganese	ug/L		2	2490	1330	353	838	2490	1260	380	2350
Total Molybdenum	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Nickel	ug/L		2	4	7	<2	<2	6	<2	<2	5
Total Selenium	ug/L		1	2	<1	<1	<1	2	<1	<1	<1
Total Silver	ug/L		0.1	0.2	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.2
Total Strontium	ug/L		5	184	104	42	42	162	52	24	177
Total Thallium	ug/L		0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Tin	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Titanium	ug/L		2	13	3	<2	<2	13	5	<2	13

Total Uranium	ug/L		0.1	0.4	0.6	<0.1	<0.1	0.4	<0.1	<0.1	0.4
Total Vanadium	ug/L		2	5	<2	<2	<2	9	3	<2	6
Total Zinc	ug/L		5	92	5	<5	<5	89	9	5	96

Total Metals

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-03

			SAMPLE DESCRIPTION:	WL 1(3)	WL 5(2)	WL 5(3)	WL 13(2)	WL 13(3)	WL 16(2)	WL 16(3)	WL 18(2)
			SAMPLE TYPE:	Water	Water	Water	Water	Water	Water	Water	Water
			DATE SAMPLED:	2018-07-25	2018-07-23	2018-07-23	2018-07-24	2018-07-24	2018-07-26	2018-07-26	2018-07-25
Parameter	**Unit**	**G / S**	**RDL**	**9437981**	**9437982**	**9437983**	**9437984**	**9437985**	**9437986**	**9437987**	**9437988**
Total Aluminum	ug/L		5	1650	147	139	14	7	23	416	1720
Total Antimony	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Arsenic	ug/L		2	2	5	5	<2	<2	<2	<2	3
Total Barium	ug/L		5	305	436	412	135	133	154	205	237
Total Beryllium	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Bismuth	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Boron	ug/L		5	74	15	17	12	12	12	12	59
Total Cadmium	ug/L		0.09	0.68	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	0.93
Total Chromium	ug/L		1	4	1	1	<1	<1	<1	1	4
Total Cobalt	ug/L		1	<1	3	3	<1	<1	<1	<1	2
Total Copper	ug/L		1	5	1	2	<1	<1	<1	3	7
Total Iron	ug/L		50	712	3440	3280	333	293	1250	1660	4720
Total Lead	ug/L		0.5	2.2	0.8	0.7	<0.5	<0.5	<0.5	1.2	2.7
Total Manganese	ug/L		2	2360	1650	1330	321	344	833	492	2890

Certificate of Analysis

AGAT WORK ORDER: 18X367355

PROJECT:

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Total Molybdenum	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Nickel	ug/L		2	5	7	7	<2	<2	<2	2	8
Total Selenium	ug/L		1	<1	<1	<1	<1	<1	<1	<1	<1
Total Silver	ug/L		0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2
Total Strontium	ug/L		5	177	99	99	41	40	42	52	149
Total Thallium	ug/L		0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Tin	ug/L		2	<2	<2	<2	<2	<2	<2	<2	<2
Total Titanium	ug/L		2	13	3	3	<2	<2	<2	8	14
Total Uranium	ug/L		0.1	0.4	0.7	0.7	<0.1	<0.1	<0.1	0.2	0.4
Total Vanadium	ug/L		2	6	<2	<2	<2	<2	<2	<2	12
Total Zinc	ug/L		5	101	6	6	<5	<5	6	14	131

Total Metals

DATE RECEIVED: 2018-07-27

DATE REPORTED: 2018-08-03

			SAMPLE DESCRIPTION:	WL 18(3)	REF 1(2)	REF 1(3)	REF 2(2)	REF 2(3)
			SAMPLE TYPE:	Water	Water	Water	Water	Water
			DATE SAMPLED:	2018-07-25	2018-07-23	2018-07-23	2018-07-26	2018-07-26
Parameter	**Unit**	**G / S**	**RDL**	**9437989**	**9437990**	**9437991**	**9437992**	**9437993**
Total Aluminum	ug/L		5	1640	551	290	104	182
Total Antimony	ug/L		2	<2	<2	<2	<2	<2
Total Arsenic	ug/L		2	4	<2	<2	<2	<2
Total Barium	ug/L		5	313	93	78	240	282
Total Beryllium	ug/L		2	<2	<2	<2	<2	<2
Total Bismuth	ug/L		2	<2	<2	<2	<2	<2
Total Boron	ug/L		5	100	13	13	12	13

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES

ATTENTION TO: Meghan Quanz

SAMPLING SITE:

SAMPLED BY:

Total Cadmium	ug/L	0.09	1.14	<0.09	<0.09	<0.09	<0.09
Total Chromium	ug/L	1	5	2	1	<1	<1
Total Cobalt	ug/L	1	2	15	7	<1	<1
Total Copper	ug/L	1	10	<1	<1	<1	<1
Total Iron	ug/L	50	4720	10200	5440	452	975
Total Lead	ug/L	0.5	3.3	2.0	1.2	<0.5	<0.5
Total Manganese	ug/L	2	3490	2690	2050	317	313
Total Molybdenum	ug/L	2	2	<2	<2	<2	<2
Total Nickel	ug/L	2	9	2	2	<2	<2
Total Selenium	ug/L	1	<1	<1	<1	<1	<1
Total Silver	ug/L	0.1	0.3	<0.1	<0.1	<0.1	<0.1
Total Strontium	ug/L	5	147	52	59	17	20
Total Thallium	ug/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Tin	ug/L	2	<2	<2	<2	<2	<2
Total Titanium	ug/L	2	16	8	5	<2	3
Total Uranium	ug/L	0.1	0.6	0.1	<0.1	<0.1	<0.1
Total Vanadium	ug/L	2	14	7	3	<2	<2
Total Zinc	ug/L	5	194	10	6	<5	6

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

Quality Assurance

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES **AGAT WORK ORDER: 18X367355**

PROJECT: **ATTENTION TO: Meghan Quanz** **SAMPLING SITE:** **SAMPLED BY:**

Soil Analysis

RPT Date:			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits Lower	Acceptable Limits Upper	Recovery	Acceptable Limits Lower	Acceptable Limits Upper	Recovery	Acceptable Limits Lower	Acceptable Limits Upper
Available Metals in Soil															
Aluminum	9430720	9430720	7460	7360	1.3%	< 10	105%	80%	120%	120%	80%	120%	NA	70%	130%
Antimony	9430720	9430720	<1	<1	NA	< 1	92%	80%	120%	111%	80%	120%	NA	70%	130%
Arsenic	9430720	9430720	3	3	NA	< 1	98%	80%	120%	110%	80%	120%	107%	70%	130%
Barium	9430720	9430720	97	97	0.1%	< 5	102%	80%	120%	106%	80%	120%	105%	70%	130%
Beryllium	9430720	9430720	<2	<2	NA	< 2	102%	80%	120%	108%	80%	120%	110%	70%	130%
Boron	9430720	9430720	<2	<2	NA	< 2	100%	80%	120%	105%	80%	120%	106%	70%	130%
Cadmium	9430720	9430720	<0.3	<0.3	NA	< 0.3	96%	80%	120%	103%	80%	120%	98%	70%	130%
Chromium	9430720	9430720	11	10	8.6%	< 2	93%	80%	120%	93%	80%	120%	122%	70%	130%
Cobalt	9430720	9430720	4	4	NA	< 1	99%	80%	120%	99%	80%	120%	114%	70%	130%
Copper	9430720	9430720	5	5	NA	< 2	93%	80%	120%	93%	80%	120%	112%	70%	130%
Iron	9430720	9430720	5600	6300	11.7%	< 50	93%	80%	120%	92%	80%	120%	111%	70%	130%
Lead	9430720	9430720	20.3	19.9	1.6%	< 0.5	109%	80%	120%	117%	80%	120%	104%	70%	130%
Lithium	9430720	9430720	13	13	NA	< 5	104%	70%	130%	114%	70%	130%	116%	70%	130%
Manganese	9430720	9430720	109	104	5.0%	< 2	95%	80%	120%	103%	80%	120%	109%	70%	130%
Molybdenum	9430720	9430720	<2	<2	NA	< 2	97%	80%	120%	99%	80%	120%	102%	70%	130%
Nickel	9430720	9430720	9	8	NA	< 2	96%	80%	120%	97%	80%	120%	117%	70%	130%
Selenium	9430720	9430720	<1	<1	NA	< 1	108%	80%	120%	103%	80%	120%	94%	70%	130%
Silver	9430720	9430720	<0.5	<0.5	NA	< 0.5	97%	80%	120%	100%	80%	120%	103%	70%	130%
Strontium	9430720	9430720	9	9	NA	< 5	98%	80%	120%	107%	80%	120%	116%	70%	130%
Thallium	9430720	9430720	<0.1	<0.1	NA	< 0.1	107%	80%	120%	113%	80%	120%	72%	70%	130%
Tin	9430720	9430720	3	3	NA	< 2	98%	80%	120%	102%	80%	120%	109%	70%	130%
Uranium	9430720	9430720	0.6	0.5	16.9%	< 0.1	107%	80%	120%	111%	80%	120%	114%	70%	130%
Vanadium	9430720	9430720	24	22	9.3%	< 2	93%	80%	120%	93%	80%	120%	120%	70%	130%
Zinc	9430720	9430720	38	36	6.9%	< 5	89%	80%	120%	92%	80%	120%	105%	70%	130%
Mercury Analysis in Soil															
Mercury	1	9427287	<0.05	<0.05	NA	< 0.05	104%	70%	130%	NA	70%	130%	96%	70%	130%
Inorganics															
Total Organic Carbon	9414196		4.0	4.1	2.5%	< 0.3	95%	80%	120%	NA	80%	120%	NA	80%	120%

Comments: NA : Non applicable

NA dans l’écart du duplicata indique que l’écart n’a pu être calculé car l’un ou les deux résultats sont < 5x LDR.

NA dans le pourcentage de récupération de l’échantillon fortifié indique que le résultat n’est pas fourni en raison de l’hétérogénéité de l’échantillon ou de la concentration trop élevée par rapport à l’ajout.

NA dans le blanc fortifié ou le MRC indique qu’il n’est pas requis par la procédure.

Le pourcentage de récupération du MRC peut être en dehors du critère d’acceptabilité de 80-120%, s’il est conforme à l’écart du certificat du matériau de référence.

Quality Assurance

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES **AGAT WORK ORDER: 18X367355**

PROJECT: **ATTENTION TO: Meghan Quanz** **SAMPLING SITE:** **SAMPLED BY:**

Soil Analysis (Continued)

RPT Date:			DUPLICATE				REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD	Method Blank	Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
Metals in Tissue															
Aluminum	9430769	9430769	36	34	NA	< 10	104%	70%	130%	116%	70%	130%	NA	70%	130%
Antimony	9430769	9430769	<2	<2	NA	< 2	91%	70%	130%	122%	70%	130%	NA	70%	130%
Arsenic	9430769	9430769	5	4	NA	< 2	105%	70%	130%	113%	70%	130%	NA	70%	130%
Barium	9430769	9430769	<5	<5	NA	< 5	98%	70%	130%	107%	70%	130%	NA	70%	130%
Beryllium	9430769	9430769	<2	<2	NA	< 2	111%	70%	130%	115%	70%	130%	NA	70%	130%
Bismuth	9430769	9430769	<5	<5	NA	< 5	107%	70%	130%	130%	130%	130%	NA	70%	130%
Boron	9430769	9430769	<2	<2	NA	< 2	104%	70%	130%	106%	70%	130%	NA	70%	130%
Cadmium	9430769	9430769	<0.3	<0.3	NA	< 0.3	101%	70%	130%	108%	70%	130%	NA	70%	130%
Chromium	9430769	9430769	<2	<2	NA	< 2	92%	70%	130%	97%	70%	130%	NA	70%	130%
Cobalt	9430769	9430769	<1	<1	NA	< 1	94%	70%	130%	103%	70%	130%	NA	70%	130%
Copper	9430769	9430769	4	4	NA	< 2	94%	70%	130%	99%	70%	130%	NA	70%	130%
Iron	9430769	9430769	1210	1140	6.5%	< 50	94%	70%	130%	99%	70%	130%	NA	70%	130%
Lead	9430769	9430769	<0.4	<0.4	NA	< 0.4	108%	70%	130%	118%	70%	130%	NA	70%	130%
Manganese	9430769	9430769	110	103	6.3%	< 2	95%	70%	130%	102%	70%	130%	NA	70%	130%
Molybdenum	9430769	9430769	<2	<2	NA	< 2	93%	90%	110%	104%	90%	110%	NA	70%	130%
Nickel	9430769	9430769	<2	<2	NA	< 2	93%	70%	130%	104%	70%	130%	NA	70%	130%
Selenium	9430769	9430769	<1	<1	NA	< 1	104%	70%	130%	118%	70%	130%	NA	70%	130%
Silver	9430769	9430769	<0.5	<0.5	NA	< 0.5	103%	70%	130%	109%	70%	130%	NA	70%	130%
Strontium	9430769	9430769	<5	<5	NA	< 5	96%	70%	130%	101%	70%	130%	NA	70%	130%
Thallium	9430769	9430769	<0.1	<0.1	NA	< 0.1	106%	70%	130%	115%	70%	130%	NA	70%	130%
Tin	9430769	9430769	8	8	NA	< 2	97%	70%	130%	107%	70%	130%	NA	70%	130%
Uranium	9430769	9430769	<0.1	<0.1	NA	< 0.1	105%	70%	130%	115%	70%	130%	NA	70%	130%
Vanadium	9430769	9430769	12	12	0.0%	< 2	92%	70%	130%	97%	70%	130%	NA	70%	130%
Zinc	9430769	9430769	29	28	3.3%	< 5	91%	70%	130%	98%	70%	130%	NA	70%	130%
Mercury Analysis in Tissue															
Mercury in Tissue	1	9430679	<0.05	<0.05	NA	< 0.05	90%	70%	130%	NA	70%	130%	103%	70%	130%

Quality Assurance

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES **AGAT WORK ORDER: 18X367355**

PROJECT: **ATTENTION TO: Meghan Quanz** **SAMPLING SITE:** **SAMPLED BY:**

Ultra Trace Analysis

RPT Date:			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
Dioxins and Furans (Soil, WHO 2005)															
2,3,7,8-Tetra CDD	1	9435450	< 0.2	< 0.2	NA	< 0.2	80%	70%	130%	NA	70%	130%	99%	70%	130%
1,2,3,7,8-Penta CDD	1	9435450	1.2	1.3	NA	< 0.2	90%	70%	130%	NA	70%	130%	109%	70%	130%
1,2,3,4,7,8-Hexa CDD	1	9435450	2.4	2.4	NA	< 0.2	97%	70%	130%	NA	70%	130%	104%	70%	130%
1,2,3,6,7,8-Hexa CDD	1	9435450	3.4	3.6	NA	< 0.2	96%	70%	130%	NA	70%	130%	108%	70%	130%
1,2,3,7,8,9-Hexa CDD	1	9435450	5.5	5.7	3.6%	< 0.1	126%	70%	130%	NA	70%	130%	127%	70%	130%
1,2,3,4,6,7,8-Hepta CDD	1	9435450	92	99	7.3%	< 0.3	93%	70%	130%	NA	70%	130%	117%	70%	130%
Octa CDD	1	9435450	531	555	4.4%	< 0.5	94%	70%	130%	NA	70%	130%	106%	70%	130%
2,3,7,8-Tetra CDF	1	9435450	1.3	1.3	NA	< 0.1	96%	70%	130%	NA	70%	130%	111%	70%	130%
1,2,3,7,8-Penta CDF	1	9435450	0.6	0.6	NA	< 0.1	103%	70%	130%	NA	70%	130%	116%	70%	130%
2,3,4,7,8-Penta CDF	1	9435450	0.7	0.7	NA	< 0.1	109%	70%	130%	NA	70%	130%	121%	70%	130%
1,2,3,4,7,8-Hexa CDF	1	9435450	1.5	1.5	NA	< 0.1	70%	70%	130%	NA	70%	130%	119%	70%	130%
1,2,3,6,7,8-Hexa CDF	1	9435450	1.2	1.3	NA	< 0.1	105%	70%	130%	NA	70%	130%	117%	70%	130%
2,3,4,6,7,8-Hexa CDF	1	9435450	2.3	2.6	NA	< 0.1	126%	70%	130%	NA	70%	130%	114%	70%	130%
1,2,3,7,8,9-Hexa CDF	1	9435450	< 0.9	< 0.6	NA	< 0.2	111%	70%	130%	NA	70%	130%	110%	70%	130%
1,2,3,4,6,7,8-Hepta CDF	1	9435450	34.3	35.9	4.6%	< 0.2	108%	70%	130%	NA	70%	130%	118%	70%	130%
1,2,3,4,7,8,9-Hepta CDF	1	9435450	2	1.3	NA	< 0.3	105%	70%	130%	NA	70%	130%	116%	70%	130%
Octa CDF	1	9435450	85	101	17.2%	< 0.5	99%	70%	130%	NA	70%	130%	127%	70%	130%
Dioxins and Furans (Tissue, WHO 2005)															
2,3,7,8-Tetra CDD	1	9451091	< 0.1	< 0.1	NA	< 0.1	98%	40%	130%	NA	40%	130%	95%	40%	130%
1,2,3,7,8-Penta CDD	1	9451091	< 0.1	< 0.1	NA	< 0.1	105%	40%	130%	NA	40%	130%	94%	40%	130%
1,2,3,4,7,8-Hexa CDD	1	9451091	< 0.2	< 0.1	NA	< 0.1	102%	40%	130%	NA	40%	130%	100%	40%	130%
1,2,3,6,7,8-Hexa CDD	1	9451091	< 0.2	< 0.1	NA	< 0.1	107%	40%	130%	NA	40%	130%	106%	40%	130%
1,2,3,7,8,9-Hexa CDD	1	9451091	< 0.1	< 0.1	NA	< 0.1	95%	40%	130%	NA	40%	130%	99%	40%	130%
1,2,3,4,6,7,8-Hepta CDD	1	9451091	< 0.3	< 0.3	NA	< 0.3	104%	40%	130%	NA	40%	130%	101%	40%	130%
Octa CDD	1	9451091	< 0.8	< 0.8	NA	< 0.8	100%	40%	130%	NA	40%	130%	100%	40%	130%
2,3,7,8-Tetra CDF	1	9451091	< 0.1	< 0.1	NA	< 0.1	110%	40%	130%	NA	40%	130%	101%	40%	130%
1,2,3,7,8-Penta CDF	1	9451091	< 0.1	< 0.1	NA	< 0.1	119%	40%	130%	NA	40%	130%	110%	40%	130%
2,3,4,7,8-Penta CDF	1	9451091	< 0.1	< 0.1	NA	< 0.1	120%	40%	130%	NA	40%	130%	120%	40%	130%
1,2,3,4,7,8-Hexa CDF	1	9451091	0.1	0.1	NA	< 0.1	118%	40%	130%	NA	40%	130%	109%	40%	130%
1,2,3,6,7,8-Hexa CDF	1	9451091	0.1	0.1	NA	< 0.1	110%	40%	130%	NA	40%	130%	113%	40%	130%
2,3,4,6,7,8-Hexa CDF	1	9451091	< 0.1	< 0.1	NA	< 0.1	118%	40%	130%	NA	40%	130%	117%	40%	130%
1,2,3,7,8,9-Hexa CDF	1	9451091	< 0.2	< 0.2	NA	< 0.2	113%	40%	130%	NA	40%	130%	110%	40%	130%

Quality Assurance

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES **AGAT WORK ORDER: 18X367355**

PROJECT: **ATTENTION TO: Meghan Quanz** **SAMPLING SITE:** **SAMPLED BY:**

Ultra Trace Analysis (Continued)

RPT Date:			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
1,2,3,4,6,7,8-Hepta CDF	1	9451091	< 0.2	< 0.2	NA	< 0.2	112%	40%	130%	NA	40%	130%	105%	40%	130%
1,2,3,4,7,8,9-Hepta CDF	1	9451091	< 0.5	< 0.5	NA	< 0.5	115%	40%	130%	NA	40%	130%	107%	40%	130%
Octa CDF	1	9451091	< 1	< 1	NA	< 0.1	104%	40%	130%	NA	40%	130%	105%	40%	130%

AGAT Laboratories

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Quality Assurance

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES **AGAT WORK ORDER: 18X367355**

