# Establishing Baseline Hydrologic Conditions of Forested Wetlands in Nova Scotia, Canada

by

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# ABSTRACT

In order to effectively restore altered wetland ecosystems to their natural state, it is critical to understand and identify the baseline hydrologic function of natural forested wetlands. An extensive dataset of water level measurements taken from 18 wetlands in the Annapolis Valley, Nova Scotia, was used to characterize water level dynamics in forested wetlands and how they vary by wetland type (wooded peatland, shrub swamp, and treed swamp), and geographic region (Western ecoregion, and Valley and Central Lowlands ecoregion). Wetland soil profiles were evaluated (drainage class of underlying soil, peat depth and decomposition), and a spatial analysis using publicly available datasets was completed to characterize important wetland and watershed characteristics (e.g. drainage area, topographic position index, watershed land use). The resulting physiographic characteristics, and climate factors, were statistically compared to the water level metrics and determined that the percentage of watershed area classified as forest cover, drainage area (Ha), and wetland topographic position index (TPI) were the key factors that influence the hydrologic regime of forested wetlands.

Forested wetlands in Nova Scotia were determined to have intermediate to long hydroperiods, drying out only during periods of low precipitation, during the mid-summer months. No significant differences in hydrologic patterns were found between treed swamps and wooded peatlands, however during the growing season (May-October), shrub swamps were found to have significantly larger range in water levels and maximum water levels compared to both treed swamps and wooded peatlands. Geographic location did not have an influence on wetland hydrology in this study as wetlands across the Valley and Central Lowlands ecoregion and Western ecoregion had similar hydrologic patterns.

As one cannot manage what they have not measured, the results of this study provide a foundation for wetland management practices and outline the baseline hydrologic conditions for forested wetlands in the Annapolis Valley region of Nova Scotia. In our changing climate, it is more important than ever to protect wetlands as they provide many beneficial ecological functions. Thus, future research should consider expanding this study to include a larger dataset, more wetland types, and all ecoregions of Nova Scotia.

## LIST OF ABBREVIATIONS USED

| | |
|---|---|
| % | Percentage |
| ANOVA | Analysis of Variance |
| CanSIS | Canadian Soil Information System |
| CCME | Canadian Council of Ministers of the Environment |
| cm | Centimetre |
| CSRS | Canadian Spatial Reference System |
| CWCS | Canadian Wetland Classification System |
| DEM | Digital Elevation Model |
| ET | Evapotranspiration |
| FW | Forested Wetland |
| ha | Hectare |
| HGM | Hydrogeomorphic |
| m | Metre |
| $m^2$ | Metre squared |
| mm | Millimetre |
| NAD83 | North American Datum 1983 |
| NACSI | National Council of the Paper Industry for Air and Steam Improvement |
| NS | Nova Scotia |
| NSDLF | Nova Scotia Department of Lands and Forestry |
| NSE | Nova Scotia Environment |
| NWWG | National Wetlands Working Group |
| PCA | Principal Components Analysis |
| TPI | Topographic Position Index |

| | |
|---|---|
| TWI | Topographic Wetness Index |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| UTM | Universal Transverse Mercator |
| WAM | Wet Areas Mapping |
| yr | Year |

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# 1 INTRODUCTION

## 1.1 Project Context

Wetlands are essential features of our landscape that provide habitat to diverse communities of flora and fauna. Forested wetlands (FW), in particular, are important ecosystems as they host a large range of plant species, from small plants, such as the endangered Eastern Mountain Aven (*Geum peckii*) to large species such as the Red Maple (*Acer rubrum*) (Cameron, 2009; Environment and Climate Change Canada, 2018). Forested wetlands have been termed "biodiversity hotspots" in the province of Nova Scotia, providing important habitat for wildlife (Brazner & Achenbach, 2020).

In addition to their ecological importance, FW provide a wide range of social and economic benefits. Some examples include, but are not limited to, the ability of wetlands to protect human health by removing harmful microorganisms and organic matter from surface water and groundwater; supporting medicinal and ceremonial plants harvested by indigenous communities; storing and sequestering carbon from the atmosphere, aiding in the fight against climate change; and buffering the impact of stormwater runoff to maintain natural drainage regimes (Province of Nova Scotia, 2011)

In Nova Scotia, approximately 6.6% of the total land area is comprised of freshwater wetlands (360,462 ha)(Province of Nova Scotia, 2011). Of this, 85% of the area is classified as forested wetlands (FW), which includes shrub swamps, treed swamps, and wooded peatlands (Nova Scotia Environment, 2011). However, as compared to other ecosystems in the province, research on FW has been minimal. Little is known about the chemical, physical, and biological conditions that exist in Nova Scotia's FW, limiting our ability to assess, manage, and restore forested wetlands.