PROJECT: **ATTENTION TO: Meghan Quanz** **SAMPLING SITE:** **SAMPLED BY:**

Water Analysis

RPT Date:			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
Total Metals															
Total Aluminum	9435091		<5	<5	NA	< 5	102%	80%	120%	93%	80%	120%	92%	70%	130%
Total Antimony	9435091		<2	<2	NA	< 2	94%	80%	120%	96%	80%	120%	92%	70%	130%
Total Arsenic	9435091		<2	<2	NA	< 2	95%	80%	120%	81%	80%	120%	88%	70%	130%
Total Barium	9435091		<5	<5	NA	< 5	93%	80%	120%	83%	80%	120%	91%	70%	130%
Total Beryllium	9435091		<2	<2	NA	< 2	97%	80%	120%	93%	80%	120%	82%	70%	130%
Total Bismuth	9435091		<2	<2	NA	< 2	107%	80%	120%	98%	80%	120%	96%	70%	130%
Total Boron	9435091		12	12	NA	< 5	98%	80%	120%	95%	80%	120%	86%	70%	130%
Total Cadmium	9435091		<0.09	<0.09	NA	< 0.09	92%	80%	120%	83%	80%	120%	87%	70%	130%
Total Chromium	9435091		<1	<1	NA	< 1	92%	80%	120%	92%	80%	120%	95%	70%	130%
Total Cobalt	9435091		<1	<1	NA	< 1	105%	80%	120%	94%	80%	120%	109%	70%	130%
Total Copper	9435091		4	3	NA	< 1	101%	80%	120%	100%	80%	120%	88%	70%	130%
Total Iron	9435091		125	121	NA	< 50	104%	80%	120%	94%	80%	120%	96%	70%	130%
Total Lead	9435091		<0.5	<0.5	NA	< 0.5	107%	80%	120%	94%	80%	120%	97%	70%	130%
Total Manganese	9435091		<2	<2	NA	< 2	100%	80%	120%	93%	80%	120%	102%	70%	130%
Total Molybdenum	9435091		<2	<2	NA	< 2	92%	80%	120%	85%	80%	120%	95%	70%	130%
Total Nickel	9435091		<2	<2	NA	< 2	95%	80%	120%	93%	80%	120%	97%	70%	130%
Total Selenium	9435091		<1	<1	NA	< 1	99%	80%	120%	81%	80%	120%	82%	70%	130%
Total Silver	9435091		<0.1	<0.1	NA	< 0.1	98%	80%	120%	91%	80%	120%	92%	70%	130%
Total Strontium	9435091		<5	<5	NA	< 5	98%	80%	120%	89%	80%	120%	103%	70%	130%
Total Thallium	9435091		<0.1	<0.1	NA	< 0.1	100%	80%	120%	92%	80%	120%	95%	70%	130%
Total Tin	9435091		<2	<2	NA	< 2	93%	80%	120%	85%	80%	120%	91%	70%	130%
Total Titanium	9435091		<2	<2	NA	< 2	101%	80%	120%	95%	80%	120%	79%	70%	130%
Total Uranium	9435091		<0.1	<0.1	NA	< 0.1	101%	80%	120%	89%	80%	120%	98%	70%	130%
Total Vanadium	9435091		<2	<2	NA	< 2	90%	80%	120%	82%	80%	120%	98%	70%	130%
Total Zinc	9435091		6	6	NA	< 5	108%	80%	120%	96%	80%	120%	102%	70%	130%

Comments: If RPD value is NA, the results of the duplicates are less than 5x the RDL and the RPD will not be calculated.

PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD	Method Blank	Measured Value	Lower	Upper	Recovery	Lower	Upper	Recovery	Lower	Upper
Mercury Analysis in Water (Total)															
Total Mercury	1	9437992	<0.026	<0.026	NA	< 0.026	98%	80%	120%		80%	120%	95%	80%	120%

Comments: If RPD value is NA, the results of the duplicates are less than 5x the RDL and the RPD will not be calculated.

PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD	Method Blank	Measured Value	Lower	Upper	Recovery	Lower	Upper	Recovery	Lower	Upper
Total Metals															
Total Aluminum	9437993	9437993	182	185	2%	< 5	103%	80%	120%	108%	80%	120%	NA	70%	130%

Quality Assurance

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES **AGAT WORK ORDER: 18X367355**

PROJECT: **ATTENTION TO: Meghan Quanz** **SAMPLING SITE:** **SAMPLED BY:**

Water Analysis (Continued)

RPT Date:			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
Total Antimony	9437993	9437993	<2	<2	NA	< 2	100%	80%	120%	119%	80%	120%	102%	70%	130%
Total Arsenic	9437993	9437993	<2	<2	NA	< 2	92%	80%	120%	93%	80%	120%	96%	70%	130%
Total Barium	9437993	9437993	282	263	7.2%	< 5	97%	80%	120%	98%	80%	120%	NA	70%	130%
Total Beryllium	9437993	9437993	<2	<2	NA	< 2	105%	80%	120%	107%	80%	120%	104%	70%	130%
Total Bismuth	9437993	9437993	<2	<2	NA	< 2	105%	80%	120%	112%	80%	120%	110%	70%	130%
Total Boron	9437993	9437993	13	13	NA	< 5	100%	80%	120%	102%	80%	120%	108%	70%	130%
Total Cadmium	9437993	9437993	<0.09	<0.09	NA	< 0.09	94%	80%	120%	95%	80%	120%	92%	70%	130%
Total Chromium	9437993	9437993	<1	<1	NA	< 1	99%	80%	120%	97%	80%	120%	117%	70%	130%
Total Cobalt	9437993	9437993	<1	<1	NA	< 1	101%	80%	120%	103%	80%	120%	116%	70%	130%
Total Copper	9437993	9437993	<1	<1	NA	< 1	98%	80%	120%	102%	80%	120%	110%	70%	130%
Total Iron	9437993	9437993	975	946	3.1%	< 50	98%	80%	120%	98%	80%	120%	NA	70%	130%
Total Lead	9437993	9437993	<0.5	<0.5	NA	< 0.5	103%	80%	120%	106%	80%	120%	111%	70%	130%
Total Manganese	9437993	9437993	313	290	7.8%	< 2	99%	80%	120%	102%	80%	120%	NA	70%	130%
Total Molybdenum	9437993	9437993	<2	<2	NA	< 2	96%	80%	120%	99%	80%	120%	108%	70%	130%
Total Nickel	9437993	9437993	<2	3	NA	< 2	99%	80%	120%	99%	80%	120%	112%	70%	130%
Total Selenium	9437993	9437993	<1	<1	NA	< 1	96%	80%	120%	98%	80%	120%	104%	70%	130%
Total Silver	9437993	9437993	<0.1	<0.1	NA	< 0.1	103%	80%	120%	102%	80%	120%	98%	70%	130%
Total Strontium	9437993	9437993	20	20	NA	< 5	95%	80%	120%	98%	80%	120%	102%	70%	130%
Total Thallium	9437993	9437993	<0.1	<0.1	NA	< 0.1	102%	80%	120%	105%	80%	120%	110%	70%	130%
Total Tin	9437993	9437993	<2	<2	NA	< 2	92%	80%	120%	97%	80%	120%	99%	70%	130%
Total Titanium	9437993	9437993	3	3	NA	< 2	104%	80%	120%	105%	80%	120%	116%	70%	130%
Total Uranium	9437993	9437993	<0.1	<0.1	NA	< 0.1	99%	80%	120%	102%	80%	120%	112%	70%	130%
Total Vanadium	9437993	9437993	<2	<2	NA	< 2	92%	80%	120%	93%	80%	120%	109%	70%	130%
Total Zinc	9437993	9437993	6	6	NA	< 5	104%	80%	120%	106%	80%	120%	106%	70%	130%

Comments: If RPD value is NA, the results of the duplicates are less than 5x the RDL and the RPD will not be calculated.

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Soil Analysis			
Aluminum	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Antimony	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Arsenic	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Barium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Beryllium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Boron	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Cadmium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Chromium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Cobalt	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Copper	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Iron	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Lead	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP-MS
Lithium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP-MS
Manganese	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Molybdenum	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Nickel	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Selenium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Silver	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Strontium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Thallium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Tin	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Uranium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Vanadium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Zinc	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Total Organic Carbon	INOR-101-6057F	MA. 405-C 1.1	TITRAGE
Mercury	INOR-121-6101 & INOR-121-6107	Based on EPA 245.5 & SM 3112B	CV/AA

Mercury in Tissue	MET-121-6101, MET-121-6107	modified from EPA 245.6	CV/AA
Aluminum	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Antimony	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Arsenic	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Barium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Beryllium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Bismuth	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP-MS
Boron	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Cadmium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Chromium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Cobalt	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Copper	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Iron	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Lead	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP-MS
Manganese	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Molybdenum	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Nickel	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Selenium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Silver	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Strontium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Thallium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Tin	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Uranium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Vanadium	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Zinc	MET-121-6105 & MET-121-6103	modified from EPA 200.8 and EPA 3050	ICP/MS
Prep Complete			N/A

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Ultra Trace Analysis			
2,3,7,8-Tetra CDD	HR-151-5400	EPA 1613	HRMS

2,3,7,8-Tetra CDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,7,8-Penta CDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,7,8-Penta CDD	HR-151-5400	EPA 1613	HRMS
1,2,3,4,7,8-Hexa CDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,7,8-Hexa CDD	HR-151-5400	EPA 1613	HRMS
1,2,3,6,7,8-Hexa CDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,6,7,8-Hexa CDD	HR-151-5400	EPA 1613	HRMS
1,2,3,7,8,9-Hexa CDD	HR-151-5400	EPA 1613	HRMS
1,2,3,7,8,9-Hexa CDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,6,7,8-Hepta CDD	HR-151-5400	EPA 1613	HRMS
1,2,3,4,6,7,8-Hepta CDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Octa CDD	HR-151-5400	EPA 1613	HRMS
Octa CDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
2,3,7,8-Tetra CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
2,3,7,8-Tetra CDF	HR-151-5400	EPA 1613	HRMS
1,2,3,7,8-Penta CDF	HR-151-5400	EPA 1613	HRMS
1,2,3,7,8-Penta CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
2,3,4,7,8-Penta CDF	HR-151-5400	EPA 1613	HRMS
2,3,4,7,8-Penta CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,7,8-Hexa CDF	HR-151-5400	EPA 1613	HRMS
1,2,3,4,7,8-Hexa CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,6,7,8-Hexa CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,6,7,8-Hexa CDF	HR-151-5400	EPA 1613	HRMS
2,3,4,6,7,8-Hexa CDF	HR-151-5400	EPA 1613	HRMS
2,3,4,6,7,8-Hexa CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,7,8,9-Hexa CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,7,8,9-Hexa CDF	HR-151-5400	EPA 1613	HRMS
1,2,3,4,6,7,8-Hepta CDF	HR-151-5400	EPA 1613	HRMS
1,2,3,4,6,7,8-Hepta CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,7,8,9-Hepta CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,7,8,9-Hepta CDF	HR-151-5400	EPA 1613	HRMS
Octa CDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Octa CDF	HR-151-5400	EPA 1613	HRMS
Total Tetrachlorodibenzodioxins	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total Tetrachlorodibenzodioxins	HR-151-5400	EPA 1613	HRMS
Total Pentachlorodibenzodioxins	HR-151-5400	EPA 1613	HRMS
Total Pentachlorodibenzodioxins	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total Hexachlorodibenzodioxins	HR-151-5400	EPA 1613	HRMS
Total Hexachlorodibenzodioxins	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total Heptachlorodibenzodioxins	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total Heptachlorodibenzodioxins	HR-151-5400	EPA 1613	HRMS
Total PCDDs	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total PCDDs	HR-151-5400	EPA 1613	HRMS
Total Tetrachlorodibenzofurans	HR-151-5400	EPA 1613	HRMS

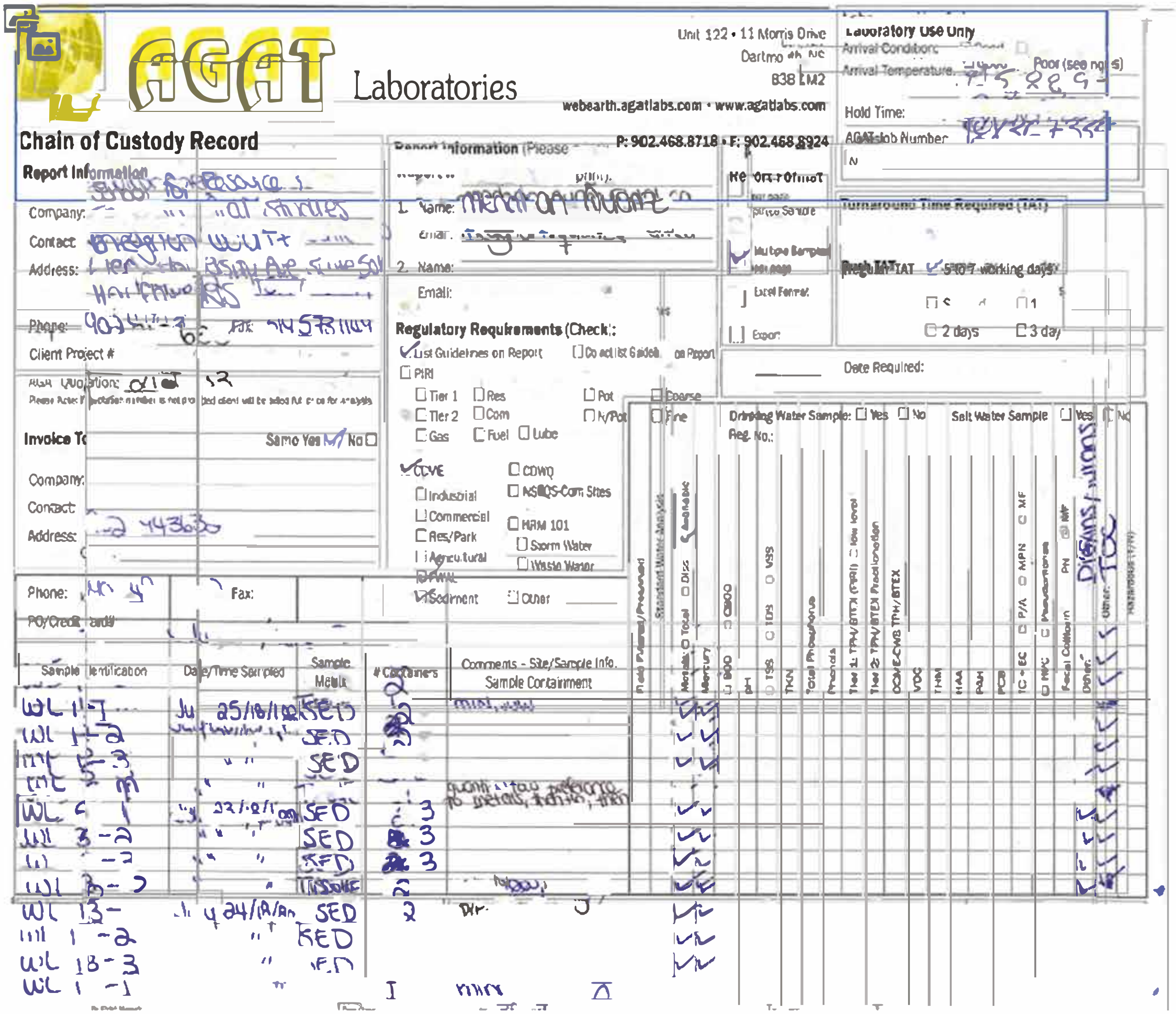
PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Total Tetrachlorodibenzofurans	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total Pentachlorodibenzofurans	HR-151-5400	EPA 1613	HRMS
Total Pentachlorodibenzofurans	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total Hexachlorodibenzofurans	HR-151-5400	EPA 1613	HRMS
Total Hexachlorodibenzofurans	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total Heptachlorodibenzofurans	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Total Heptachlorodibenzofurans	HR-151-5400	EPA 1613	HRMS
Total PCDFs	HR-151-5400	EPA 1613	HRMS
Total PCDFs	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
2,3,7,8-Tetra CDD (TEF 1.0)	HR-151-5400	EPA 1613	HRMS
2,3,7,8-Tetra CDD (TEF 1.0)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,7,8-Penta CDD (TEF 1.0)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,7,8-Penta CDD (TEF 1.0)	HR-151-5400	EPA 1613	HRMS
1,2,3,4,7,8-Hexa CDD (TEF 0.1)	HR-151-5400	EPA 1613	HRMS
1,2,3,4,7,8-Hexa CDD (TEF 0.1)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,6,7,8-Hexa CDD (TEF 0.1)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,6,7,8-Hexa CDD (TEF 0.1)	HR-151-5400	EPA 1613	HRMS
1,2,3,7,8,9-Hexa CDD (TEF 0.1)	HR-151-5400	EPA 1613	HRMS
1,2,3,7,8,9-Hexa CDD (TEF 0.1)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,6,7,8-Hepta CDD (TEF 0.01)	HR-151-5400	EPA 1613	HRMS
1,2,3,4,6,7,8-Hepta CDD (TEF 0.01)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Octa CDD (TEF 0.0003)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Octa CDD (TEF 0.0003)	HR-151-5400	EPA 1613	HRMS
2,3,7,8-Tetra CDF (TEF 0.1)	HR-151-5400	EPA 1613	HRMS
2,3,7,8-Tetra CDF (TEF 0.1)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,7,8-Penta CDF (TEF 0.03)	HR-151-5400	EPA 1613	HRMS
1,2,3,7,8-Penta CDF (TEF 0.03)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
2,3,4,7,8-Penta CDF (TEF 0.3)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
2,3,4,7,8-Penta CDF (TEF 0.3)	HR-151-5400	EPA 1613	HRMS
1,2,3,4,7,8-Hexa CDF (TEF 0.1)	HR_151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,7,8-Hexa CDF (TEF 0.1)	HR_151-5400	EPA 1613	HRMS
1,2,3,6,7,8-Hexa CDF (TEF 0.1)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,6,7,8-Hexa CDF (TEF 0.1)	HR-151-5400	EPA 1613	HRMS
2,3,4,6,7,8-Hexa CDF (TEF 0.1)	HR-151-5400	EPA 1613	HRMS
2,3,4,6,7,8-Hexa CDF (TEF 0.1)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,7,8,9-Hexa CDF (TEF 0.1)	HR-151-5400	EPA 1613	HRMS
1,2,3,7,8,9-Hexa CDF (TEF 0.1)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,6,7,8-Hepta CDF (TEF 0.01)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
1,2,3,4,6,7,8-Hepta CDF (TEF 0.01)	HR-151-5400	EPA 1613	HRMS
1,2,3,4,7,8,9-Hepta CDF (TEF 0.01)	HR-151-5400	EPA 1613	HRMS
1,2,3,4,7,8,9-Hepta CDF (TEF 0.01)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Octa CDF (TEF 0.0003)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
Octa CDF (TEF 0.0003)	HR-151-5400	EPA 1613	HRMS
Total PCDDs and PCDFs (TEQ)	HR-151-5400	EPA 1613	HRMS
Total PCDDs and PCDFs (TEQ)	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-2378-TCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-2378-TCDF	HR-151-5400	EPA 1613	HRMS

13C-12378-PeCDF	HR-151-5400	EPA 1613	HRMS
13C-12378-PeCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-23478-PeCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-23478-PeCDF	HR-151-5400	EPA 1613	HRMS
13C-123478-HxCDF	HR-151-5400	EPA 1613	HRMS
13C-123478-HxCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-123678-HxCDF	HR-151-5400	EPA 1613	HRMS

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
13C-123678-HxCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-234678-HxCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-234678-HxCDF	HR-151-5400	EPA 1613	HRMS
13C-123789-HxCDF	HR-151-5400	EPA 1613	HRMS
13C-123789-HxCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-1234678-HpCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-1234678-HpCDF	HR-151-5400	EPA 1613	HRMS
13C-1234789-HpCDF	HR-151-5400	EPA 1613	HRMS
13C-1234789-HpCDF	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-2378-TCDD	HR-151-5400	EPA 1613	HRMS
13C-2378-TCDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-12378-PeCDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-12378-PeCDD	HR-151-5400	EPA 1613	HRMS
13C-123478-HxCDD	HR-151-5400	EPA 1613	HRMS
13C-123478-HxCDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-123678-HxCDD	HR-151-5400	EPA 1613	HRMS
13C-123678-HxCDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-1234678-HpCDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS
13C-1234678-HpCDD	HR-151-5400	EPA 1613	HRMS
13C-OCDD	HR-151-5400	EPA 1613	HRMS
13C-OCDD	HR-151-5400	CEAEQ MA.400 - DF 1.0	HRMS

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Water Analysis			
Total Mercury	MET-121-6100 & MET-121-6107	SM 3112 B	CV/AA
Total Aluminum	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Antimony	MET121-6104 & MET-121-6105	SM 3125	ICP-MS
Total Arsenic	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Barium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Beryllium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Bismuth	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Boron	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Cadmium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS

Total Chromium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Cobalt	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Copper	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Iron	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Lead	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Manganese	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Molybdenum	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Nickel	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Selenium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Silver	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Strontium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Thallium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Tin	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Titanium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Uranium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Vanadium	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS
Total Zinc	MET121-6104 & MET-121-6105	modified from SM 3125/SM 3030 B/SM 3030 D	ICP-MS



AGAT Laboratories

Unit 122 • 11 Morris Drive
Dartmouth, NS
B3B 1M2
webearth.agatlabs.com • www.agatlabs.com
P: 902.468.8718 • F: 902.468.8924

Chain of Custody Record

Laboratory Use Only
Arrival Condition: ☐ Good ☐ Poor (see notes)
Arrival Temperature: 7.5 8.8 9
Hold Time:
AGAT Job Number: 10X[illegible]7354

Report Information
School for Resource and Environmental Studies
Company: [illegible]
Contact: [illegible]
Address: [illegible] Ave, Suite 501
Halifax NS
Phone: 902 [illegible] Fax: 494 578 1164
Client Project #
AGAT Quotation: [illegible]
Please note: if quotation number is not provided client will be billed full price for analysis.

Report Information (Please print):
1. Name: [illegible]
Email: [illegible]
2. Name:
Email:

Report Format
☐ Single Sample per page
☑ Multiple Samples per page
☐ Excel Format
☐ Export

Turnaround Time Required (TAT)
Regular TAT ☑ 5 to 7 working days
Rush TAT ☐ [illegible] ☐ 1 ☐ 2 days ☐ 3 days
Date Required:

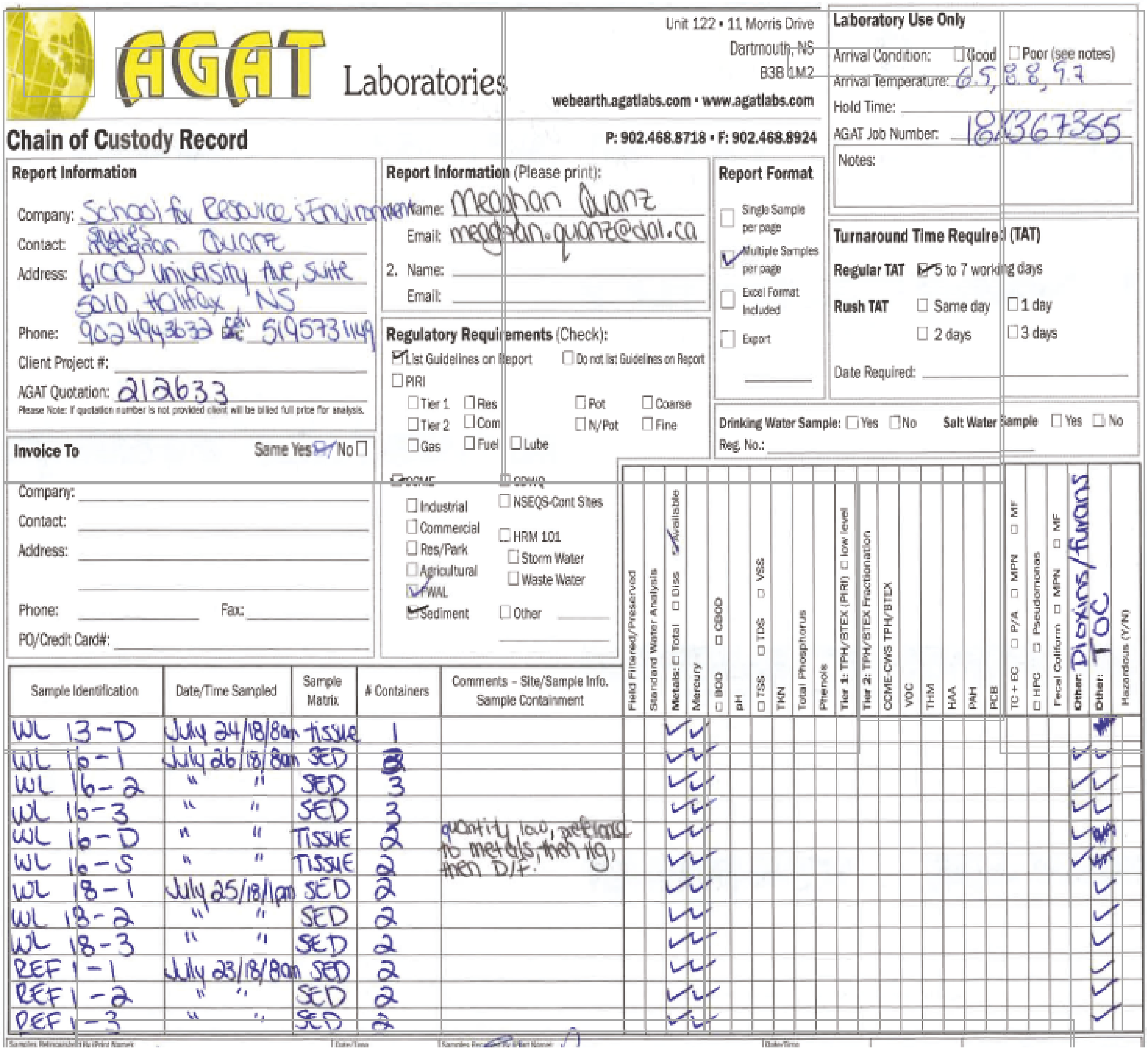
Regulatory Requirements (Check):
☑ List Guidelines on Report ☐ Do not list Guidelines on Report
☐ PIRI
☐ Tier 1 ☐ Res ☐ Pot ☐ Coarse
☐ Tier 2 ☐ Com ☐ N/Pot ☐ Fine
☐ Gas ☐ Fuel ☐ Lube
☑ CCME ☐ CDWQ
☐ Industrial ☐ NSEQS-Con Sites
☐ Commercial ☐ HRM 101
☐ Res/Park ☐ Storm Water
☐ Agricultural ☐ Waste Water
☐ FWAL
☑ Sediment ☐ Other

Invoice To Same Yes ☑ No ☐
Company:
Contact:
Address: [illegible] 443630
Phone: Fax:
PO/Credit Card#

Drinking Water Sample: ☐ Yes ☐ No Reg. No.:
Salt Water Sample ☐ Yes ☐ No

Field Filtered/Preserved; Standard Water Analysis; Metals: ☐ Total ☐ Diss; Mercury; ☐ BOD; ☐ CBOD; pH; ☐ TSS; ☐ TDS; ☐ VSS; TKN; Total Phosphorus; Phenols; Tier 1: TPH/BTEX (PIRI) ☐ low level; Tier 2: TPH/BTEX Fractionation; CCME-CWS TPH/BTEX; VOC; THM; HAA; PAH; PCB; IC + EC; ☐ P/A ☐ MPN ☐ MF; ☐ HPC; Pseudomonas; Fecal Coliform; PN; Other: Dioxins/Furans TOC; Other; Hazardous

Sample Identification	Date/Time Sampled	Sample Matrix	# Containers	Comments - Site/Sample Info. Sample Containment	Metals	Mercury	Other
WL 1-1	Jul 25/10	SED	2	[illegible]	✓	✓	✓
WL 1-2	"	SED	2		✓	✓	✓
WL 5-3	" "	SED			✓	✓	✓
WL 5	"			quantities preference to metals, [illegible]			✓
WL 6-1	Jul 23/10	SED	3		✓	✓	✓ ✓
WL 3-2	" "	SED	3		✓	✓	✓ ✓
WL -2	" "	SED	3		✓	✓	✓ ✓
WL 3-2	"	TISSUE	2	[illegible]	✓	✓	✓ ✓
WL 13-	Jul 24/10	SED	2	[illegible]	✓	✓	
WL 1-2	"	SED			✓	✓	
WL 18-3	"	SED			✓	✓	
WL 1-1	"						



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Dartmouth, NS
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P: 902.468.8718 • F: 902.468.8924

Chain of Custody Record

Laboratory Use Only

Arrival Condition: ☐ Good ☐ Poor (see notes)
Arrival Temperature: 6.5, 8.8, 9.7
Hold Time:
AGAT Job Number: 18X367355
Notes:

Report Information

Company: School for Resource & Environment
Contact: Shayes Meaghan Quanz
Address: 6100 University Ave, Suite 5010, Halifax, NS
Phone: 9024943632 cell: 5195731149
Client Project #:
AGAT Quotation: 212633
Please Note: If quotation number is not provided client will be billed full price for analysis.

Report Information (Please print):

1. Name: Meaghan Quanz
Email: meaghan.quanz@dal.ca
2. Name:
Email:

Report Format

☐ Single Sample per page
☑ Multiple Samples per page
☐ Excel Format Included
☐ Export

Turnaround Time Required (TAT)

Regular TAT ☑ 5 to 7 working days
Rush TAT ☐ Same day ☐ 1 day ☐ 2 days ☐ 3 days
Date Required:

Regulatory Requirements (Check):

☑ List Guidelines on Report ☐ Do not list Guidelines on Report
☐ PIRI
☐ Tier 1 ☐ Tier 2 ☐ Gas ☐ Res ☐ Com ☐ Fuel ☐ Lube ☐ Pot ☐ N/Pot ☐ Coarse ☐ Fine
☑ CCME
☐ Industrial ☐ Commercial ☐ Res/Park ☐ Agricultural ☑ FWAL ☑ Sediment
☐ CDWQ
☐ NSEQS-Cont Sites
☐ HRM 101
☐ Storm Water ☐ Waste Water
☐ Other

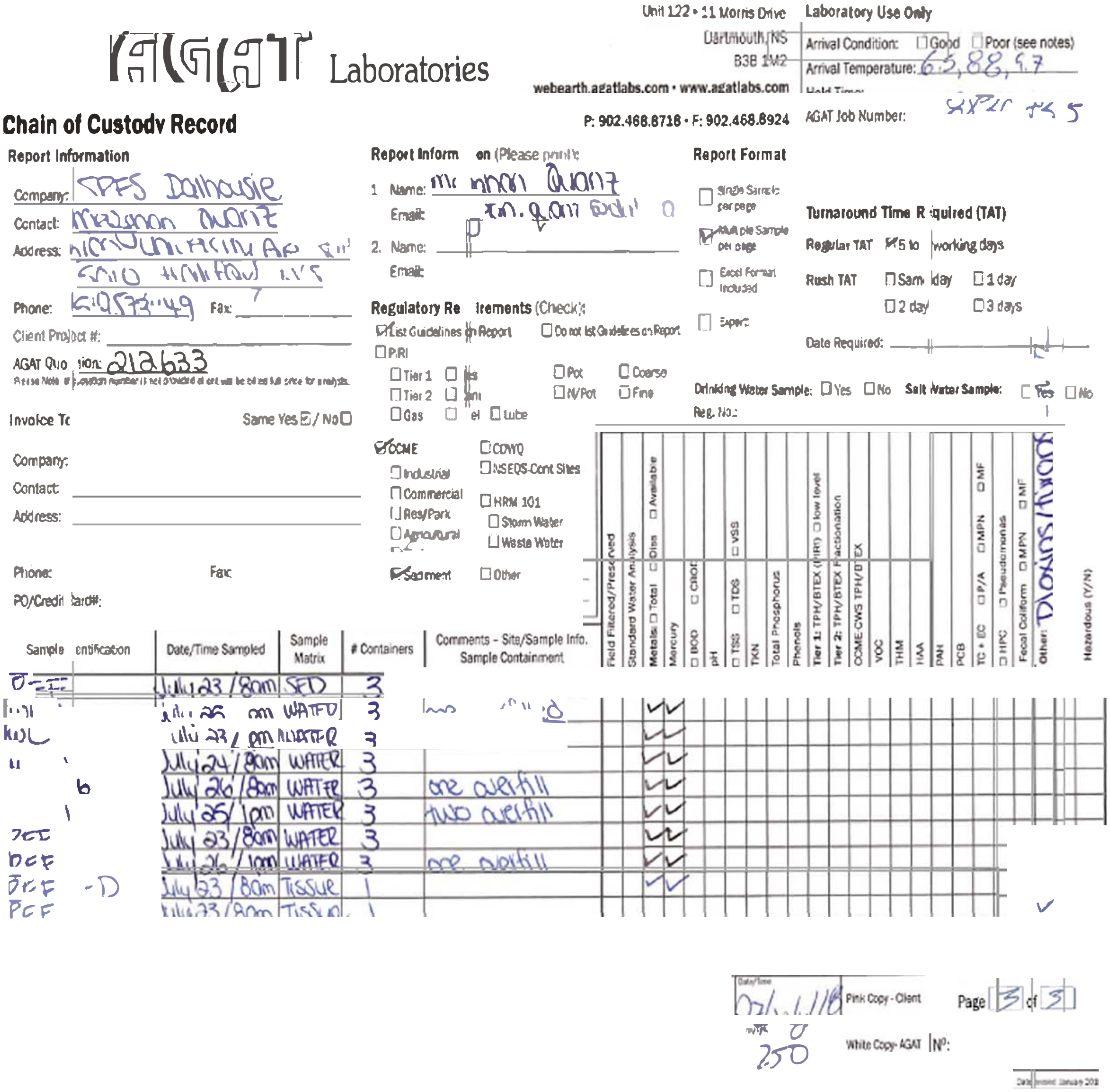
Drinking Water Sample: ☐ Yes ☐ No **Salt Water Sample** ☐ Yes ☐ No
Reg. No.:

Invoice To Same Yes ☑ No ☐

Company:
Contact:
Address:
Phone: Fax:
PO/Credit Card#:

Sample Identification	Date/Time Sampled	Sample Matrix	# Containers	Comments - Site/Sample Info. Sample Containment	Field Filtered/Preserved	Standard Water Analysis	Metals: ☐ Total ☐ Diss ☑ Available	Mercury	☐ BOD ☐ CBOD	pH	☐ TSS ☐ TDS ☐ VSS	TKN	Total Phosphorus	Phenols	Tier 1: TPH/BTEX (PIRI) ☐ low level	Tier 2: TPH/BTEX Fractionation	CCME-CWS TPH/BTEX	VOC	THM	HAA	PAH	PCB	TC + EC ☐ P/A ☐ MPN ☐ MF	☐ HPC ☐ Pseudomonas	Fecal Coliform ☐ MPN ☐ MF	Other: Dioxins/Furans	Other: TOC	Hazardous (Y/N)
WL 13-D	July 24/18/8am	tissue	1				✓	✓																				
WL 16-1	July 26/18/8am	SED	2				✓	✓																		✓	✓	
WL 16-2	" "	SED	3				✓	✓																		✓	✓	
WL 16-3	" "	SED	3				✓	✓																		✓	✓	
WL 16-D	" "	TISSUE	2	quantity low, preference to metals, then Hg, then D/F.			✓	✓																		✓		
WL 16-S	" "	TISSUE	2				✓	✓																		✓		
WL 18-1	July 25/18/1pm	SED	2				✓	✓																			✓	
WL 18-2	" "	SED	2				✓	✓																			✓	
WL 18-3	" "	SED	2				✓	✓																			✓	
REF 1-1	July 23/18/8am	SED	2				✓	✓																			✓	
REF 1-2	" "	SED	2				✓	✓																			✓	
REF 1-3	" "	SED	2				✓	✓																			✓	

Samples Relinquished By (Print Name): Date/Time Samples Received By (Print Name): Date/Time



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B3B 1M2
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P: 902.468.8718 • F: 902.468.8924

Laboratory Use Only
Arrival Condition: ☐ Good ☐ Poor (see notes)
Arrival Temperature: 6.5, 8.8, 9.7
Hold Time:
AGAT Job Number: 8X726 745

Chain of Custody Record

Report Information

Company: SPES Dalhousie
Contact: Meaghan Quanz
Address: 1360 Barrington St
Halifax NS
Phone: 6:9573449 Fax:
Client Project #:
AGAT Quotation: 212633
Please Note: If quotation number is not provided client will be billed full price for analysis.

Invoice To Same Yes ☑ / No ☐

Company:
Contact:
Address:
Phone: Fax:
PO/Credit Card#:

Report Information (Please print)

1. Name: Meaghan Quanz
Email: m.quanz@dal.ca
2. Name:
Email:

Regulatory Requirements (Check):
☑ List Guidelines on Report ☐ Do not list Guidelines on Report
☐ PIRI
☐ Tier 1 ☐ Res ☐ Pot ☐ Coarse
☐ Tier 2 ☐ Com ☐ N/Pot ☐ Fine
☐ Gas ☐ Fuel ☐ Lube
☑ CCME ☐ CDWQ
☐ Industrial ☐ NSEQS-Cont Sites
☐ Commercial ☐ HRM 101
☐ Res/Park ☐ Storm Water
☐ Agricultural ☐ Waste Water
☑ Sediment ☐ Other

Report Format
☐ Single Sample per page
☑ Multiple Sample per page
☐ Excel Format Included
☐ Export

Turnaround Time Required (TAT)
Regular TAT ☑ 5 to 7 working days
Rush TAT ☐ Same day ☐ 1 day
☐ 2 day ☐ 3 days
Date Required:

Drinking Water Sample: ☐ Yes ☐ No Salt Water Sample: ☑ Yes ☐ No
Reg. No.:

Sample Identification	Date/Time Sampled	Sample Matrix	# Containers	Comments - Site/Sample Info. Sample Containment	Field Filtered/Preserved	Standard Water Analysis	Metals: ☐ Total ☐ Diss ☐ Available	Mercury	☐ BOD ☐ CBOD	pH	☐ TSS ☐ TDS ☐ VSS	TKN	Total Phosphorus	Phenols	Tier 1: TPH/BTEX (PIRI) ☐ low level	Tier 2: TPH/BTEX Fractionation	CCME-CWS TPH/BTEX	VOC	THM	HAA	PAH	PCB	TC + EC ☐ P/A ☐ MPN ☐ MF	☐ HPC ☐ Pseudomonas ☐ MPN ☐ MF	Fecal Coliform	Other: Dioxins/Furans	Hazardous (Y/N)
0-I	July 23/8am	SED	3																								
	July 26 am	WATER	3				✓	✓																			
	July 23/ am	WATER	3				✓	✓																			
	July 24/8am	WATER	3				✓	✓																			
6	July 26/8am	WATER	3	one overfill			✓	✓																			
	July 25/1pm	WATER	3	two overfill			✓	✓																			
7CE	July 23/8am	WATER	3				✓	✓																			
DCF	July 26/10am	WATER	3	one overfill			✓	✓																			
DCF -D	July 23/8am	TISSUE	1				✓	✓																			
PCF	July 23/8am	TISSUE	1																							✓	

Date/Time
27/7/18
250

Pink Copy - Client
White Copy - AGAT
Page 3 of 3
Nº:

Appendix D

Bureau Veritas DGT Certificate of Analysis and Chain of Custody

Your C.O.C. #: 08471354

Attention: Tony Walker
DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2

Report Date: 2019/07/17
Report #: R2753511
Version: 1 - Final

CERTIFICATE OF ANALYSIS

BV LABS JOB #: B948830
Received: 2019/06/20, 09:00

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	tical Method
Mercury (Total) by CV		/07/05	2019/07/10	BBY7SOP-00015	BCMOE BCLM Oct2013 m
Elements by ICPMS Digested LL (total)		07/05	2019/07/11	BBY7SOP-00003 / BBY7SOP-00002	EPA 6020b R2 m

Remarks:

Bureau Veritas Laboratories are accredited to ISO/IEC 17025 for specific parameters on scopes of accreditation. Unless otherwise noted, procedures used by BV Labs are based upon recognized Provincial, Federal or US method compendia such as CCME, MDDELCC, EPA, APHA.

All work recorded herein has been done in accordance with procedures and practices ordinarily exercised by professionals in BV Labs profession using accepted testing methodologies, quality assurance and quality control procedures (except where otherwise agreed by the client and BV Labs in writing). All data is in statistical control and has met quality control and method performance criteria unless otherwise noted. All method blanks are reported; unless indicated otherwise, associated sample data are not blank corrected. Where applicable, unless otherwise noted, Measurement Uncertainty has not been accounted for when stating conformity to the referenced standard.