## 1.2 Wetland Restoration and Compensation in Nova Scotia

In Nova Scotia, following the European settlement in the early 1700s, it is presumed that there was a high loss of marine and freshwater wetland area in the Annapolis Valley and other fertile regions across the province (Nova Scotia Environment, 2011). Wetland areas were lost to agriculture and development of settlements by the Acadians and early settlers of NS. In recent years, wetland loss has not been well documented in Nova Scotia as it has been in other areas worldwide. In the northeastern United States, the loss of wetland area has been estimated to be up to 87%; Due to the similarities in the northeastern United States and southeastern Canada's landscape and climate, the wetland loss patterns are likely similar (Brazner & Achenbach, 2020).

Wetlands that are altered or destroyed due to human activity can no longer provide useful ecological functions such as flood and contaminant control (Mitsch & Gosselink, 2015). In 2011, to prevent and control the net loss of wetland areas, the Province of Nova Scotia implemented the Wetland Conservation Policy (2011). This policy was created to conserve natural wetlands in Nova Scotia. With this policy in place, developers must apply to alter wetland areas and, if approved, must compensate for wetland area lost or degraded. Depending on the project, wetland compensation requirements can vary from restoration, enhancement, creation, or expansion of existing wetlands (Table 1).

Table 1: Types of wetland compensation and ratios of compensation requirements. (Province of Nova Scotia, 2011)

| Compensation type | Ratio | Description |
|---|---|---|
| **Restoration** | **2:1** – for every hectare of wetland altered, two hectares must be restored | Restoration involves re-establishing wetland where it previously occurred. This method has the highest success rate. |
| **Enhancement** | At least **3:1** – compensation amounts for enhancement vary depending on the type of enhancement undertaken but are at least 3 hectares of enhanced wetland per hectare of wetland altered | Enhancement is a management activity conducted in existing wetlands that increases the capacity of one or more wetland functions. |
| **Creation** | **4:1** – for every hectare of wetland altered, four hectares of new wetland is created | Creation of wetland where none existed previously. |
| **Expansion** | **2:1** – for every hectare of wetland altered, two hectares must be added to an existing wetland | Expansion of an existing wetland into adjacent areas. This type of compensation has a lower ratio than creation as it has proven to be more successful than creating a new wetland. |

The compensation requirements call for the creation, restoration, enhancement, or expansion of wetlands but are not specific to wetland types. For example, if a wooded peatland is altered, the project's proponent may restore a salt marsh to fulfill compensation requirements, resulting in a shift in wetland function. Overall, the province's goal is to prevent net loss of wetland area and function across the province, so it would be prudent and in keeping with existing legislation to consider the consequences of shifts in wetland function (Smith et al., 1995) that result from a compensation approach that is focused solely on replacing altered area.

## 1.3 Project Objectives

Currently, there are no established hydrologic guidelines – specific to wetland types – for wetland management and restoration in the province of Nova Scotia. This study focused on FW in the Annapolis Valley region of Nova Scotia. A total of 18 wetlands, located across the Valley and Central Lowlands Ecoregion and the Western Ecoregion were studied. The specific objectives of the research were to:

(1) characterize key features of FW hydropatterns,
(2) determine if there are differences in hydropattern characteristics as a function of wetland type (wooded peatland, shrub swamp, treed swamp) and ecoregion (Valley and Central Lowlands vs. Western), and
(3) assess relationships between landscape variables and wetland hydroperiod characteristics.

# 2 LITERATURE REVIEW

## 2.1 Natural wetlands

Wetlands are naturally occurring, biodiverse landscapes that support both human and environmental health. Wetlands are defined by the Province of Nova Scotia (2006) and the National Wetlands Working Group (1997) as:

"*Land commonly referred to as marsh, swamp, fen or bog that either periodically or permanently has a water table at, near or above the land's surface or that is saturated with water, and sustains aquatic processes as indicated by the presence of poorly drained soils, hydrophytic vegetation, and biological activities adapted to wet conditions.*"

As the term suggests, natural wetlands are wetlands that have not been significantly altered or impacted by anthropogenic activities such as ditching, deforestation, or re-wetting (Campbell et al., 2000). Due to the prolonged saturated conditions in wetlands, the soils in wetlands are hydric and support the growth of hydrophytic vegetation (Vepraskas & Craft, 2016). The presence of hydrophytic vegetation can help visually differentiate wetland areas from adjacent upland areas (Tiner, 2016).

The Province of Nova Scotia (2018) recognizes five different wetland classes – swamp, bog, fen, open water, and marsh (Table 2). The wetland types are differentiated based on topographical features, water source, water chemistry, soil types, and vegetation. The Canadian Wetland Classification System (1997) is used to sub-classify the wetlands into more specific classifications (wetland forms and sub-forms).