BV Labs liability is limited to the actual cost of the requested analyses, unless otherwise agreed in writing. There is no other warranty expressed or implied. BV Labs has been retained to provide analysis of samples provided by the Client using the testing methodology referenced in this report. Interpretation and use of test results are the sole responsibility of the Client and are not within the scope of services provided by BV Labs, unless otherwise agreed in writing. BV Labs is not responsible for the accuracy or any data impacts, that result from the information provided by the customer or their agent.

Solid sample results, except biota, are based on dry weight unless otherwise indicated. Organic analyses are not recovery corrected except for isotope dilution methods.

Your C.O.C. #: 08471354

Attention: Tony Walker

DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2

Report Date: 2019/07/17
Report #: R2753511
Version: 1 - Final

CERTIFICATE OF ANALYSIS

BV LABS JOB #: B948830

Received: 2019/06/20, 09:00

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager. Nahed Amer, Project Manager
Email: Nahed.AMER@bvlabs.com
Phone# (604) 734 7276
===

BV Labs has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per ISO/IEC 17025, signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

Total Cover Pages : 2

MERCURY BY COLD VAPOR (WATER)

BV Labs ID		VY0296	VY0297	VY0298	VY0299	VY0300	VY0301	VY0302		
Sampling Date		2019/06/18 09:35	2019/06/18 09:42	2019/06/18 09:50	2019/06/18 09:52	2019/06/18 09:59	2019/06/18 10:07	2019/06/18 10:15		
COC Number		08471354	08471354	08471354	08471354	08471354	08471354	08471354		
	UNITS	**BHHG-1**	**BHHG-2**	**BHHG-3**	**BHHG-4**	**BHHG-5**	**BHHG-6**	**BHHG-7**	**RDL**	**QC Batch**
Elements										
Total Mercury (Hg)	ug/L	<0.020	<0.020	<0.020	0.030	<0.020	<0.020	<0.020	0.020	9494808
RDL = Reportable Detection Limit										

BV Labs ID		VY0303	VY0304	VY0305		
Sampling Date		2019/06/18 10:21	2019/06/18 10:22	2019/06/18 10:36		
COC Number		08471354	08471354	08471354		
	UNITS	**BHHG-8**	**BHHG-9**	**BHHG-10**	**RDL**	**QC Batch**
Elements						
Total Mercury (Hg)	ug/L	0.030	0.025	<0.020	0.020	9494808
RDL = Reportable Detection Limit						

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

BV Labs ID		VY0286	VY0287	VY0288	VY0289	VY0290	VY0291	VY0292		
Sampling Date		2019/06/18 09:35	2019/06/18 09:42	2019/06/18 09:50	2019/06/18 09:52	2019/06/18 09:59	2019/06/18 10:07	2019/06/18 10:15		
COC Number		08471354	08471354	08471354	08471354	08471354	08471354	08471354		
	UNITS	**BHM-1**	**BHM-2**	**BHM-3**	**BHM-4**	**BHM-5**	**BHM-6**	**BHM-7**	**RDL**	**QC Batch**
Total Metals by ICPMS										
Total Aluminum (Al)	ug/L	351	576	528	263	610	568	661	30	9494801
Total Antimony (Sb)	ug/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	9494801
Total Arsenic (As)	ug/L	1.07	1.60	1.31	1.39	1.35	1.16	1.56	0.20	9494801
Total Barium (Ba)	ug/L	658	1180	711	732	788	602	874	0.50	9494801
Total Beryllium (Be)	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	9494801
Total Bismuth (Bi)	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	9494801
Total Boron (B)	ug/L	<100	<100	<100	<100	<100	<100	<100	100	9494801
Total Cadmium (Cd)	ug/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.050	9494801
Total Chromium (Cr)	ug/L	1.4	1.4	1.3	2.0	1.4	1.3	1.2	1.0	9494801
Total Cobalt (Co)	ug/L	0.18	0.27	0.18	0.46	0.31	0.18	0.20	0.10	9494801
Total Copper (Cu)	ug/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	9494801
Total Iron (Fe)	ug/L	60	<50	194	96	505	480	458	50	9494801
Total Lead (Pb)	ug/L	0.81	1.05	0.94	1.22	1.11	1.15	1.49	0.20	9494801
Total Lithium (Li)	ug/L	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	9494801
Total Manganese (Mn)	ug/L	10100	10300	8540	12700	9610	6320	9770	1.0	9494801
Total Molybdenum (Mo)	ug/L	<0.50	<0.50	<0.50	<0.50	<0.50	0.77	1.00	0.50	9494801
Total Nickel (Ni)	ug/L	2.7	2.5	<1.0	2.3	1.0	1.0	1.4	1.0	9494801
Total Phosphorus (P)	ug/L	1820	2190	1360	2250	821	668	761	50	9494801
Total Selenium (Se)	ug/L	0.57	<0.40	<0.40	0.99	<0.40	<0.40	<0.40	0.40	9494801
Total Silicon (Si)	ug/L	<500	909	<500	670	<500	<500	<500	500	9494801
Total Silver (Ag)	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	9494801
Total Strontium (Sr)	ug/L	49.5	131	45.4	55.7	44.2	29.0	45.7	0.50	9494801
Total Thallium (Tl)	ug/L	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.027	0.020	9494801
Total Tin (Sn)	ug/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.0	9494801
Total Titanium (Ti)	ug/L	386	524	433	590	307	286	417	20	9494801
Total Uranium (U)	ug/L	0.102	0.214	0.290	0.087	0.751	0.621	0.766	0.050	9494801
Total Vanadium (V)	ug/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.0	9494801
Total Zinc (Zn)	ug/L	<10	<10	<10	<10	20	19	25	10	9494801
Total Zirconium (Zr)	ug/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	9494801
Total Sulphur (S)	ug/L	<6000	<6000	<6000	<6000	<6000	<6000	<6000	6000	9494801

RDL = Reportable Detection Limit

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

BV Labs ID		VY0293	VY0294	VY0295		
Sampling Date		2019/06/18 10:21	2019/06/18 10:22	2019/06/18 10:36		
COC Number		08471354	08471354	08471354		
	UNITS	BHM-8	BHM-9	BHM-10	RDL	QC Batch
Total Metals by ICPMS						
Total Aluminum (Al)	ug/L	523	402	389	30	9494801
Total Antimony (Sb)	ug/L	<0.20	<0.20	<0.20	0.20	9494801
Total Arsenic (As)	ug/L	1.41	1.33	1.48	0.20	9494801
Total Barium (Ba)	ug/L	846	894	378	0.50	9494801
Total Beryllium (Be)	ug/L	<0.10	<0.10	<0.10	0.10	9494801
Total Bismuth (Bi)	ug/L	<0.10	<0.10	<0.10	0.10	9494801
Total Boron (B)	ug/L	<100	<100	<100	100	9494801
Total Cadmium (Cd)	ug/L	<0.050	<0.050	<0.050	0.050	9494801
Total Chromium (Cr)	ug/L	1.7	1.4	1.3	1.0	9494801
Total Cobalt (Co)	ug/L	0.39	0.20	0.32	0.10	9494801
Total Copper (Cu)	ug/L	1.3	<1.0	<1.0	1.0	9494801
Total Iron (Fe)	ug/L	<50	<50	<50	50	9494801
Total Lead (Pb)	ug/L	0.93	1.07	1.65	0.20	9494801
Total Lithium (Li)	ug/L	<5.0	<5.0	<5.0	5.0	9494801
Total Manganese (Mn)	ug/L	10500	9080	2450	1.0	9494801
Total Molybdenum (Mo)	ug/L	<0.50	0.54	1.63	0.50	9494801
Total Nickel (Ni)	ug/L	2.1	1.4	1.7	1.0	9494801
Total Phosphorus (P)	ug/L	1780	1600	875	50	9494801
Total Selenium (Se)	ug/L	<0.40	0.57	<0.40	0.40	9494801
Total Silicon (Si)	ug/L	797	610	1440	500	9494801
Total Silver (Ag)	ug/L	<0.10	<0.10	<0.10	0.10	9494801
Total Strontium (Sr)	ug/L	85.6	122	169	0.50	9494801
Total Thallium (Tl)	ug/L	<0.020	<0.020	<0.020	0.020	9494801
Total Tin (Sn)	ug/L	<2.0	<2.0	<2.0	2.0	9494801
Total Titanium (Ti)	ug/L	459	461	548	20	9494801
Total Uranium (U)	ug/L	0.196	0.325	0.174	0.050	9494801
Total Vanadium (V)	ug/L	<2.0	<2.0	<2.0	2.0	9494801
Total Zinc (Zn)	ug/L	<10	<10	20	10	9494801
Total Zirconium (Zr)	ug/L	<1.0	<1.0	<1.0	1.0	9494801
Total Sulphur (S)	ug/L	<6000	<6000	<6000	6000	9494801
RDL = Reportable Detection Limit						

GENERAL COMMENTS

Each temperature is the average of up to three cooler temperatures taken at receipt

Package 1	13.7°C
Package 2	8.3°C

Results relate only to the items tested.

QUALITY ASSURANCE REPORT

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
9494801	VCN	Spiked Blank	Total Aluminum (Al)	2019/07/11		102	%	80 - 120
			Total Antimony (Sb)	2019/07/11		95	%	80 - 120
			Total Arsenic (As)	2019/07/11		100	%	80 - 120
			Total Barium (Ba)	2019/07/11		98	%	80 - 120
			Total Beryllium (Be)	2019/07/11		89	%	80 - 120
			Total Bismuth (Bi)	2019/07/11		80	%	80 - 120
			Total Boron (B)	2019/07/11		102	%	80 - 120
			Total Cadmium (Cd)	2019/07/11		93	%	80 - 120
			Total Chromium (Cr)	2019/07/11		91	%	80 - 120
			Total Cobalt (Co)	2019/07/11		87	%	80 - 120
			Total Copper (Cu)	2019/07/11		84	%	80 - 120
			Total Iron (Fe)	2019/07/11		103	%	80 - 120
			Total Lead (Pb)	2019/07/11		92	%	80 - 120
			Total Lithium (Li)	2019/07/11		88	%	80 - 120
			Total Manganese (Mn)	2019/07/11		91	%	80 - 120
			Total Molybdenum (Mo)	2019/07/11		102	%	80 - 120
			Total Nickel (Ni)	2019/07/11		90	%	80 - 120
			Total Selenium (Se)	2019/07/11		100	%	80 - 120
			Total Silver (Ag)	2019/07/11		89	%	80 - 120
			Total Strontium (Sr)	2019/07/11		103	%	80 - 120
			Total Thallium (Tl)	2019/07/11		90	%	80 - 120
			Total Tin (Sn)	2019/07/11		94	%	80 - 120
			Total Titanium (Ti)	2019/07/11		98	%	80 - 120
			Total Uranium (U)	2019/07/11		94	%	80 - 120
			Total Vanadium (V)	2019/07/11		89	%	80 - 120
			Total Zinc (Zn)	2019/07/11		91	%	80 - 120
			Total Zirconium (Zr)	2019/07/11		70 (1)	%	80 - 120
9494801	VCN	RPD	Total Aluminum (Al)	2019/07/11	7.8		%	20
			Total Antimony (Sb)	2019/07/11	96 (1)		%	20
			Total Arsenic (As)	2019/07/11	28 (1)		%	20
			Total Barium (Ba)	2019/07/11	0.62		%	20
			Total Beryllium (Be)	2019/07/11	2.7		%	20
			Total Bismuth (Bi)	2019/07/11	51 (1)		%	20
			Total Boron (B)	2019/07/11	6.0		%	20
			Total Cadmium (Cd)	2019/07/11	1.1		%	20
			Total Chromium (Cr)	2019/07/11	13		%	20
			Total Cobalt (Co)	2019/07/11	6.5		%	20
			Total Copper (Cu)	2019/07/11	11		%	20
			Total Iron (Fe)	2019/07/11	26 (1)		%	20

			Total Lead (Pb)	2019/07/11	4.4		%	20
			Total Lithium (Li)	2019/07/11	4.5		%	20
			Total Manganese (Mn)	2019/07/11	8.6		%	20
			Total Molybdenum (Mo)	2019/07/11	19		%	20
			Total Nickel (Ni)	2019/07/11	5.1		%	20
			Total Selenium (Se)	2019/07/11	27 (1)		%	20
			Total Silver (Ag)	2019/07/11	7.1		%	20
			Total Strontium (Sr)	2019/07/11	10		%	20
			Total Thallium (Tl)	2019/07/11	16		%	20
			Total Tin (Sn)	2019/07/11	25 (1)		%	20
			Total Titanium (Ti)	2019/07/11	21 (1)		%	20
			Total Uranium (U)	2019/07/11	29 (1)		%	20
			Total Vanadium (V)	2019/07/11	12		%	20
			Total Zinc (Zn)	2019/07/11	3.9		%	20
			Total Zirconium (Zr)	2019/07/11	28 (1)		%	20
			Total Aluminum (Al)	2019/07/11	NC		%	20

QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
			Total Antimony (Sb)	2019/07/11	NC		%	20
			Total Arsenic (As)	2019/07/11	144 (1)		%	20
			Total Barium (Ba)	2019/07/11	74 (1)		%	20
			Total Beryllium (Be)	2019/07/11	NC		%	20
			Total Bismuth (Bi)	2019/07/11	NC		%	20
			Total Boron (B)	2019/07/11	NC		%	20
			Total Cadmium (Cd)	2019/07/11	NC		%	20
			Total Chromium (Cr)	2019/07/11	NC		%	20
			Total Cobalt (Co)	2019/07/11	NC		%	20
			Total Copper (Cu)	2019/07/11	NC		%	20
			Total Iron (Fe)	2019/07/11	NC		%	20
			Total Lead (Pb)	2019/07/11	147 (1)		%	20
			Total Lithium (Li)	2019/07/11	NC		%	20
			Total Manganese (Mn)	2019/07/11	NC		%	20
			Total Molybdenum (Mo)	2019/07/11	NC		%	20
			Total Nickel (Ni)	2019/07/11	NC		%	20
			Total Phosphorus (P)	2019/07/11	NC		%	20
			Total Selenium (Se)	2019/07/11	NC		%	20
			Total Silicon (Si)	2019/07/11	NC		%	20
			Total Silver (Ag)	2019/07/11	NC		%	20
			Total Strontium (Sr)	2019/07/11	157 (1)		%	20
			Total Thallium (Tl)	2019/07/11	NC		%	20
			Total Tin (Sn)	2019/07/11	NC		%	20

			Total Titanium (Ti)	2019/07/11	180 (1)		%	20
			Total Uranium (U)	2019/07/11	NC		%	20
			Total Vanadium (V)	2019/07/11	NC		%	20
			Total Zinc (Zn)	2019/07/11	NC		%	20
			Total Zirconium (Zr)	2019/07/11	NC		%	20
			Total Sulphur (S)	2019/07/11	NC		%	20
9494801	VCN	Method Blank	Total Aluminum (Al)	2019/07/16	<30		ug/L	
			Total Antimony (Sb)	2019/07/16	<0.20		ug/L	
			Total Arsenic (As)	2019/07/16	<0.20		ug/L	
			Total Barium (Ba)	2019/07/16	0.95, RDL=0.50 (2)		ug/L	
			Total Beryllium (Be)	2019/07/16	<0.10		ug/L	
			Total Bismuth (Bi)	2019/07/16	<0.10		ug/L	
			Total Boron (B)	2019/07/16	<100		ug/L	
			Total Cadmium (Cd)	2019/07/16	<0.050		ug/L	
			Total Chromium (Cr)	2019/07/16	<1.0		ug/L	
			Total Cobalt (Co)	2019/07/16	<0.10		ug/L	
			Total Copper (Cu)	2019/07/16	<1.0		ug/L	
			Total Iron (Fe)	2019/07/16	<50		ug/L	
			Total Lead (Pb)	2019/07/16	<0.20		ug/L	
			Total Lithium (Li)	2019/07/16	<5.0		ug/L	
			Total Manganese (Mn)	2019/07/16	<1.0		ug/L	
			Total Molybdenum (Mo)	2019/07/16	<0.50		ug/L	
			Total Nickel (Ni)	2019/07/16	<1.0		ug/L	
			Total Phosphorus (P)	2019/07/16	<50		ug/L	
			Total Selenium (Se)	2019/07/16	<0.40		ug/L	
			Total Silicon (Si)	2019/07/16	<500		ug/L	
			Total Silver (Ag)	2019/07/16	<0.10		ug/L	
			Total Strontium (Sr)	2019/07/16	0.54, RDL=0.50 (3)		ug/L	
			Total Thallium (Tl)	2019/07/16	<0.020		ug/L	
			Total Tin (Sn)	2019/07/16	<2.0		ug/L	

QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
			Total Titanium (Ti) 2019/07/16 <20 ug/L Total Uranium (U) 2019/07/16 <0.050 ug/L Total Vanadium (V) 2019/07/16 <2.0 ug/L Total Zinc (Zn) 2019/07/16 <10 ug/L Total Zirconium (Zr) 2019/07/16 <1.0 ug/L					
			Total Sulphur (S)	2019/07/16	<6000		ug/L	
9494808 EL2 Spiked Blank Total Mercury (Hg) 2019/07/10 83 % 80 - 120 9494808 EL2 RPD Total Mercury (Hg) 2019/07/10 20 % 20								
			Total Mercury (Hg)	2019/07/10	NC		%	20
9494808	EL2	Method Blank	Total Mercury (Hg)	2019/07/10	<0.020		ug/L	

Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.
Spiked Blank: A blank matrix sample to which a known amount of the analyte, usually from a second source, has been added. Used to evaluate method accuracy. Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.
NC (Duplicate RPD): The duplicate RPD was not calculated. The concentration in the sample and/or duplicate was too low to permit a reliable RPD calculation
(absolute difference <= 2x RDL).

(1) Recovery or RPD for this parameter is outside control limits. The overall quality control for this analysis meets acceptability criteria.

(2) Reagent Blank exceeds acceptance limits for (Barium) - 2X RDL acceptable for low level metals determination.

(3) Reagent Blank exceeds acceptance limits for (Strontium) - 2X RDL acceptable for low level metals determination.

FUNDAMENTAL LABORATORY ACCEPTANCE GUIDELINE

BV Labs Job #: B948830
Date Received: 2019/06/20
Your C.O.C. #: 08471354
BV Labs Project Manager: Nahed Amer
Quote #: B81333

Invoice To:
DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
ATTN: Tony Walker
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2
Client Contact: Tony Walker

No discrepancies noted.