Table 2: Wetland classifications and descriptions (Nova Scotia Environment, 2011)

| **Wetland Class** | **Source of Water** | **Water Chemistry** | **Soil Characteristics** | **Vegetation** |
|---|---|---|---|---|
| **Swamp** | Groundwater or seepage | Freshwater, neutral pH | Mixed mineral and organic soils with a woody organic layer | Trees and shrubs e.g. Black spruce, Red maple, Alder |
| **Bog** | Precipitation | Freshwater, stagnant water, acidic pH | Layers of decomposed peat (often >40 cm deep) | Low lying ombrotrophic vegetation e.g. peat moss, cotton grass, pitcher plants |
| **Fen** | Seepage from ground or surface waters | Freshwater, slightly alkaline to slightly acidic pH | Layers of decomposed peat (often >40 cm deep) | Bog plants plus sedges and wildflowers |
| **Open Water - Vernal pools (VP) and coastal saline ponds (CSP)** | Storm surge, groundwater discharge, | Saltwater and brackish water (CSP) or freshwater (VP) Slightly acidic to slightly alkaline pH | Organic, mucky surface layer (CSP), layers of decomposed peat (often >40 cm deep) (VP) | Aquatic freshwater and saline water plants |
| **Marsh** | Precipitation, seepage, tidal flooding | Can be saltwater or freshwater, neutral to alkaline pH | Organic, mucky surface layer with mineral soils below | Aquatic plants, e.g., rushes, cattails, water lilies, and arrowheads |

Wetland hydropatterns specific to wetland types have not been well established, however, it is known that hydropatterns for wetlands generally have a water table within 30 cm of the ground surface for the majority of the year (Mitsch & Gosselink, 2015). Similarly, the hydroperiod of a wetland indicates the length of time and frequency that water is present at or above the ground surface (Naja & Volesky, 2011). Each wetland has its own hydroperiod, but would be expected to have similar hydroperiods to other wetlands of the same class (Naja & Volesky, 2011).

### 2.2.1 Forested Wetlands

Forested wetlands include bogs, fens, shrub swamps, and treed swamps (National Wetlands Working Group, 1997). This sub-class includes wetlands with the presence of woody species at least six metres tall (National Wetlands Working Group, 1997). Brazner and Achenbach (2020) used 5% cover of woody species greater than 2 m tall as the threshold for including sites as FW in their study in western Nova Scotia. Cowardin et. al. (1979) described two general hydrologic patterns for FW:

(1) the wetland is flooded annually in the late winter or spring or covered locally with surface water; and

(2) the wetland is semi-permanently or permanently inundated.

In 1989, the National Council of the Paper Industry for Air and Steam Improvement (NACSI) launched a research program to evaluate the environmental effects of harvesting timber in FW (Mader, 1991). Forested wetlands are important sources of timber in some parts of the world and are valued for high productivity (Mader, 1991). Mader (1991) concluded that regulations on tree harvesting in FW are necessary for conservation of these ecosystems and wetland regulations should be established in the United States and Canada.

Forested wetlands, particularly in NS, are still being lost at a higher rate than any other wetland type (Brazner & Achenbach, 2020). In the past five years, estimated loses to suburban, commercial, and industrial development in Nova Scotia were between 80-100 ha per year (Brazner & Achenbach, 2020) and an estimated additional 500 ha per year have been harvested by forestry operations since 2017, 90% of those as clearcuts (Brazner & MacKinnon, 2020).

Despite the high productivity and value of FW, classification methods and research on this FW ecosystems are lacking. There have been very few studies in the past two decades on these wetland types. Further research is required to better understand the characteristics of FW, such as the hydrology, soils, topography, and chemistry to ensure these systems can be properly managed and protected.

## 2.2 Wetland Classification

Wetland classification is essential on a provincial, national, and international level as it standardizes and defines terms used to describe wetland types (Finlayson & van der Valk, 1995). Wetland areas are inherently difficult to classify as wetlands are transitions between aquatic and terrestrial habitat, thus range in substrate type, topography, vegetation cover, and water source (Finlayson & van der Valk, 1995). Under the Ramsar definition of wetlands, 32 natural wetland types are recognized (Scott, 1989). The Canadian Wetland Classification System (CWCS) was developed to provide scientists and non-scientists with a practical and easy-to-use system for distinguishing wetland types (National Wetlands Working Group, 1997). The CWCS uses wetland characteristics such as water source, water chemistry, soil type, landscape position, and vegetation cover to classify wetlands into five classes (Table 2), then wetlands are grouped into forms and types (National Wetlands Working Group, 1997).

Cowardin et al. (1997) proposed a more thorough wetland classification system that was adopted in the United States and is now considered one of the most well-known wetland classification systems in the world (Finlayson & van der Valk, 1995). Compared to other wetland classifications, the US classification system divides wetlands into systems, sub-systems, classes, then sub-classes while also addressing regional applicability and providing modifiers to these groupings. The basic units are environmental systems and include palustrine, lacustrine, riverine, estuarine, and marine. The classification system provides a list of modifiers for different water regimes, water chemistries, soils, and an additional list of special modifiers.

The traditional methods for identifying and classifying wetlands are to use field measurements to determine the water source, soil type, vegetation cover, and water chemistry of the site (Amani et al., 2017). Using this information and a wetland classification system, the wetland can be classified. Alternative methods for wetland identification and classification include imagery-based approaches using satellite and/or lidar imagery (Bian et al., 2016; Mahdianpari et al., 2020; Sader et al., 1995) and the hydrogeomorphic (HGM) approach proposed by Brinson (1993).