Report Comments

Received Date: 2019/06/20 **Time:** 09:00 **By:** ________

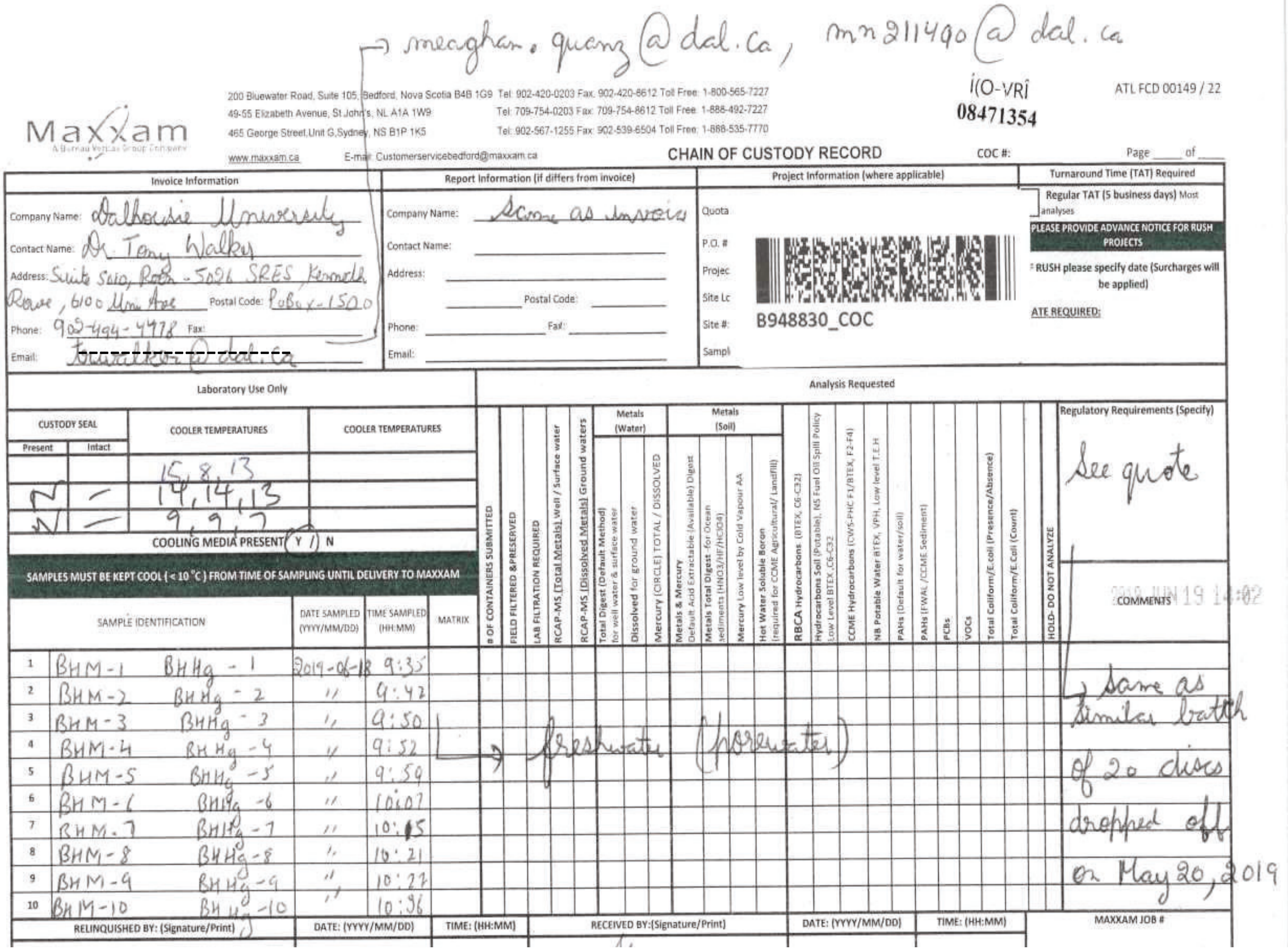
Inspected Date:Time:By: ________ **FLAG** ________ ________

Created Date:Time:By: ________ ________ ________

VALIDATION SIGNATURE PAGE

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Rob Reinert, B.Sc., Scientific Specialist



→ meaghan.quanz@dal.ca, mn211490@dal.ca

Maxxam
A Bureau Veritas Group Company

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i(O-VRÎ
08471354

ATL FCD 00149 / 22

CHAIN OF CUSTODY RECORD

COC #:

Page ____ of ____

Invoice Information

Company Name: Dalhousie University
Contact Name: Dr. Tony Walker
Address: Suite 5010, Room - 5026 SRES, Kenneth Rowe, 6100 Uni Ave Postal Code: PoBox-1500
Phone: 902-494-4978 Fax:
Email: ~~twalker@dal.ca~~

Report Information (if differs from invoice)

Company Name: Same as invoice
Contact Name:
Address:
Postal Code:
Phone: Fax:
Email:

Project Information (where applicable)

Quota
P.O. #
Projec
Site Lc
Site #: B948830_COC
Sampl

Turnaround Time (TAT) Required

Regular TAT (5 business days) Most analyses

PLEASE PROVIDE ADVANCE NOTICE FOR RUSH PROJECTS

RUSH please specify date (Surcharges will be applied)

ATE REQUIRED:

Laboratory Use Only

CUSTODY SEAL		COOLER TEMPERATURES	COOLER TEMPERATURES
Present	Intact		
		15, 8, 13	
N	—	14, 14, 13	
N	—	9, 9, 7	

COOLING MEDIA PRESENT [✓ Y] / N

SAMPLES MUST BE KEPT COOL (< 10 °C) FROM TIME OF SAMPLING UNTIL DELIVERY TO MAXXAM

Analysis Requested

- # OF CONTAINERS SUBMITTED
- FIELD FILTERED &PRESERVED
- LAB FILTRATION REQUIRED
- RCAP-MS (Total Metals) Well / Surface water
- RCAP-MS (Dissolved Metals) Ground waters
- Metals (Water): Total Digest (Default Method) for well water & surface water
- Metals (Water): Dissolved for ground water
- Metals (Water): Mercury (CIRCLE) TOTAL / DISSOLVED
- Metals (Soil): Metals & Mercury Default Acid Extractable (Available) Digest
- Metals (Soil): Metals Total Digest -for Ocean sediments (HNO3/HF/HClO4)
- Metals (Soil): Mercury Low level by Cold Vapour AA
- Metals (Soil): Hot Water Soluble Boron (required for CCME Agricultural/ Landfill)
- RBCA Hydrocarbons (BTEX, C6-C32)
- Hydrocarbons Soil (Potable), NS Fuel Oil Spill Policy Low Level BTEX, C6-C32
- CCME Hydrocarbons (CWS-PHC F1/BTEX, F2-F4)
- NB Potable Water BTEX, VPH, Low level T.E.H
- PAHs (Default for water/soil)
- PAHs (FWAL /CCME Sediment)
- PCBs
- VOCs
- Total Coliform/E.coli (Presence/Absence)
- Total Coliform/E.Coli (Count)
- HOLD- DO NOT ANALYZE

Regulatory Requirements (Specify): See quote

2019 JUN 19 14:02

	SAMPLE IDENTIFICATION		DATE SAMPLED (YYYY/MM/DD)	TIME SAMPLED (HH:MM)	MATRIX
1	BHM-1	BHHg - 1	2019-06-18	9:35	
2	BHM-2	BHHg - 2	"	9:42	
3	BHM-3	BHHg - 3	"	9:50	
4	BHM-4	BHHg - 4	"	9:52	
5	BHM-5	BHHg - 5	"	9:59	
6	BHM-6	BHHg - 6	"	10:07	
7	BHM-7	BHHg - 7	"	10:15	
8	BHM-8	BHHg - 8	"	10:21	
9	BHM-9	BHHg - 9	"	10:27	
10	BHM-10	BHHg - 10	"	10:36	

→ freshwater (porewater)

COMMENTS: → Same as similar batch of 20 discs dropped off on May 20, 2019

RELINQUISHED BY: (Signature/Print)	DATE: (YYYY/MM/DD)	TIME: (HH:MM)	RECEIVED BY:(Signature/Print)	DATE: (YYYY/MM/DD)	TIME: (HH:MM)	MAXXAM JOB #

Your C.O.C. #: 08471354

Attention: Tony Walker
DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2

Report Date: 2019/07/17
Report #: R2753511
Version: 1 - Final

CERTIFICATE OF ANALYSIS

BV LABS JOB #: B948830
Received: 2019/06/20, 09:00

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Analytical Method
Mercury (Total) by CV	10	2019/07/05	2019/07/10	BBY7SOP-00015	BCMOE BCLM Oct2013 m
Elements by ICPMS Digested LL (total)	10	2019/07/05	2019/07/11	BBY7SOP-00003 / BBY7SOP-00002	EPA 6020b R2 m

Remarks:

Bureau Veritas Laboratories are accredited to ISO/IEC 17025 for specific parameters on scopes of accreditation. Unless otherwise noted, procedures used by BV Labs are based upon recognized Provincial, Federal or US method compendia such as CCME, MDDELCC, EPA, APHA.

All work recorded herein has been done in accordance with procedures and practices ordinarily exercised by professionals in BV Labs profession using accepted testing methodologies, quality assurance and quality control procedures (except where otherwise agreed by the client and BV Labs in writing). All data is in statistical control and has met quality control and method performance criteria unless otherwise noted. All method blanks are reported; unless indicated otherwise, associated sample data are not blank corrected. Where applicable, unless otherwise noted, Measurement Uncertainty has not been accounted for when stating conformity to the referenced standard.

BV Labs liability is limited to the actual cost of the requested analyses, unless otherwise agreed in writing. There is no other warranty expressed or implied. BV Labs has been retained to provide analysis of samples provided by the Client using the testing methodology referenced in this report. Interpretation and use of test results are the sole responsibility of the Client and are not within the scope of services provided by BV Labs, unless otherwise agreed in writing. BV Labs is not responsible for the accuracy or any data impacts, that result from the information provided by the customer or their agent.

Solid sample results, except biota, are based on dry weight unless otherwise indicated. Organic analyses are not recovery corrected except for isotope dilution methods.
Results relate to samples tested. When sampling is not conducted by BV Labs, results relate to the supplied samples tested. This Certificate shall not be reproduced except in full, without the written approval of the laboratory.
Reference Method suffix “m” indicates test methods incorporate validated modifications from specific reference methods to improve performance. * RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

Attention: Tony Walker
DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2

Report Date: 2019/07/17
Report #: R2753511
Version: 1 - Final

CERTIFICATE OF ANALYSIS

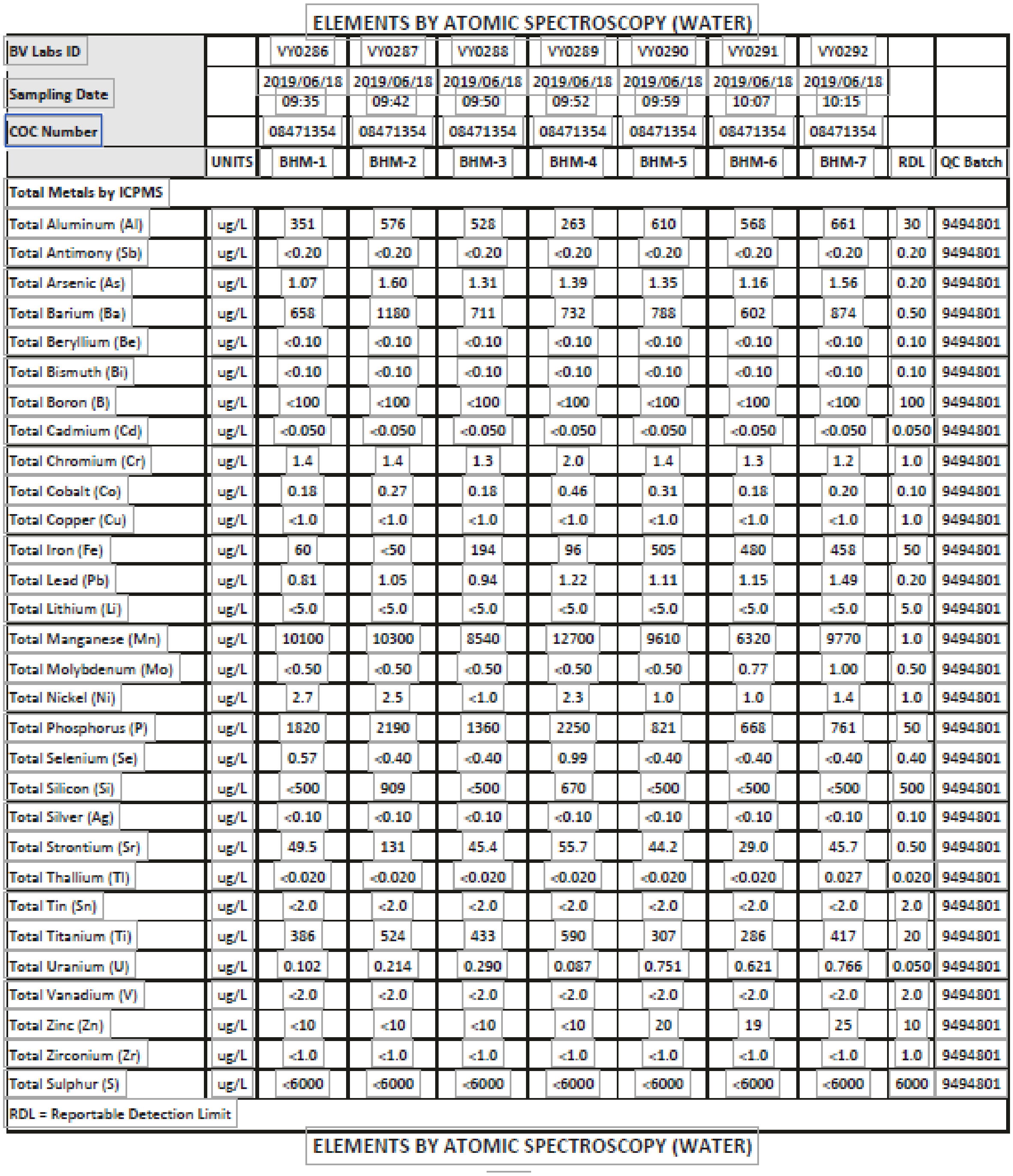
BV LABS JOB #: B948830
Received: 2019/06/20, 09:00

Encry
ption
Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager. Nahed Amer, Project Manager
Email: Nahed.AMER@bvlabs.com
Phone# (604) 734 7276
==

BV Labs ID		VY0296	VY0297	VY0298	VY0299	VY0300	VY0301	VY0302		
Sampling Date		2019/06/18 09:35	2019/06/18 09:42	2019/06/18 09:50	2019/06/18 09:52	2019/06/18 09:59	2019/06/18 10:07	2019/06/18 10:15		
COC Number		08471354	08471354	08471354	08471354	08471354	08471354	08471354		
	UNITS	**BHHG-1**	**BHHG-2**	**BHHG-3**	**BHHG-4**	**BHHG-5**	**BHHG-6**	**BHHG-7**	**RDL**	**QC Batch**
Elements										
Total Mercury (Hg)	ug/L	<0.020	<0.020	<0.020	0.030	<0.020	<0.020	<0.020	0.020	9494808
RDL = Reportable Detection Limit										

BV Labs ID		VY0303	VY0304	VY0305		
Sampling Date		2019/06/18 10:21	2019/06/18 10:22	2019/06/18 10:36		
COC Number		08471354	08471354	08471354		
	UNITS	**BHHG-8**	**BHHG-9**	**BHHG-10**	**RDL**	**QC Batch**
Elements						
Total Mercury (Hg)	ug/L	0.030	0.025	<0.020	0.020	9494808
RDL = Reportable Detection Limit						



ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

BV Labs ID		VY0286	VY0287	VY0288	VY0289	VY0290	VY0291	VY0292		
Sampling Date		2019/06/18 09:35	2019/06/18 09:42	2019/06/18 09:50	2019/06/18 09:52	2019/06/18 09:59	2019/06/18 10:07	2019/06/18 10:15		
COC Number		08471354	08471354	08471354	08471354	08471354	08471354	08471354		
	UNITS	BHM-1	BHM-2	BHM-3	BHM-4	BHM-5	BHM-6	BHM-7	RDL	QC Batch
Total Metals by ICPMS										
Total Aluminum (Al)	ug/L	351	576	528	263	610	568	661	30	9494801
Total Antimony (Sb)	ug/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	9494801
Total Arsenic (As)	ug/L	1.07	1.60	1.31	1.39	1.35	1.16	1.56	0.20	9494801
Total Barium (Ba)	ug/L	658	1180	711	732	788	602	874	0.50	9494801
Total Beryllium (Be)	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	9494801
Total Bismuth (Bi)	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	9494801
Total Boron (B)	ug/L	<100	<100	<100	<100	<100	<100	<100	100	9494801
Total Cadmium (Cd)	ug/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.050	9494801
Total Chromium (Cr)	ug/L	1.4	1.4	1.3	2.0	1.4	1.3	1.2	1.0	9494801
Total Cobalt (Co)	ug/L	0.18	0.27	0.18	0.46	0.31	0.18	0.20	0.10	9494801
Total Copper (Cu)	ug/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	9494801
Total Iron (Fe)	ug/L	60	<50	194	96	505	480	458	50	9494801
Total Lead (Pb)	ug/L	0.81	1.05	0.94	1.22	1.11	1.15	1.49	0.20	9494801
Total Lithium (Li)	ug/L	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	9494801
Total Manganese (Mn)	ug/L	10100	10300	8540	12700	9610	6320	9770	1.0	9494801
Total Molybdenum (Mo)	ug/L	<0.50	<0.50	<0.50	<0.50	<0.50	0.77	1.00	0.50	9494801
Total Nickel (Ni)	ug/L	2.7	2.5	<1.0	2.3	1.0	1.0	1.4	1.0	9494801
Total Phosphorus (P)	ug/L	1820	2190	1360	2250	821	668	761	50	9494801
Total Selenium (Se)	ug/L	0.57	<0.40	<0.40	0.99	<0.40	<0.40	<0.40	0.40	9494801
Total Silicon (Si)	ug/L	<500	909	<500	670	<500	<500	<500	500	9494801
Total Silver (Ag)	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	9494801
Total Strontium (Sr)	ug/L	49.5	131	45.4	55.7	44.2	29.0	45.7	0.50	9494801
Total Thallium (Tl)	ug/L	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.027	0.020	9494801
Total Tin (Sn)	ug/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.0	9494801
Total Titanium (Ti)	ug/L	386	524	433	590	307	286	417	20	9494801
Total Uranium (U)	ug/L	0.102	0.214	0.290	0.087	0.751	0.621	0.766	0.050	9494801
Total Vanadium (V)	ug/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.0	9494801
Total Zinc (Zn)	ug/L	<10	<10	<10	<10	20	19	25	10	9494801
Total Zirconium (Zr)	ug/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	9494801
Total Sulphur (S)	ug/L	<6000	<6000	<6000	<6000	<6000	<6000	<6000	6000	9494801
RDL = Reportable Detection Limit										

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

BV Labs ID		VY0293	VY0294	VY0295		
Sampling Date		2019/06/18 10:21	2019/06/18 10:22	2019/06/18 10:36		
COC Number		08471354	08471354	08471354		
	UNITS	**BHM-8**	**BHM-9**	**BHM-10**	**RDL**	**QC Batch**
Total Metals by ICPMS						
Total Aluminum (Al)	ug/L	523	402	389	30	9494801
Total Antimony (Sb)	ug/L	<0.20	<0.20	<0.20	0.20	9494801
Total Arsenic (As)	ug/L	1.41	1.33	1.48	0.20	9494801
Total Barium (Ba)	ug/L	846	894	378	0.50	9494801
Total Beryllium (Be)	ug/L	<0.10	<0.10	<0.10	0.10	9494801
Total Bismuth (Bi)	ug/L	<0.10	<0.10	<0.10	0.10	9494801
Total Boron (B)	ug/L	<100	<100	<100	100	9494801
Total Cadmium (Cd)	ug/L	<0.050	<0.050	<0.050	0.050	9494801
Total Chromium (Cr)	ug/L	1.7	1.4	1.3	1.0	9494801
Total Cobalt (Co)	ug/L	0.39	0.20	0.32	0.10	9494801
Total Copper (Cu)	ug/L	1.3	<1.0	<1.0	1.0	9494801
Total Iron (Fe)	ug/L	<50	<50	<50	50	9494801
Total Lead (Pb)	ug/L	0.93	1.07	1.65	0.20	9494801
Total Lithium (Li)	ug/L	<5.0	<5.0	<5.0	5.0	9494801
Total Manganese (Mn)	ug/L	10500	9080	2450	1.0	9494801
Total Molybdenum (Mo)	ug/L	<0.50	0.54	1.63	0.50	9494801
Total Nickel (Ni)	ug/L	2.1	1.4	1.7	1.0	9494801
Total Phosphorus (P)	ug/L	1780	1600	875	50	9494801
Total Selenium (Se)	ug/L	<0.40	0.57	<0.40	0.40	9494801
Total Silicon (Si)	ug/L	797	610	1440	500	9494801
Total Silver (Ag)	ug/L	<0.10	<0.10	<0.10	0.10	9494801
Total Strontium (Sr)	ug/L	85.6	122	169	0.50	9494801
Total Thallium (Tl)	ug/L	<0.020	<0.020	<0.020	0.020	9494801
Total Tin (Sn)	ug/L	<2.0	<2.0	<2.0	2.0	9494801
Total Titanium (Ti)	ug/L	459	461	548	20	9494801
Total Uranium (U)	ug/L	0.196	0.325	0.174	0.050	9494801
Total Vanadium (V)	ug/L	<2.0	<2.0	<2.0	2.0	9494801
Total Zinc (Zn)	ug/L	<10	<10	20	10	9494801
Total Zirconium (Zr)	ug/L	<1.0	<1.0	<1.0	1.0	9494801
Total Sulphur (S)	ug/L	<6000	<6000	<6000	6000	9494801
RDL = Reportable Detection Limit						

GENERAL COMMENTS

Each temperature is the average of up to three cooler temperatures taken at receipt

Package 1	13.7°C
Package 2	8.3°C

Results relate only to the items tested.