With the advancement of remote sensing technology, imagery-based approaches are becoming more common for wetland identification and classification (Lane et al., 2014). The quality of satellite imagery and lidar data are sufficient enough to accurately distinguish wetland areas from adjacent upland areas (Amani et al., 2017; Jahncke et al., 2018; Lane et al., 2014). These methods use a combination of wet areas mapping (WAM) and satellite imagery to predict wetland occurrence and characteristics (Rebelo et al., 2009; Sader et al., 1995). In some jurisdictions, this method of wetland classification is widely applied, however a study by Jahncke et al. (2018) in Nova Scotia documented challenges in differentiating between FW classes. The inaccuracy of FW classification by spatial analysis and imagery-based approaches can be attributed to the higher percentage of tree canopy in these wetlands compared to other wetland types (Jahncke et al., 2018).

The HGM approach was developed in 1993 as a wetland classification tool (Brinson, 1993). It has also been used as a tool to predict wetland function in the landscape (Cole et al., 2002; Hauer & Smith, 1998). Essentially, the HGM approach classifies wetlands based on geomorphic position and hydrologic components (Merkey, 2006). In addition to identifying the source of water for wetland classification, the HGM approach incorporates water level dynamics (Brooks et al., 2011). Other studies have concluded that wetland functions appear to be most influenced by hydrologic and geomorphic controls (Franklin et al., 2009).

## 2.3 Wetland Hydrology Studies

This section reviews studies which have investigated the hydrologic patterns in various wetland types across North America. The hydrologic patterns of FWs are not well understood as few studies have investigated this topic. To the author's knowledge, no studies have investigated the hydrologic patterns of FW in Canada. This section will review pertinent literature from the Southern United States (different climate, FW studies), Northeastern United States (similar climate, FW and other wetland types), and Eastern Canada (similar climate, other wetland types).

### 2.3.1 Canadian Studies

Research on the characterization of wetland hydrology in Canada has been limited. Recent literature which has examined the fluctuations and patterns of hydrodynamics in coastal wetlands and bogs are presented in this section to describe the performance and challenges associated with characterizing hydrologic conditions in wetlands in Canada.

A relevant study by Grabas and Rokitnicki-Wojcik (2015) from the Lake Ontario region of Southern Ontario, evaluated the water level fluctuation intensity at 16 coastal wetland sites surrounding Lake Ontario. Water level fluctuation intensity was calculated for each year as the back-transformed logarithmic mean of one-half the sum of daily water level measurements measured every 15 minutes, as developed by Trebitz (2006) (Grabas and Rokitnicki-Wojcik, 2015). The authors goals were to determine if water level fluctuation intensities were different among hydrogeomorphic wetland classes and across elevation gradients within the Lake Ontario study region. They found that water levels fluctuations were greatest at open bay wetlands (fluctuation intensity of 125.25 cm), and drowned river mouth wetlands possessing the least amount of water level fluctuation (fluctuation intensity of 8.96 cm). The topography and geomorphology of the sites was speculated to have influenced the hydrologic patterns as it was found that long upstream runs of the drowned river mouth sites dampen the water level oscillations (Grabas & Rokitnicki-Wojcik, 2015).

The Grabas and Rokitnicki-Wojcik study (2015) demonstrated that hydrologic differences can be detected among wetland classes using a small suite of wetlands (16 wetlands). This is notable as time and funding constraints may not permit for the installation of data equipment in a large number of wetlands. Grabas and Rokitnicki-Wojcik (2015) recommended that similar studies be conducted in the remaining Great Lakes regions and more broadly across Canada.

Locally, MacIntyre (2017) completed a study on wetland hydrology of seven peat wetlands in the Fundy Ecoregion of Nova Scotia. This study evaluated the baseline hydrology of both natural and altered wetland sites over one field season in 2016. It was hypothesized that wetlands characterized as bogs would have greater seasonal fluctuation than wetlands characterized as fens during the growing season (MacIntyre, 2017). Secondly, altered sites were expected to have greater hydrologic variability due to the impacts from drainage ditches (MacIntyre, 2017). The results confirmed the hypothesis as fens were found to have stable water levels at or near the ground surface for the majority of the study period. Altered sites had greater fluctuations in water levels an overall lower water table than natural sites. MacIntyre (2017) suggested that further research be conducted on underlying physiographic factors that may be driving the hydrologic patterns in these wetlands such as soil, geology, and topography of the sites as this could provide a greater understanding of water level dynamics.

### 2.3.2 American Forested Wetland Studies – Different Climate

The American Southeast is dominated by wet areas (Kaplan et al., 2010) and therefore there has been a focus on wetland conservation in this region. The American Southeast has a sub-tropical climate, and an extended growing season (Amatya et al., 2020). In some areas, upland forests are less abundant, which has led to the harvesting of timber from forested wetlands (Berkowitz et al., 2020). This, in turn, has spurred research efforts to understand hydrological patterns of natural forested wetland systems, to facilitate the management and restoration of altered systems.

Two recent studies investigated the patterns and drivers of hydrology in forested wetlands in this region (Amatya et al., 2020; Berkowitz et al., 2020). Berkowitz et. al. (2020) evaluated the water level dynamics of 56 forested wetlands throughout the Yazoo Basin in Mississippi. The purpose of this study was to determine the natural hydrologic regime of these systems and evaluate differences among sources of saturation events (precipitation-based events, flood-based events, precipitation followed by flooding, and precipitation induced saturation followed by low water table period). Ninety-five saturation events, defined as a water level within 30 cm of the ground surface for ≥14 days, were recorded over the growing season. They found that precipitation-based events were the most frequent source of saturation events (Berkowitz et al., 2020). This finding contrasts with other literature which states that sources of water for FW are usually surface flow and GW discharge (Mitsch & Gosselink, 2015).

Amatya et. al. (2020) studied the water table dynamics and effects of disturbances of FW in the Atlantic Coastal Plains region of North and South Carolina. The hydrologic patterns of four natural (undrained) FW and six altered (drained) FW sites were compared. The altered wetlands were drained for silviculture uses prior to the beginning of this study (Amatya et al., 2020). The water tables of natural FWs were closer to the ground surface than those of drained FW in all cases; during the winter months into the early spring season, the water tables of natural sites were at or above the ground surface. Wetland hydrology status – having a water table within 30 cm of the ground surface – was observed only in natural sites (Amatya et al., 2020). The large differences between drained and undrained sites indicated that management practices should be implemented in the drained sites to maintain wetland status of these FWs. The drainage of FW systems results in less frequent, shorter duration ponding and deeper overall water table depths than undrained sites (Amatya et al., 2020).

### 2.3.3 American Studies – Similar Climate

Perhaps the most relevant studies on wetland hydrology have been those conducted in the Northeastern United States between New Jersey and Pennsylvania (Cole et al., 1997; Cole & Brooks, 2000; Ehrenfeld et al., 2003), a comprehensive study conducted in Northern Oregon (Shaffer et al., 1999), and a study evaluating the transferability of the HGM classification method of FW between Eastern US and Oregon (Cole et al., 2002). These studies not only reviewed the hydrologic metrics of wetlands, but also compared the hydrologic patterns of multiple HGM subclasses. The climates of New Jersey, Pennsylvania, and Oregon are more comparable to that of Nova Scotia in that they experience a winter dormant season.

Cole et al. (1997) characterized the hydrology of 24 wetlands in Pennsylvania using the HGM approach developed by Brinson (1995). The wetlands were monitored for two years to assess mean, median, maximum, minimum water levels, and variability (range) in water levels. This initial study concluded that there is insufficient information to fully characterize moisture regimes and year-round hydrodynamics for the various wetland types (Cole et al., 1997). Cole and Brooks (2000) published a follow-up study that expanded the analysis to a larger suite of wetlands over an extended period of time. The second study classified wetlands based on their HGM subclass (as they did in Cole et al., (1997)) and the subclasses included riparian, depression, slope, headwater floodplain, and mainstem floodplain (Cole & Brooks, 2000). The number of wetlands increased from 24 (Cole et al., 1997) to 32 (Cole & Brooks, 2000) and the follow up study identified significant differences among HGM subclass wetlands. Overall, the groundwater dominated sites were the wettest (riparian, depression, and slopes) while surface water systems were the driest (headwater- and mainstem floodplain) (Cole & Brooks, 2000). It was also determined that disturbance has a significant influence on wetland hydrographs – sites which had presence of disturbance were found to have “flashier” hydrographs and overall lower water tables, as found in other studies (Amatya et al., 2020; MacIntyre, 2017).

Similarly, Schaffer (1999) monitored 45 wetlands over a period of three years in the vicinity of Portland, Oregon to determine if hydrologic patterns differed by HGM subclass and if hydrologic attributes such as land use, soil type, and wetland area affect wetland hydrology. They also monitored constructed wetlands to allow for a comparison of naturally occurring wetlands to altered systems. The hydrology metrics used included range in water levels, extent of inundation, and likelihood of lacking standing water. No relationship was found between hydrologic attributes and hydrologic metrics, however significant differences were found between hydrologic metrics and wetland types. All HGM subclasses were found to have significantly different water levels and extent and duration of inundation. Slope wetlands had the lowest water levels and the lowest extent and duration of inundation while depression wetlands had the highest water levels and greatest extent and duration of inundation. Finally, according to Schaffer (1999), unless wetlands are restored or created in a manner that reproduces the natural HGM characteristics in a region, management activities are unlikely to maintain or restore hydrologic functions in created or restored sites.

Ehrenfeld et. al. (2003) studied the hydrology of FW in Northeastern New Jersey. Twenty one FWs were equipped with water level monitoring equipment for a period of 2.5 years to evaluate water level dynamics, variability, discharge-recharge relationships, and frequency of hydrologic indicators across five HGM subclasses (riverine, depression, slope, mineral flats, and mineral flat-riverine) (Ehrenfeld et al., 2003). They found mineral-riverine wetlands sites to be the wettest, and riverine sites to be the driest. This is contradictory to the above study by Cole and Brooks (2000) which determined that riverine sites in Pennsylvania were wettest. These differences in regionality of wetland sites proves that regional characterization of wetland hydrology, especially by wetland type, is necessary.