QUALITY ASSURANCE REPORT

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
9494801	VCN	Spiked Blank	Total Aluminum (Al)	2019/07/11		102	%	80 - 120
			Total Antimony (Sb)	2019/07/11		95	%	80 - 120
			Total Arsenic (As)	2019/07/11		100	%	80 - 120
			Total Barium (Ba)	2019/07/11		98	%	80 - 120
			Total Beryllium (Be)	2019/07/11		89	%	80 - 120
			Total Bismuth (Bi)	2019/07/11		80	%	80 - 120
			Total Boron (B)	2019/07/11		102	%	80 - 120
			Total Cadmium (Cd)	2019/07/11		93	%	80 - 120
			Total Chromium (Cr)	2019/07/11		91	%	80 - 120
			Total Cobalt (Co)	2019/07/11		87	%	80 - 120
			Total Copper (Cu)	2019/07/11		84	%	80 - 120
			Total Iron (Fe)	2019/07/11		103	%	80 - 120
			Total Lead (Pb)	2019/07/11		92	%	80 - 120
			Total Lithium (Li)	2019/07/11		88	%	80 - 120
			Total Manganese (Mn)	2019/07/11		91	%	80 - 120
			Total Molybdenum (Mo)	2019/07/11		102	%	80 - 120
			Total Nickel (Ni)	2019/07/11		90	%	80 - 120
			Total Selenium (Se)	2019/07/11		100	%	80 - 120
			Total Silver (Ag)	2019/07/11		89	%	80 - 120
			Total Strontium (Sr)	2019/07/11		103	%	80 - 120
			Total Thallium (Tl)	2019/07/11		90	%	80 - 120
			Total Tin (Sn)	2019/07/11		94	%	80 - 120
			Total Titanium (Ti)	2019/07/11		98	%	80 - 120
			Total Uranium (U)	2019/07/11		94	%	80 - 120
			Total Vanadium (V)	2019/07/11		89	%	80 - 120
			Total Zinc (Zn)	2019/07/11		91	%	80 - 120
			Total Zirconium (Zr)	2019/07/11		70 (1)	%	80 - 120
9494801	VCN	RPD	Total Aluminum (Al)	2019/07/11	7.8		%	20
			Total Antimony (Sb)	2019/07/11	96 (1)		%	20
			Total Arsenic (As)	2019/07/11	28 (1)		%	20
			Total Barium (Ba)	2019/07/11	0.62		%	20
			Total Beryllium (Be)	2019/07/11	2.7		%	20
			Total Bismuth (Bi)	2019/07/11	51 (1)		%	20
			Total Boron (B)	2019/07/11	6.0		%	20
			Total Cadmium (Cd)	2019/07/11	1.1		%	20
			Total Chromium (Cr)	2019/07/11	13		%	20
			Total Cobalt (Co)	2019/07/11	6.5		%	20
			Total Copper (Cu)	2019/07/11	11		%	20
			Total Iron (Fe)	2019/07/11	26 (1)		%	20

			Total Lead (Pb)	2019/07/11	4.4		%	20
			Total Lithium (Li)	2019/07/11	4.5		%	20
			Total Manganese (Mn)	2019/07/11	8.6		%	20
			Total Molybdenum (Mo)	2019/07/11	19		%	20
			Total Nickel (Ni)	2019/07/11	5.1		%	20
			Total Selenium (Se)	2019/07/11	27 (1)		%	20
			Total Silver (Ag)	2019/07/11	7.1		%	20
			Total Strontium (Sr)	2019/07/11	10		%	20
			Total Thallium (Tl)	2019/07/11	16		%	20
			Total Tin (Sn)	2019/07/11	25 (1)		%	20
			Total Titanium (Ti)	2019/07/11	21 (1)		%	20
			Total Uranium (U)	2019/07/11	29 (1)		%	20
			Total Vanadium (V)	2019/07/11	12		%	20
			Total Zinc (Zn)	2019/07/11	3.9		%	20
			Total Zirconium (Zr)	2019/07/11	28 (1)		%	20
			Total Aluminum (Al)	2019/07/11	NC		%	20

QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
			Total Antimony (Sb)	2019/07/11	NC		%	20
			Total Arsenic (As)	2019/07/11	144 (1)		%	20
			Total Barium (Ba)	2019/07/11	74 (1)		%	20
			Total Beryllium (Be)	2019/07/11	NC		%	20
			Total Bismuth (Bi)	2019/07/11	NC		%	20
			Total Boron (B)	2019/07/11	NC		%	20
			Total Cadmium (Cd)	2019/07/11	NC		%	20
			Total Chromium (Cr)	2019/07/11	NC		%	20
			Total Cobalt (Co)	2019/07/11	NC		%	20
			Total Copper (Cu)	2019/07/11	NC		%	20
			Total Iron (Fe)	2019/07/11	NC		%	20
			Total Lead (Pb)	2019/07/11	147 (1)		%	20
			Total Lithium (Li)	2019/07/11	NC		%	20
			Total Manganese (Mn)	2019/07/11	NC		%	20
			Total Molybdenum (Mo)	2019/07/11	NC		%	20
			Total Nickel (Ni)	2019/07/11	NC		%	20
			Total Phosphorus (P)	2019/07/11	NC		%	20
			Total Selenium (Se)	2019/07/11	NC		%	20
			Total Silicon (Si)	2019/07/11	NC		%	20
			Total Silver (Ag)	2019/07/11	NC		%	20
			Total Strontium (Sr)	2019/07/11	157 (1)		%	20
			Total Thallium (Tl)	2019/07/11	NC		%	20
			Total Tin (Sn)	2019/07/11	NC		%	20

			Total Titanium (Ti)	2019/07/11	180 (1)		%	20
			Total Uranium (U)	2019/07/11	NC		%	20
			Total Vanadium (V)	2019/07/11	NC		%	20
			Total Zinc (Zn)	2019/07/11	NC		%	20
			Total Zirconium (Zr)	2019/07/11	NC		%	20
			Total Sulphur (S)	2019/07/11	NC		%	20
9494801	VCN	Method Blank	Total Aluminum (Al)	2019/07/16	<30		ug/L	
			Total Antimony (Sb)	2019/07/16	<0.20		ug/L	
			Total Arsenic (As)	2019/07/16	<0.20		ug/L	
			Total Barium (Ba)	2019/07/16	0.95, RDL=0.50 (2)		ug/L	
			Total Beryllium (Be)	2019/07/16	<0.10		ug/L	
			Total Bismuth (Bi)	2019/07/16	<0.10		ug/L	
			Total Boron (B)	2019/07/16	<100		ug/L	
			Total Cadmium (Cd)	2019/07/16	<0.050		ug/L	
			Total Chromium (Cr)	2019/07/16	<1.0		ug/L	
			Total Cobalt (Co)	2019/07/16	<0.10		ug/L	
			Total Copper (Cu)	2019/07/16	<1.0		ug/L	
			Total Iron (Fe)	2019/07/16	<50		ug/L	
			Total Lead (Pb)	2019/07/16	<0.20		ug/L	
			Total Lithium (Li)	2019/07/16	<5.0		ug/L	
			Total Manganese (Mn)	2019/07/16	<1.0		ug/L	
			Total Molybdenum (Mo)	2019/07/16	<0.50		ug/L	
			Total Nickel (Ni)	2019/07/16	<1.0		ug/L	
			Total Phosphorus (P)	2019/07/16	<50		ug/L	
			Total Selenium (Se)	2019/07/16	<0.40		ug/L	
			Total Silicon (Si)	2019/07/16	<500		ug/L	
			Total Silver (Ag)	2019/07/16	<0.10		ug/L	
			Total Strontium (Sr)	2019/07/16	0.54, RDL=0.50 (3)		ug/L	
			Total Thallium (Tl)	2019/07/16	<0.020		ug/L	
			Total Tin (Sn)	2019/07/16	<2.0		ug/L	

QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNI	QC Limits

Total Titanium (Ti) 2019/07/16 <20 ug/L Total Uranium (U) 2019/07/16 <0.050 ug/L Total Vanadium (V) 2019/07/16 <2.0 ug/L Total Zinc (Zn) 2019/07/16 <10 ug/L Total Zirconium (Zr) 2019/07/16 <1.0 ug/L

			Total Sulphur (S)	2019/07/16	<6000		ug/L	

9494808 EL2 Spiked Blank Total Mercury (Hg) 2019/07/10 83 % 80 - 120 9494808 EL2 RPD Total Mercury (Hg) 2019/07/10 20 % 20

			Total Mercury (Hg)	2019/07/10	NC		%	20
9494808	EL2	Method Blank	Total Mercury (Hg)	2019/07/10	<0.020		ug/L	

Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.
Spiked Blank: A blank matrix sample to which a known amount of the analyte, usually from a second source, has been added. Used to evaluate method accuracy. Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.
NC (Duplicate RPD): The duplicate RPD was not calculated. The concentration in the sample and/or duplicate was too low to permit a reliable RPD calculation
(absolute difference <= 2x RDL).

(1) Recovery or RPD for this parameter is outside control limits. The overall quality control for this analysis meets acceptability criteria.

(2) Reagent Blank exceeds acceptance limits for (Barium) - 2X RDL acceptable for low level metals determination.

(3) Reagent Blank exceeds acceptance limits for (Strontium) - 2X RDL acceptable for low level metals determination.

FUNDAMENTAL LABORATORY ACCEPTANCE GUIDELINE

BV Labs Job #: B948830
Date Received: 2019/06/20
Your C.O.C. #: 08471354
BV Labs Project Manager: Nahed Amer
Quote #: B81333

Invoice To:
DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
ATTN: Tony Walker
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2
Client Contact: Tony Walker

No discrepancies noted.

Report Comments

Received Date: 2019/06/20 **Time:** 09:00 **By:** ______________

Inspected Date:Time:By: ____________ **FLAG** ____________ ______________

Created Date:Time:By: ____________ ____________ ______________

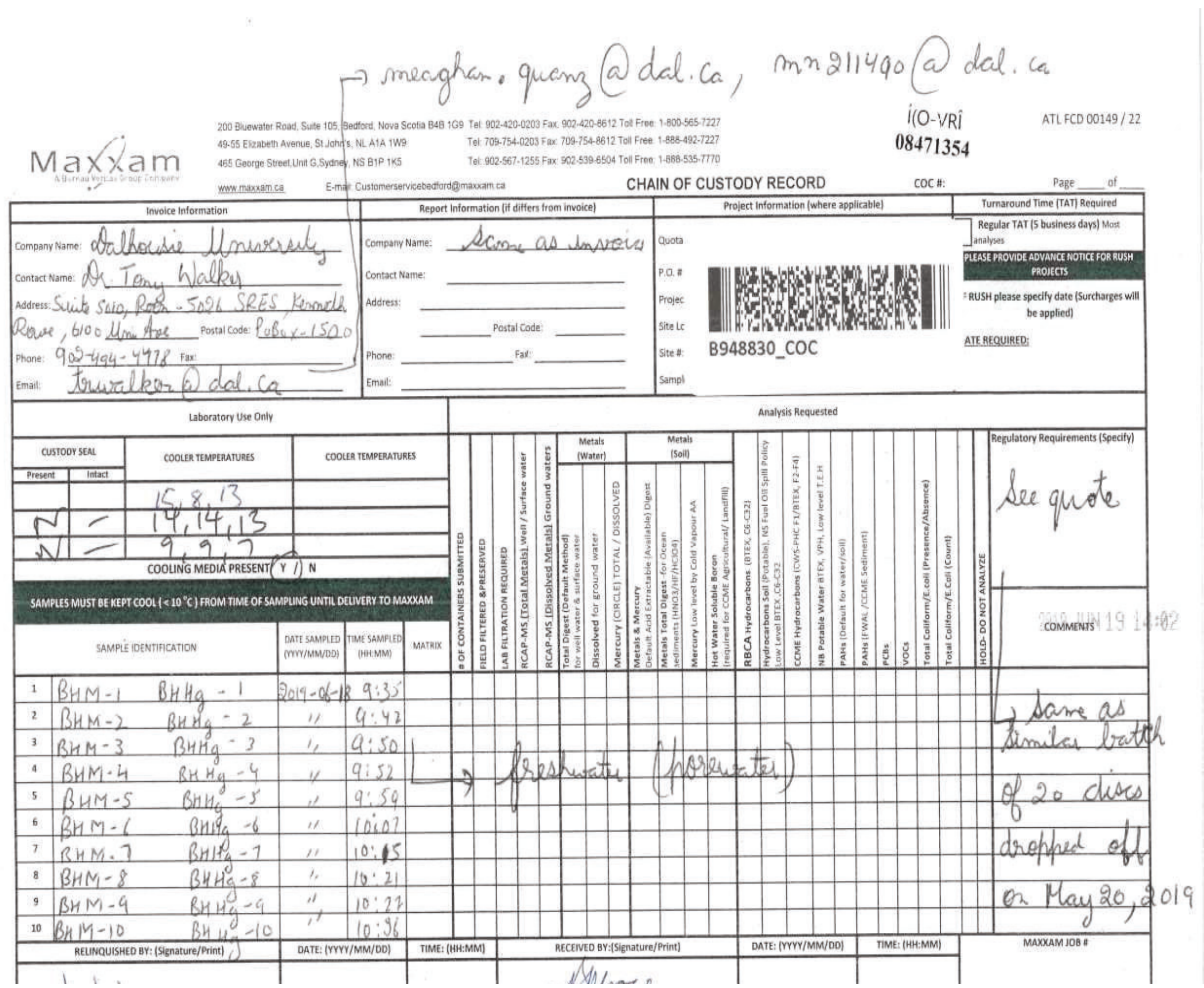
BV Labs Job #: B948830
Report Date: 2019/07/17

DALHOUSIE UNIVERSITY

VALIDATION SIGNATURE PAGE

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Rob Reinert, B.Sc., Scientific
Specialist



→ meaghan.quanz@dal.ca, mn211490@dal.ca

Maxxam
A Bureau Veritas Group Company

200 Bluewater Road, Suite 105, Bedford, Nova Scotia B4B 1G9 Tel: 902-420-0203 Fax: 902-420-8612 Toll Free: 1-800-565-7227
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465 George Street,Unit G,Sydney, NS B1P 1K5 Tel: 902-567-1255 Fax: 902-539-6504 Toll Free: 1-888-535-7770
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i(O-VRI
08471354

ATL FCD 00149 / 22

CHAIN OF CUSTODY RECORD

COC #:

Page ____ of ____

Invoice Information

Company Name: Dalhousie University
Contact Name: Dr. Tony Walker
Address: Suite 5010, Room - 5026 SRES Kenneth Rowe, 6100 Uni Ave Postal Code: PoBox-15000
Phone: 902-494-4778 Fax:
Email: trwalker@dal.ca

Report Information (if differs from invoice)

Company Name: Same as invoice
Contact Name:
Address:
Postal Code:
Phone: Fax:
Email:

Project Information (where applicable)

Quota
P.O. #
Projec
Site Lc
Site #: B948830_COC
Sampl

Turnaround Time (TAT) Required

☐ Regular TAT (5 business days) Most analyses

PLEASE PROVIDE ADVANCE NOTICE FOR RUSH PROJECTS

☐ RUSH please specify date (Surcharges will be applied)

ATE REQUIRED:

Laboratory Use Only

CUSTODY SEAL Present	CUSTODY SEAL Intact	COOLER TEMPERATURES	COOLER TEMPERATURES
		15, 8, 13	
N	—	14, 14, 13	
N	—	9, 9, 7	

COOLING MEDIA PRESENT [✓ Y] / N

SAMPLES MUST BE KEPT COOL (< 10 °C) FROM TIME OF SAMPLING UNTIL DELIVERY TO MAXXAM

Analysis Requested: # OF CONTAINERS SUBMITTED; FIELD FILTERED &PRESERVED; LAB FILTRATION REQUIRED; RCAP-MS (Total Metals) Well / Surface water; RCAP-MS (Dissolved Metals) Ground waters; Metals (Water): Total Digest (Default Method) for well water & surface water; Dissolved for ground water; Mercury (CIRCLE) TOTAL / DISSOLVED; Metals (Soil): Metals & Mercury Default Acid Extractable (Available) Digest; Metals Total Digest -for Ocean sediments (HNO3/HF/HClO4); Mercury Low level by Cold Vapour AA; Hot Water Soluble Boron (required for CCME Agricultural/ Landfill); RBCA Hydrocarbons (BTEX, C6-C32); Hydrocarbons Soil (Potable), NS Fuel Oil Spill Policy Low Level BTEX, C6-C32; CCME Hydrocarbons (CWS-PHC F1/BTEX, F2-F4); NB Potable Water BTEX, VPH, Low level T.E.H; PAHs (Default for water/soil); PAHs (FWAL /CCME Sediment); PCBs; VOCs; Total Coliform/E.coli (Presence/Absence); Total Coliform/E.Coli (Count); HOLD- DO NOT ANALYZE

Regulatory Requirements (Specify): See quote

2019 JUN 19 14:02

COMMENTS

	SAMPLE IDENTIFICATION	DATE SAMPLED (YYYY/MM/DD)	TIME SAMPLED (HH:MM)	MATRIX
1	BHM-1 BHHg-1	2019-06-18	9:35	
2	BHM-2 BHHg-2	"	9:42	
3	BHM-3 BHHg-3	"	9:50	
4	BHM-4 BHHg-4	"	9:52	
5	BHM-5 BHHg-5	"	9:59	
6	BHM-6 BHHg-6	"	10:07	
7	BHM-7 BHHg-7	"	10:15	
8	BHM-8 BHHg-8	"	10:21	
9	BHM-9 BHHg-9	"	10:27	
10	BHM-10 BHHg-10	"	10:36	

→ freshwater (porewater)

→ Same as similar batch of 20 discs dropped off on May 20, 2019

RELINQUISHED BY: (Signature/Print)	DATE: (YYYY/MM/DD)	TIME: (HH:MM)	RECEIVED BY:(Signature/Print)	DATE: (YYYY/MM/DD)	TIME: (HH:MM)	MAXXAM JOB #

Attention: Tony Walker
DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2

Report Date: 2019/07/31
Report #: R2761155
Version: 2 - Revision

CERTIFICATE OF ANALYSIS – REVISED REPORT

BV LABS JOB #: B948833
Received: 2019/06/20, 09:00

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	
Mercury (Total) by CV	10	2019/07/05	2019/07/10	BBY7SOP-00015	BCMOE BCLM Oct2013 m
Mercury (Total) by CV	10	2019/07/05	2019/07/29	BBY7SOP-00015	BCMOE BCLM Oct2013 m
Elements by ICPMS Digested LL (total)	10	2019/07/05	2019/07/11	BBY7SOP-00003 / BBY7SOP-00002	EPA 6020b R2 m

Remarks:

Bureau Veritas Laboratories are accredited to ISO/IEC 17025 for specific parameters on scopes of accreditation. Unless otherwise noted, procedures used by BV Labs are based upon recognized Provincial, Federal or US method compendia such as CCME, MELCC, EPA, APHA.

All work recorded herein has been done in accordance with procedures and practices ordinarily exercised by professionals in BV Labs profession using accepted testing methodologies, quality assurance and quality control procedures (except where otherwise agreed by the client and BV Labs in writing). All data is in statistical control and has met quality control and method performance criteria unless otherwise noted. All method blanks are reported; unless indicated otherwise, associated sample data are not blank corrected. Where applicable, unless otherwise noted, Measurement Uncertainty has not been accounted for when stating conformity to the referenced standard.

BV Labs liability is limited to the actual cost of the requested analyses, unless otherwise agreed in writing. There is no other warranty expressed or implied. BV Labs has been retained to provide analysis of samples provided by the Client using the testing methodology referenced in this report. Interpretation and use of test results are the sole responsibility of the Client and are not within the scope of services provided by BV Labs, unless otherwise agreed in writing. BV Labs is not responsible for the accuracy or any data impacts, that result from the information provided by the customer or their agent.