Finally, Cole et. al. (2002) assessed the transferability of the HGM approach for wetland classification between sites from Pensylvannia and Oregon, USA. As it is difficult to develop wetland inventories and functional assessment models, the ability to apply wetland classification methods in other areas of the country would be beneficial. Hydrologic data from 18 wetlands in the Ridge and Valley province in Pennsylvania were compared to the hydrologic data from 16 wetlands between the Portland metropolitan area and the Willamette Valley plains sub ecoregion in Oregon (Cole et al., 2002). Three HGM classes were used in this study – Slope, headwater floodplain, and mainstem floodplain wetlands. The results found slope wetlands in both regions had similar hydrologic characteristics, however mainstem floodplain and headwater floodplain wetlands did not share similar hydrologic characteristics (Cole et. al., 2002). The differences in hydrologic characteristics in headwater floodplain and mainstem floodplain wetlands were attributed to the higher percentage of urban development within the watersheds of wetlands in Oregon, particularly around the Portland, OR area (Cole et al., 2002). Cole et. al. (2002) caution that if HGM classification methods are to be used outside of the region which they were developed, wetlands may not be properly classified.

## 2.4 Research Gaps

Research on wetland ecosystems in Atlantic Canada has been limited, especially research on FW. In recent years, there has been a slight increase in research on wetlands as the ecological functions that wetlands provide are being recognized (Amatya et al., 2020; Berkowitz et al., 2020). Of the studies which have been conducted, few have been based in Canada, and even less in the Atlantic provinces (Grabas & Rokitnicki-Wojcik, 2015). In NS, only recently have there been publications specifically evaluating the value of FW functions (Brazner & Achenbach, 2020).

Providing restoration guidance, including hydrologic guidance, would likely improve the effectiveness of compensation projects implemented to meet the requirements under the Nova Scotia Wetland Conservation Policy. To do so, baseline hydrologic conditions of all wetland types must be established. This paper aims to establish the hydrologic conditions of FW in two productive ecoregions of Nova Scotia to fill this research gap. Re-establishing hydrologic conditions in altered FW sites will help ensure that wetland function will restored.

# 3 METHODOLOGY

This study aims to combine the traditional classification methods (field methods) and the HGM approach to establish the baseline hydrology of FW in the Annapolis Valley.

## 3.1 Site description

This study evaluated 18 wetlands located across two ecoregions in the Annapolis Valley of Nova Scotia (Figure 1). The research focused on what is likely Nova Scotia's most common wetland type – forested wetlands. The wetlands were divided into three wetland types: nine wooded peatlands (*Aylesford Bog, Caribou Bog, Dorey Rd. Bog, Meadowvale Bog, Old French Bog, Poor Farm Bog, Red Shirt Bog, West Dalhousie Bog,* and *Whitman Rd. Bog*), five treed swamps (*Cornwallis River TS, Cloud Lake Rd. TS, Kingston TS, North River Rd TS,* and *Payzant TS*), and four shrub swamps (*Cornwallis River SS, Harmony SS, Highway 12 SS,* and *Lakeview SS*) and these wetlands were widely distributed across two ecoregions (Western Ecoregion and Valley and Central Lowlands Ecoregion) (Table 3). All sites were in relatively undisturbed areas and were considered as natural wetlands – wetlands that have not been altered anthropogenically in any way.

Table 3: Wetlands classified by wetland type and ecoregion.

| | **Wooded Peatlands** | **Shrub Swamps** | **Treed Swamps** |
|---|---|---|---|
| **Western Ecoregion** | Aylesford Bog<br>Red Shirt Bog<br>West Dalhousie Bog | Harmony SS<br>Highway 12 SS<br>Lakeview SS | Cloud Lake Rd TS<br>North River Rd TS |
| **Valley and Central Lowlands Ecoregion** | Old French Bog<br>Whitman Rd Bog<br>Poor Farm Bog<br>Dorey Rd Bog<br>Meadowvale Bog<br>Caribou Bog | Cornwallis River SS | Cornwallis River TS<br>Payzant TS<br>Kingston TS |

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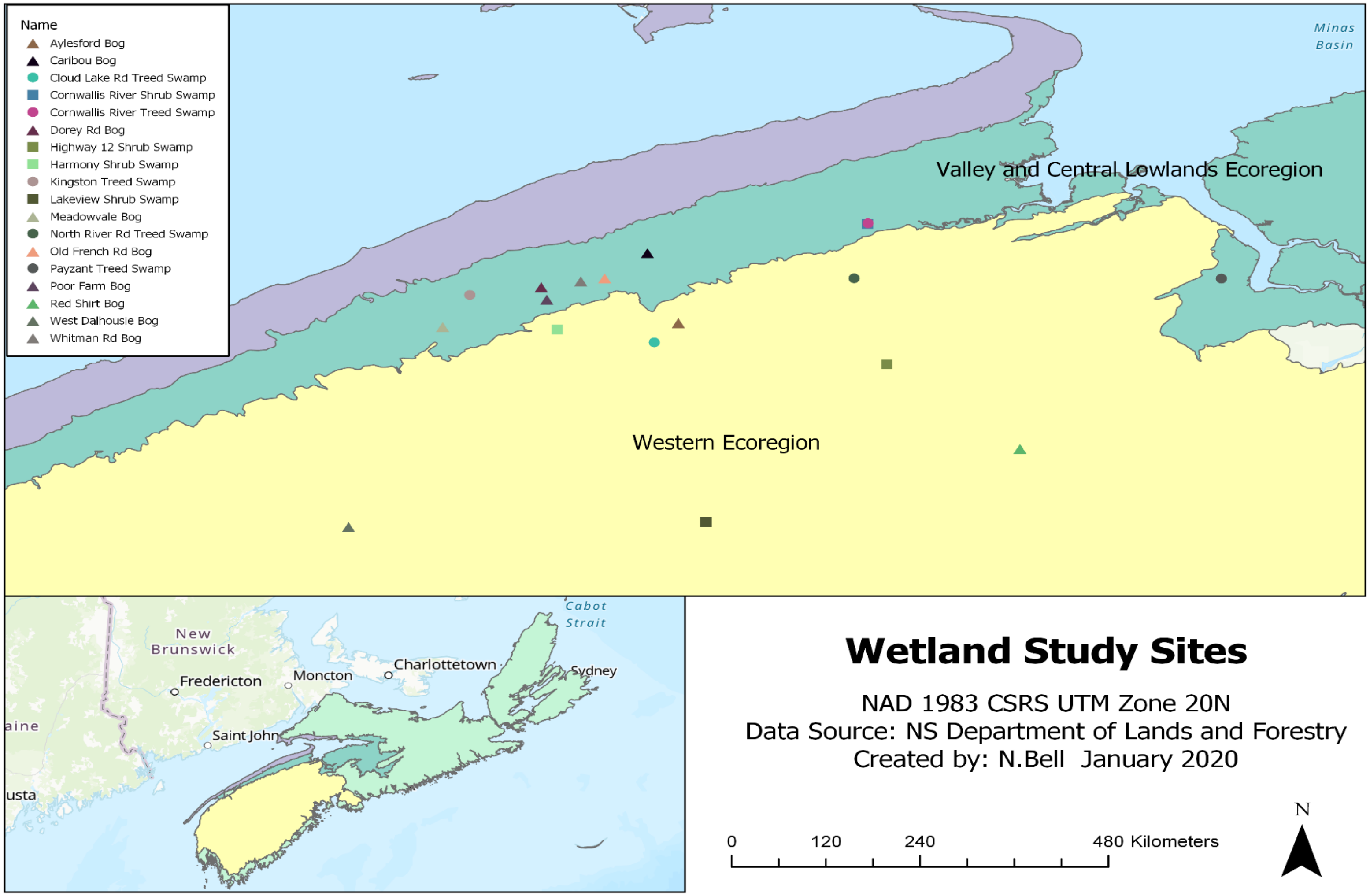


Figure 1: Map of wetland study sites across the Western Ecoregion and Valley and Central Lowlands Ecoregion of Nova Scotia, Canada.

## 3.2 Data collection

### 3.2.1 Water level monitoring

Between 2015 and 2018, the 18 wetlands were instrumented with a central monitoring well equipped with a HOBO U20L Water Level logger. Wells were constructed from 38 mm ABS pipe, 1.5 m in length (1.05 m below ground with 0.45 m stick-up) and were wrapped with a lightweight landscaping fabric which acted as a filter for the well (Figure 2). The wells had one hundred, 5-mm diameter holes drilled into the lower 1.0 m with 3-5 cm spacing.

Figure 2: Well installation in Aylesford Bog November 2015. Photo from Dr. John Brazner.

Each well was placed in the approximate centre of each wetland, at least 50 m from the edges. Once the locations were selected, a 50 mm steel auger was used to hand-auger the well hole 1.0 m deep, or until refusal. Wells were inserted into the auger holes and surficial peat was tampered into the holes to form a seal around the well casing.

Once wells were installed, the HOBO U20L Water Level loggers were programmed to record a  water level hourly. The loggers were tied to the well casings using a 0.75 m string to ensure the loggers were always submerged. Data from the loggers were downloaded once a year in the fall; during the download, a manual water level measurement was taken using a Heron Water Level Meter (Figure 3). The manual water level measurement was used to calibrate the data loggers before final water level compensation was completed using R Software. Water levels were corrected for barometric pressure differences using the nearest Environment Canada weather station – either Greenwood Airport or Kentville CDA.

Figure 3: Taking a manual water level measurement using the Heron Water Level Meter.