Solid sample results, except biota, are based on dry weight unless otherwise indicated. Organic analyses are not recovery corrected except for isotope dilution methods.
Results relate to samples tested. When sampling is not conducted by BV Labs, results relate to the supplied samples tested. This Certificate shall not be reproduced except in full, without the written approval of the laboratory.
Reference Method suffix “m” indicates test methods incorporate validated modifications from specific reference methods to improve performance. * RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

Attention: Tony Walker
DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2

Report Date: 2019/07/31
Report #: R2761155
Version: 2 - Revision

CERTIFICATE OF ANALYSIS – REVISED REPORT

BV LABS JOB #: B948833
Received: 2019/06/20, 09:00

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager. Nahed Amer, Project Manager
Email: Nahed.AMER@bvlabs.com
Phone# (604) 734 7276
==
BV Labs has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per ISO/IEC 17025, signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

MERCURY BY COLD VAPOR (WATER)

BV Labs ID		VY0319	VY0320	VY0321	VY0322	VY0323	VY0324	VY0325		
Sampling Date		2019/06/18 12:15	2019/06/18 12:18	2019/06/18 12:20	2019/06/18 12:25	2019/06/18 12:27	2019/06/18 12:32	2019/06/18 12:34		
COC Number		08471440	08471440	08471440	08471440	08471440	08471440	08471440		
	UNITS	**DCM-1**	**DCM-2**	**DCM-3**	**DCM-4**	**DCM-5**	**DCM-6**	**DCM-7**	**RDL**	**QC Batch**
Elements										
Total Mercury (Hg)	ug/L	<0.020 (1)	<0.020 (1)	<0.020 (1)	<0.020 (1)	<0.020 (1)	<0.020 (1)	<0.020 (1)	0.020	9518064

RDL = Reportable Detection Limit
(1) Detection limit raised based on sample volume used for analysis.

BV Labs ID		VY0326	VY0327	VY0328		VY0329	VY0330	VY0331		
Sampling Date		2019/06/18 12:39	2019/06/18 12:42	2019/06/18 12:50		2019/06/18 12:15	2019/06/18 12:18	2019/06/18 12:20		
COC Number		08471440	08471440	08471440		08471440	08471440	08471440		
	UNITS	**DCM-8**	**DCM-9**	**DCM-10**	**QC Batch**	**DCHG-1**	**DCHG-2**	**DCHG-3**	**RDL**	**QC Batch**
Elements										
Total Mercury (Hg)	ug/L	<0.020 (1)	<0.020 (1)	<0.020 (1)	9518064	0.024	<0.020	<0.020	0.020	9494808

RDL = Reportable Detection Limit
(1) Detection limit raised based on sample volume used for analysis.

BV Labs ID		VY0332	VY0333	VY0334	VY0335	VY0336	VY0337	VY0338		
Sampling Date		2019/06/18 12:25	2019/06/18 12:27	2019/06/18 12:32	2019/06/18 12:34	2019/06/18 12:39	2019/06/18 12:42	2019/06/18 12:50		
COC Number		08471440	08471440	08471440	08471440	08471440	08471440	08471440		
	UNITS	**DCHG-4**	**DCHG-5**	**DCHG-6**	**DCHG-7**	**DCHG-8**	**DCHG-9**	**DCHG-10**	**RDL**	**QC Batch**
Elements										
Total Mercury (Hg)	ug/L	<0.020	<0.020	<0.020	0.025	0.028	<0.020	<0.020	0.020	9494808

RDL = Reportable Detection Limit

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

BV Labs ID		VY0319	VY0320	VY0321	VY0322	VY0323	VY0324	VY0325		
Sampling Date		2019/06/18 12:15	2019/06/18 12:18	2019/06/18 12:20	2019/06/18 12:25	2019/06/18 12:27	2019/06/18 12:32	2019/06/18 12:34		
COC Number		08471440	08471440	08471440	08471440	08471440	08471440	08471440		
	UNITS	DCM-1	DCM-2	DCM-3	DCM-4	DCM-5	DCM-6	DCM-7	RDL	QC Batch
Total Metals by ICPMS										
Total Aluminum (Al)	ug/L	189	199	127	138	329	168	198	30	9494801
Total Antimony (Sb)	ug/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	9494801
Total Arsenic (As)	ug/L	1.62	1.55	1.68	1.49	2.92	1.92	1.75	0.20	9494801
Total Barium (Ba)	ug/L	851	471	414	333	640	406	528	0.50	9494801
Total Beryllium (Be)	ug/L	<0.10	0.10	<0.10	0.10	0.17	0.16	<0.10	0.10	9494801
Total Bismuth (Bi)	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	9494801
Total Boron (B)	ug/L	<100	<100	<100	<100	<100	<100	<100	100	9494801
Total Cadmium (Cd)	ug/L	<0.050	<0.050	<0.050	<0.050	<0.050	0.073	<0.050	0.050	9494801
Total Chromium (Cr)	ug/L	2.2	2.1	2.0	2.4	3.3	3.4	2.0	1.0	9494801
Total Cobalt (Co)	ug/L	0.25	0.22	0.38	0.18	0.50	0.61	0.27	0.10	9494801
Total Copper (Cu)	ug/L	<1.0	<1.0	<1.0	<1.0	3.5	1.1	<1.0	1.0	9494801
Total Iron (Fe)	ug/L	6650	2470	1080	1570	15900	1350	1920	50	9494801
Total Lead (Pb)	ug/L	1.54	1.97	1.55	1.91	3.14	2.16	2.13	0.20	9494801
Total Lithium (Li)	ug/L	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	9494801
Total Manganese (Mn)	ug/L	8380	2170	5600	788	3720	1240	4020	1.0	9494801
Total Molybdenum (Mo)	ug/L	0.97	1.92	2.60	2.57	3.15	2.07	2.22	0.50	9494801
Total Nickel (Ni)	ug/L	1.4	<1.0	1.0	<1.0	2.7	1.8	1.2	1.0	9494801
Total Phosphorus (P)	ug/L	1560	877	1160	1250	2710	1270	1410	50	9494801
Total Selenium (Se)	ug/L	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	0.40	9494801
Total Silicon (Si)	ug/L	621	771	506	961	2030	1300	959	500	9494801
Total Silver (Ag)	ug/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	9494801
Total Strontium (Sr)	ug/L	58.9	81.2	53.7	86.5	160	95.7	99.5	0.50	9494801
Total Thallium (Tl)	ug/L	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.020	9494801
Total Tin (Sn)	ug/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.0	9494801
Total Titanium (Ti)	ug/L	516	474	606	562	914	685	572	20	9494801
Total Uranium (U)	ug/L	0.320	0.497	0.451	0.511	0.827	0.480	0.542	0.050	9494801
Total Vanadium (V)	ug/L	2.1	9.9	6.8	10.5	17.2	14.2	4.8	2.0	9494801
Total Zinc (Zn)	ug/L	11	12	14	11	19	22	15	10	9494801
Total Zirconium (Zr)	ug/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	9494801
Total Sulphur (S)	ug/L	<6000	<6000	<6000	<6000	<6000	<6000	<6000	6000	9494801
RDL = Reportable Detection Limit										

ELEMENTS BY ATOMIC SPECTROSCOPY (WATER)

BV Labs ID		VY0326	VY0327	VY0328		
Sampling Date		2019/06/18 12:39	2019/06/18 12:42	2019/06/18 12:50		
COC Number		08471440	08471440	08471440		
	UNITS	**DCM-8**	**DCM-9**	**DCM-10**	**RDL**	**QC Batch**
Total Metals by ICPMS						
Total Aluminum (Al)	ug/L	258	80	131	30	9494801
Total Antimony (Sb)	ug/L	<0.20	<0.20	<0.20	0.20	9494801
Total Arsenic (As)	ug/L	3.40	1.42	1.82	0.20	9494801
Total Barium (Ba)	ug/L	961	275	451	0.50	9494801
Total Beryllium (Be)	ug/L	0.17	0.11	0.10	0.10	9494801
Total Bismuth (Bi)	ug/L	<0.10	<0.10	<0.10	0.10	9494801
Total Boron (B)	ug/L	<100	<100	<100	100	9494801
Total Cadmium (Cd)	ug/L	<0.050	<0.050	<0.050	0.050	9494801
Total Chromium (Cr)	ug/L	2.5	2.2	2.1	1.0	9494801
Total Cobalt (Co)	ug/L	0.28	0.12	0.27	0.10	9494801
Total Copper (Cu)	ug/L	<1.0	<1.0	<1.0	1.0	9494801
Total Iron (Fe)	ug/L	22500	572	643	50	9494801
Total Lead (Pb)	ug/L	2.34	2.03	2.53	0.20	9494801
Total Lithium (Li)	ug/L	<5.0	<5.0	<5.0	5.0	9494801
Total Manganese (Mn)	ug/L	4770	967	2760	1.0	9494801
Total Molybdenum (Mo)	ug/L	2.29	1.38	1.55	0.50	9494801
Total Nickel (Ni)	ug/L	1.1	<1.0	<1.0	1.0	9494801
Total Phosphorus (P)	ug/L	2030	1560	1520	50	9494801
Total Selenium (Se)	ug/L	<0.40	<0.40	<0.40	0.40	9494801
Total Silicon (Si)	ug/L	1150	1490	1980	500	9494801
Total Silver (Ag)	ug/L	<0.10	<0.10	<0.10	0.10	9494801
Total Strontium (Sr)	ug/L	87.5	124	100	0.50	9494801
Total Thallium (Tl)	ug/L	<0.020	<0.020	<0.020	0.020	9494801
Total Tin (Sn)	ug/L	<2.0	<2.0	<2.0	2.0	9494801
Total Titanium (Ti)	ug/L	670	686	786	20	9494801
Total Uranium (U)	ug/L	0.547	0.374	0.577	0.050	9494801
Total Vanadium (V)	ug/L	15.3	9.9	5.8	2.0	9494801
Total Zinc (Zn)	ug/L	<10	<10	11	10	9494801
Total Zirconium (Zr)	ug/L	<1.0	<1.0	<1.0	1.0	9494801
Total Sulphur (S)	ug/L	<6000	<6000	<6000	6000	9494801
RDL = Reportable Detection Limit						

GENERAL COMMENTS

Each temperature is the average of up to three cooler temperatures taken at receipt

Package 1	13.7°C
Package 2	8.3°C

Results relate only to the items tested.

QUALITY ASSURANCE REPORT

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
9494801	VCN	Spiked Blank	Total Aluminum (Al)	2019/07/11		102	%	80 - 120
			Total Antimony (Sb)	2019/07/11		95	%	80 - 120
			Total Arsenic (As)	2019/07/11		100	%	80 - 120
			Total Barium (Ba)	2019/07/11		98	%	80 - 120
			Total Beryllium (Be)	2019/07/11		89	%	80 - 120
			Total Bismuth (Bi)	2019/07/11		80	%	80 - 120
			Total Boron (B)	2019/07/11		102	%	80 - 120
			Total Cadmium (Cd)	2019/07/11		93	%	80 - 120
			Total Chromium (Cr)	2019/07/11		91	%	80 - 120
			Total Cobalt (Co)	2019/07/11		87	%	80 - 120
			Total Copper (Cu)	2019/07/11		84	%	80 - 120
			Total Iron (Fe)	2019/07/11		103	%	80 - 120
			Total Lead (Pb)	2019/07/11		92	%	80 - 120
			Total Lithium (Li)	2019/07/11		88	%	80 - 120
			Total Manganese (Mn)	2019/07/11		91	%	80 - 120
			Total Molybdenum (Mo)	2019/07/11		102	%	80 - 120
			Total Nickel (Ni)	2019/07/11		90	%	80 - 120
			Total Selenium (Se)	2019/07/11		100	%	80 - 120
			Total Silver (Ag)	2019/07/11		89	%	80 - 120
			Total Strontium (Sr)	2019/07/11		103	%	80 - 120
			Total Thallium (Tl)	2019/07/11		90	%	80 - 120
			Total Tin (Sn)	2019/07/11		94	%	80 - 120
			Total Titanium (Ti)	2019/07/11		98	%	80 - 120
			Total Uranium (U)	2019/07/11		94	%	80 - 120
			Total Vanadium (V)	2019/07/11		89	%	80 - 120
			Total Zinc (Zn)	2019/07/11		91	%	80 - 120
			Total Zirconium (Zr)	2019/07/11		70 (1)	%	80 - 120
9494801	VCN	RPD	Total Aluminum (Al)	2019/07/11	7.8		%	20
			Total Antimony (Sb)	2019/07/11	96 (1)		%	20
			Total Arsenic (As)	2019/07/11	28 (1)		%	20
			Total Barium (Ba)	2019/07/11	0.62		%	20
			Total Beryllium (Be)	2019/07/11	2.7		%	20
			Total Bismuth (Bi)	2019/07/11	51 (1)		%	20
			Total Boron (B)	2019/07/11	6.0		%	20
			Total Cadmium (Cd)	2019/07/11	1.1		%	20
			Total Chromium (Cr)	2019/07/11	13		%	20
			Total Cobalt (Co)	2019/07/11	6.5		%	20
			Total Copper (Cu)	2019/07/11	11		%	20
			Total Iron (Fe)	2019/07/11	26 (1)		%	20

			Total Lead (Pb)	2019/07/11	4.4		%	20
			Total Lithium (Li)	2019/07/11	4.5		%	20
			Total Manganese (Mn)	2019/07/11	8.6		%	20
			Total Molybdenum (Mo)	2019/07/11	19		%	20
			Total Nickel (Ni)	2019/07/11	5.1		%	20
			Total Selenium (Se)	2019/07/11	27 (1)		%	20
			Total Silver (Ag)	2019/07/11	7.1		%	20
			Total Strontium (Sr)	2019/07/11	10		%	20
			Total Thallium (Tl)	2019/07/11	16		%	20
			Total Tin (Sn)	2019/07/11	25 (1)		%	20
			Total Titanium (Ti)	2019/07/11	21 (1)		%	20
			Total Uranium (U)	2019/07/11	29 (1)		%	20
			Total Vanadium (V)	2019/07/11	12		%	20
			Total Zinc (Zn)	2019/07/11	3.9		%	20
			Total Zirconium (Zr)	2019/07/11	28 (1)		%	20
			Total Aluminum (Al)	2019/07/11	NC		%	20

QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits
			Total Antimony (Sb)	2019/07/11	NC		%	20
			Total Arsenic (As)	2019/07/11	144 (1)		%	20
			Total Barium (Ba)	2019/07/11	74 (1)		%	20
			Total Beryllium (Be)	2019/07/11	NC		%	20
			Total Bismuth (Bi)	2019/07/11	NC		%	20
			Total Boron (B)	2019/07/11	NC		%	20
			Total Cadmium (Cd)	2019/07/11	NC		%	20
			Total Chromium (Cr)	2019/07/11	NC		%	20
			Total Cobalt (Co)	2019/07/11	NC		%	20
			Total Copper (Cu)	2019/07/11	NC		%	20
			Total Iron (Fe)	2019/07/11	NC		%	20
			Total Lead (Pb)	2019/07/11	147 (1)		%	20
			Total Lithium (Li)	2019/07/11	NC		%	20
			Total Manganese (Mn)	2019/07/11	NC		%	20
			Total Molybdenum (Mo)	2019/07/11	NC		%	20
			Total Nickel (Ni)	2019/07/11	NC		%	20
			Total Phosphorus (P)	2019/07/11	NC		%	20
			Total Selenium (Se)	2019/07/11	NC		%	20
			Total Silicon (Si)	2019/07/11	NC		%	20
			Total Silver (Ag)	2019/07/11	NC		%	20
			Total Strontium (Sr)	2019/07/11	157 (1)		%	20
			Total Thallium (Tl)	2019/07/11	NC		%	20
			Total Tin (Sn)	2019/07/11	NC		%	20

			Total Titanium (Ti)	2019/07/11	180 (1)		%	20
			Total Uranium (U)	2019/07/11	NC		%	20
			Total Vanadium (V)	2019/07/11	NC		%	20
			Total Zinc (Zn)	2019/07/11	NC		%	20
			Total Zirconium (Zr)	2019/07/11	NC		%	20
			Total Sulphur (S)	2019/07/11	NC		%	20
9494801	VCN	Method Blank	Total Aluminum (Al)	2019/07/16	<30		ug/L	
			Total Antimony (Sb)	2019/07/16	<0.20		ug/L	
			Total Arsenic (As)	2019/07/16	<0.20		ug/L	
			Total Barium (Ba)	2019/07/16	0.95, RDL=0.50 (2)		ug/L	
			Total Beryllium (Be)	2019/07/16	<0.10		ug/L	
			Total Bismuth (Bi)	2019/07/16	<0.10		ug/L	
			Total Boron (B)	2019/07/16	<100		ug/L	
			Total Cadmium (Cd)	2019/07/16	<0.050		ug/L	
			Total Chromium (Cr)	2019/07/16	<1.0		ug/L	
			Total Cobalt (Co)	2019/07/16	<0.10		ug/L	
			Total Copper (Cu)	2019/07/16	<1.0		ug/L	
			Total Iron (Fe)	2019/07/16	<50		ug/L	
			Total Lead (Pb)	2019/07/16	<0.20		ug/L	
			Total Lithium (Li)	2019/07/16	<5.0		ug/L	
			Total Manganese (Mn)	2019/07/16	<1.0		ug/L	
			Total Molybdenum (Mo)	2019/07/16	<0.50		ug/L	
			Total Nickel (Ni)	2019/07/16	<1.0		ug/L	
			Total Phosphorus (P)	2019/07/16	<50		ug/L	
			Total Selenium (Se)	2019/07/16	<0.40		ug/L	
			Total Silicon (Si)	2019/07/16	<500		ug/L	
			Total Silver (Ag)	2019/07/16	<0.10		ug/L	
			Total Strontium (Sr)	2019/07/16	0.54, RDL=0.50 (3)		ug/L	
			Total Thallium (Tl)	2019/07/16	<0.020		ug/L	
			Total Tin (Sn)	2019/07/16	<2.0		ug/L	

QUALITY ASSURANCE REPORT(CONT'D)

QA/QC Batch	Init	QC Type	Parameter	Date Analyzed	Value	Recovery	UNITS	QC Limits

Total Titanium (Ti) 2019/07/16 <20 ug/L Total Uranium (U) 2019/07/16 <0.050 ug/L Total Vanadium (V) 2019/07/16 <2.0 ug/L Total Zinc (Zn) 2019/07/16 <10 ug/L Total Zirconium (Zr) 2019/07/16 <1.0 ug/L

Total Sulphur (S) 2019/07/16 <6000 ug/L

9494808 EL2 Spiked Blank Total Mercury (Hg) 2019/07/10 83 % 80 - 120 9494808 EL2 RPD Total Mercury (Hg) 2019/07/10 20 % 20

Total Mercury (Hg) 2019/07/10 NC % 20

9494808 EL2 Method Blank Total Mercury (Hg) 2019/07/10 <0.020 ug/L

9518064 CJY Spiked Blank Total Mercury (Hg) 2019/07/29 92 % 80 - 120 9518064 CJY RPD Total Mercury (Hg) 2019/07/29 0.77 % 20

Total Mercury (Hg) 2019/07/29 NC (4) % 20 9518064 CJY Method Blank

Total Mercury (Hg) 2019/07/29 <0.020 (4) ug/L

Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.

Spiked Blank: A blank matrix sample to which a known amount of the analyte, usually from a second source, has been added. Used to evaluate method accuracy.

Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.

NC (Duplicate RPD): The duplicate RPD was not calculated. The concentration in the sample and/or duplicate was too low to permit a reliable RPD calculation (absolute difference <= 2x RDL).

(1) Recovery or RPD for this parameter is outside control limits. The overall quality control for this analysis meets acceptability criteria.

(2) Reagent Blank exceeds acceptance limits for (Barium) - 2X RDL acceptable for low level metals determination.

(3) Reagent Blank exceeds acceptance limits for (Strontium) - 2X RDL acceptable for low level metals determination.

(4) Detection limit raised based on sample volume used for analysis.

FUNDAMENTAL LABORATORY ACCEPTANCE GUIDELINE

BV Labs Job #:	B948833
Date Received:	2019/06/20
Your C.O.C. #:	08471440
BV Labs Project Manager:	Nahed Amer
Quote #:	B81333

Invoice To:
DALHOUSIE UNIVERSITY
WATER RESOURCE STUDIES
ATTN: Tony Walker
PO 15000 (D401)
1360 BARRINGTON ST
HALIFAX, NS
CANADA B3H 4R2
Client Contact: Tony Walker

No discrepancies noted.

Report Comments

Received Date: 2019/06/20 **Time:** 09:00 **By:** __________

Inspected Date:Time:By: __________ **FLAG** __________ __________

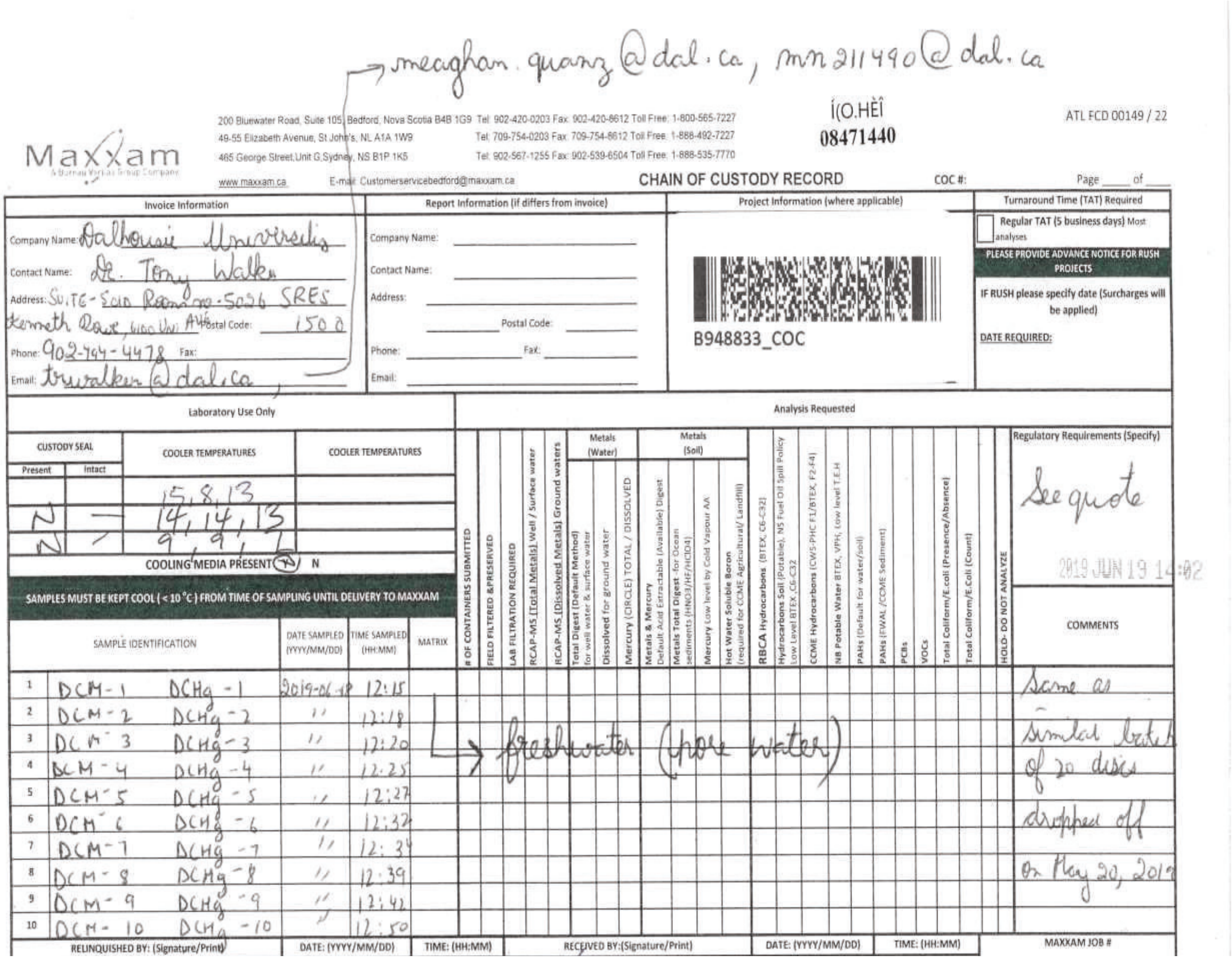
Created Date:Time:By: __________ __________ __________

VALIDATION SIGNATURE PAGE

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Andy Lu, Ph.D., P.Chem., Scientific Specialist

BV Labs has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per ISO/IEC 17025, signing the reports. For Service Group specific validation please refer to t



→ meaghan.quanz@dal.ca, mn211490@dal.ca

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08471440

ATL FCD 00149 / 22

CHAIN OF CUSTODY RECORD COC #: Page ____ of ____

Invoice Information

Company Name: Dalhousie University
Contact Name: Dr. Tony Walker
Address: Suite-5010 Room no-5036 SRES
Kenneth Rowe, 6100 Uni Ave Postal Code: 1500
Phone: 902-494-4478 Fax:
Email: trwalker@dal.ca,

Report Information (if differs from invoice)

Company Name:
Contact Name:
Address:
Postal Code:
Phone: Fax:
Email:

Project Information (where applicable)

B948833_COC

Turnaround Time (TAT) Required

☐ Regular TAT (5 business days) Most analyses

PLEASE PROVIDE ADVANCE NOTICE FOR RUSH PROJECTS

IF RUSH please specify date (Surcharges will be applied)

DATE REQUIRED:

Laboratory Use Only

CUSTODY SEAL		COOLER TEMPERATURES	COOLER TEMPERATURES
Present	Intact		
		15, 8, 13	
N	—	14, 14, 13	
N	/	9, 9, 1	

COOLING MEDIA PRESENT [✓ Y] N

SAMPLES MUST BE KEPT COOL (< 10 °C) FROM TIME OF SAMPLING UNTIL DELIVERY TO MAXXAM

Analysis Requested

Regulatory Requirements (Specify): See quote

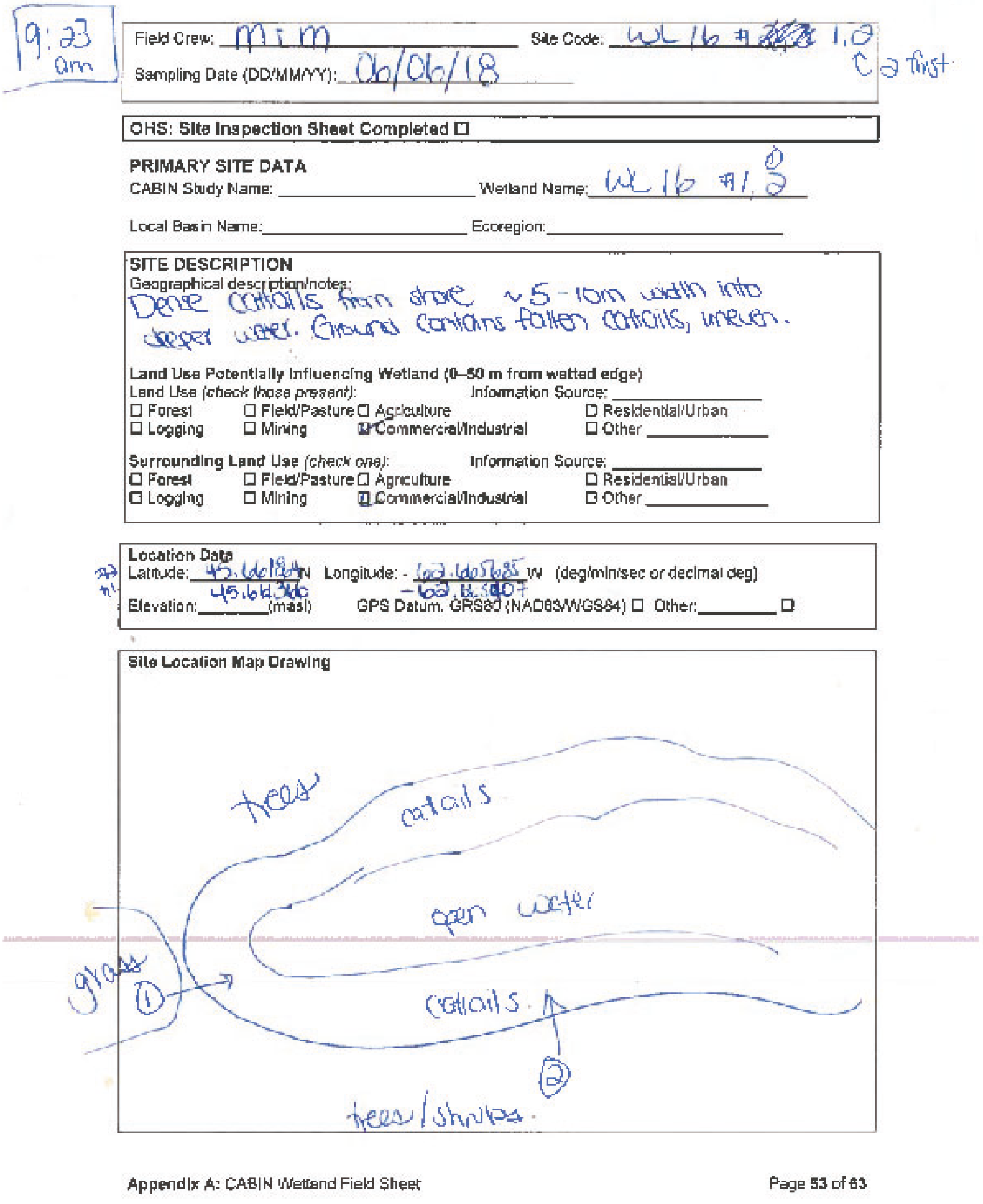
2019 JUN 19 14:02

	SAMPLE IDENTIFICATION	DATE SAMPLED (YYYY/MM/DD)	TIME SAMPLED (HH:MM)	MATRIX	# OF CONTAINERS SUBMITTED	FIELD FILTERED &PRESERVED	LAB FILTRATION REQUIRED	RCAP-MS [Total Metals] Well / Surface water	RCAP-MS [Dissolved Metals] Ground waters	Metals (Water)			Metals (Soil)				RBCA Hydrocarbons (BTEX, C6-C32)	Hydrocarbons Soil (Potable), NS Fuel Oil Spill Policy Low Level BTEX, C6-C32	CCME Hydrocarbons (CWS-PHC F1/BTEX, F2-F4)	NB Potable Water BTEX, VPH, Low level T.E.H	PAHs (Default for water/soil)	PAHs (FWAL /CCME Sediment)	PCBs	VOCs	Total Coliform/E.coli (Presence/Absence)	Total Coliform/E.Coli (Count)		HOLD- DO NOT ANALYZE	COMMENTS
										Total Digest (Default Method) for well water & surface water	Dissolved for ground water	Mercury (CIRCLE) TOTAL / DISSOLVED	Metals & Mercury Default Acid Extractable (Available) Digest	Metals Total Digest - for Ocean sediments (HNO3/HF/HClO4)	Mercury Low level by Cold Vapour AA	Hot Water Soluble Boron (required for CCME Agricultural/ Landfill)													
1	DCM-1 DCHg-1	2019-06-18	12:15																										Same as
2	DCM-2 DCHg-2	''	12:18																										
3	DCM-3 DCHg-3	''	12:20	→ freshwater (pore water)																									similar batch
4	DCM-4 DCHg-4	''	12:25																										of 20 discs
5	DCM-5 DCHg-5	''	12:27																										
6	DCM-6 DCHg-6	''	12:32																										dropped off
7	DCM-7 DCHg-7	''	12:34																										
8	DCM-8 DCHg-8	''	12:39																										On May 20, 2019
9	DCM-9 DCHg-9	''	12:42																										
10	DCM-10 DCHg-10	''	12:50																										

RELINQUISHED BY: (Signature/Print)	DATE: (YYYY/MM/DD)	TIME: (HH:MM)	RECEIVED BY:(Signature/Print)	DATE: (YYYY/MM/DD)	TIME: (HH:MM)	MAXXAM JOB #

Appendix E

Example of CABIN Wetland Field Notes



9:23 am

Field Crew: mim

Site Code: WL 16 # 1.2 C 2 first

Sampling Date (DD/MM/YY): 06/06/18

OHS: Site Inspection Sheet Completed ☐

PRIMARY SITE DATA

CABIN Study Name: ______

Wetland Name: WL 16 #1.2

Local Basin Name: ______

Ecoregion: ______

SITE DESCRIPTION

Geographical description/notes: Dense cattails from shore ~5-10m width into deeper water. Ground contains fallen cattails, uneven.

Land Use Potentially Influencing Wetland (0–50 m from wetted edge)

Land Use (*check those present*):

Information Source: ______

☐ Forest
☐ Field/Pasture
☐ Agriculture
☐ Residential/Urban
☐ Logging
☐ Mining
☑ Commercial/Industrial
☐ Other ______

Surrounding Land Use (*check one*):

Information Source: ______

☐ Forest
☐ Field/Pasture
☐ Agriculture
☐ Residential/Urban
☐ Logging
☐ Mining
☑ Commercial/Industrial
☐ Other ______

Location Data

Latitude: 45.66184 N 45.66366

Longitude: - 63.665685 W -63.65407 (deg/min/sec or decimal deg)

Elevation: ______ (masl)

GPS Datum. GRS80 (NAD83/WGS84) ☐ Other: ______ ☐

Site Location Map Drawing

Appendix A: CABIN Wetland Field Sheet

Page 53 of 63

Field Crew: mjm Site Code: WL 16 #1, 2

Sampling Date (DD/MM/YY): 06/06/18

Photos and Photo Numbers

Field sheet ☑ North ☑ East ☑ South ☑ West ☑

Vegetation ☑ (in sampled area)____ Exposed Substrate/Mud Flat ☐________

Access Point ☐_______ Aerial Photo ☑_______ Other ☐_______ (i.e., Sampling photos)

WETLAND CHARACTERISTICS

Whole Wetland

Hydrological Type

Basin/Pond/Pool ☐ Lacustrine ☐ Riverine ☐

Water-level stage at the time of sampling *(check one)*:

Dry ☐ Vestigial ☐ Recessional ☐ Intermediate ☐ Full ☐

Flooded ☐ Overflowing ☐ Typical Depth __________(m)

Vegetation Cover

Higher Plants

Emergent

0% ☐ 1–5% ☐ 6–25% ☐ 26–50% ☐ 51–75% ☐ 76–100% ☑

Floating

0% ☐ 1–5% ☑ 6–25% ☐ 26–50% ☐ 51–75% ☐ 76–100% ☐

Submergent

0% ☐ 1-5% ☐ 6-25% ☑ 26-50% ☐ 51-75% ☐ 76-100% ☐

Algae / Cyanobacteria

Algal bloom and/or cyanobacterial bloom

Absent ☐ Present ☑

Filamentous Algae

Absent ☐ Present ☐

Biofilm Present Yes ☐ No ☐

Comments *(thickness, abundance, marl)*:________________

Marginal Wetland

Wetland Marginal Vegetation 0–50 m around wetland (*check those present)*:

ferns/grasses/sedges ☑ shrubs ☑ deciduous trees ☑ coniferous trees ☑

agricultural crops ☐

Dominant Wetland Marginal Vegetation *(check one)*:

ferns/grasses/sedges ☐ shrubs ☑ deciduous trees ☐ coniferous trees ☐

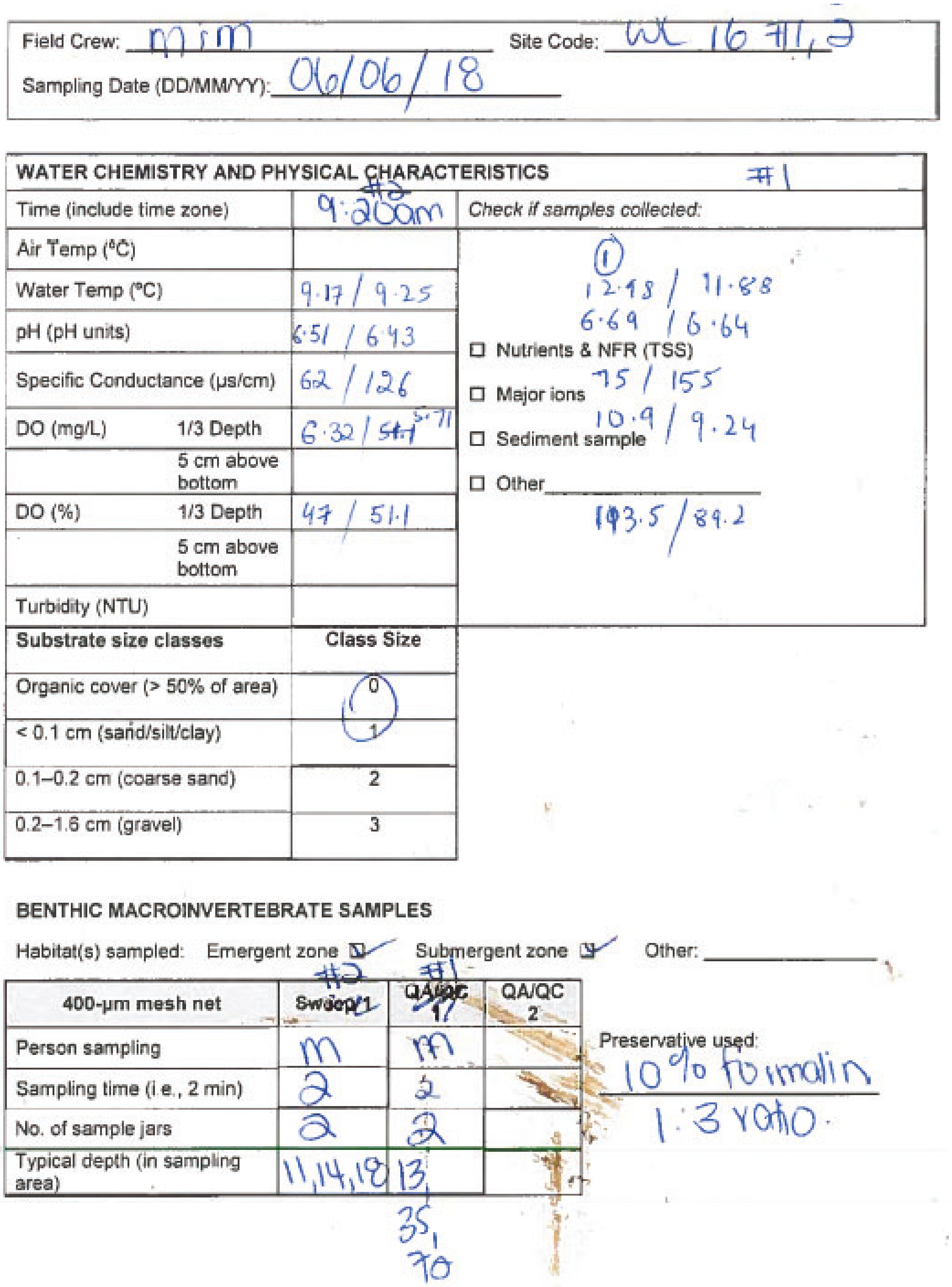
agricultural crops ☐

Canopy Cover / Shading

Not shaded ☑ Partially shaded ☐ Fully shaded ☐

Managed Buffer Strip

Absent ☐ Present ☑ Natural setting, no buffer ☐



Field Crew: mim

Site Code: WL 16 #1,2

Sampling Date (DD/MM/YY): 06/06/18

WATER CHEMISTRY AND PHYSICAL CHARACTERISTICS			#1
Time (include time zone)		#2 9:20am	*Check if samples collected:*
Air Temp (°C)			①
Water Temp (°C)		9.17 / 9.25	12.98 / 11.88
pH (pH units)		6.51 / 6.43	6.69 / 6.64 ☐ Nutrients & NFR (TSS)
Specific Conductance (µs/cm)		62 / 126	75 / 155 ☐ Major ions
DO (mg/L)	1/3 Depth	6.32 / ~~5.1~~ 5.71	10.9 / 9.24 ☐ Sediment sample
	5 cm above bottom		☐ Other
DO (%)	1/3 Depth	47 / 51.1	103.5 / 89.2
	5 cm above bottom		
Turbidity (NTU)			

Substrate size classes	Class Size
Organic cover (> 50% of area)	[✓ 0]
< 0.1 cm (sand/silt/clay)	[✓ 1]
0.1–0.2 cm (coarse sand)	2
0.2–1.6 cm (gravel)	3

BENTHIC MACROINVERTEBRATE SAMPLES

Habitat(s) sampled: Emergent zone ☑ Submergent zone ☑ Other: ________

400-µm mesh net	#2 Sweep 1	#1 ~~QA/QC~~ 1	QA/QC 2
Person sampling	m	m	
Sampling time (i.e., 2 min)	2	2	
No. of sample jars	2	2	
Typical depth (in sampling area)	11, 14, 18	13, 35, 70	

Preservative used: 10% formalin

1:3 ratio.