#### 3.2.1.1 Piezometer well installation

To measure the vertical hydraulic gradient, piezometer nests were installed at six wetland sites: *Aylesford Bog, Old French Bog, Cornwallis River Treed Swamp, Cornwallis River Shrub Swamp, Harmony Shrub Swamp,* and *Cloud Lake Road Treed Swamp*. Each nest consisted of two piezometers – one deep (total length = 1.53 m) and one shallow (total length = 0.92 m) – constructed of 38 mm ABS pipe. Holes were drilled in the bottom 10 cm of the pipe, spaced 3-5 cm apart, and the wells were wrapped in 5 cm filter sock. The piezometer nests were installed adjacent to the central well in each of the six sites (Figure 4).

Figure 4: Piezometer nests in Cornwallis River Treed Swamp installed on December 5, 2019

The nested piezometers were also equipped with HOBO U20L Water Level loggers, that recorded a water level measurement hourly. The pressure difference between the deep and shallow piezometer indicated the direction and magnitude of vertical hydraulic gradients.

### 3.2.2 Soils Analysis

Peat depth measurements were performed on the 18 wetland sites in the Fall of 2019. At each site, adjacent to the central well, 1.5 m chimney sweep rods attached together totalling a maximum of 4.5 m in length were pushed into the organic layer until refusal (Figure 5). The depth of the organic layer was recorded for each wetland site as the total length of the chimney rods subtract the length of stickup when pushed into ground.

Figure 5: Chimney sweep rods placed adjacent to the central well at Red Shirt Bog.

Additionally, boreholes were augered using a 50-mm steel auger at each wetland site to evaluate the decomposition of organic material at various depths (Figure 6). The boreholes were advanced at 50-cm increments until a mineral soil layer, or bedrock, was reached. At each increment, the decomposition level of the peat was characterized using the von Post scale of decomposition; this was done by squeezing the peat in a closed hand and observing the color of the solution that was expressed through the fingers, the nature of the fibres, and the proportion of the peat sample that remains in the hand (von Post, 1922).

Figure 6: Auger used to drill boreholes for peat decomposition testing.

## 3.3 Spatial Analysis

The spatial analysis considered six parameters for evaluation: total wetland area in hectares (*wetland area*), total watershed area in hectares (*watershed area*), percent of watershed area that is forested (*%Forested*), percent of the watershed area that has been anthropogenically influenced (*%Anthropogenic*), percent of wetland area with TPI of flat slopes (*wetland TPI*), average topographic wetness index (*wetland TWI*), and dominant watershed soil drainage classification (*soil drainage class*).

### 3.3.1 Wetland and Watershed Delineation

As the wetlands and watersheds of the 18 study sites had not been previously studied, it was necessary to first delineate the wetland and watershed areas. The location of the central well was georeferenced, and the wetland area was delineated using aerial imagery and wet areas mapping (WAM) from the Department of Lands and Forestry (2012) to develop the wetland area polygons in ArcGIS Pro.

The watershed delineations were performed using the ArcHydro tool on ESRI's ArcMap version 10.5. The watershed delineation process began by importing the Nova Scotia provincial digital elevation model (DEM) (Department of Lands and Forestry, 2006) and clipping it to extents larger than the wetland areas to reduce processing time by decreasing the processing extents. Next, the DEM was manipulated such that the low points were "filled" with water (Fill Sinks), and the flow direction was determined (Flow Direction). The Flow Accumulation tool then used the flow direction to determine approximately how many cells were required to initiate a stream; In this case, it was determined that 150 cells would be used to initiate a stream. Next, the stream definition was performed (Stream Definition), followed by stream segmentation (Stream Segmentation). The subcatchments were converted to raster form using Catchment Grid Delineation and Catchment Polygon Processing. The drainage lines through the subcatchments were delineated using Drainage Line Processing. Adjoint catchments were determined using Adjoint Catchment Processing. Finally, the watershed was delineated automatically using the Outlet Point Processing tool and a selected outlet point. It is important to note that it was necessary to ensure that the outlet point was located on a drainage line for the watershed to be properly delineated.

### 3.3.2 Land cover layers

For the land cover layers – *%Forested, %Anthropogenic, soil drainage class* – it was necessary to first clip them to each watershed and individually process the layers. Once the layers were clipped, they were projected to the same data projection as the wetlands (NAD 1983 CSRS UTM Zone 20N) and the percentage of land attributed to each parameter was calculated from the attribute table.

The *%Forested* parameter was chosen as the amount of forested land in a wetland contributes to its classification type and influences the hydrology as trees uptake water from the soil (Ehrenfeld et. al., 2003). The data for the forestry layer of the wetlands was obtained from the Department of Lands and Forestry (2015).

The *%Anthropogenic* layer was chosen to evaluate the amount of potential runoff present in the wetland due to impervious surfaces such as roads and buildings. The land uses in each watershed that were classified as developed, roadways, urban, or agricultural were totalled to assess the percentage of each watershed that was anthropogenically influenced. Data for the *%Anthropogenic* layer was obtained from GeoNova's Data Locator and the NS Topographic Database for Roads/Rails and Buildings layers (2018) and the Forestry land cover layer from the Department of Lands and Forestry (2015).

The *soil drainage class* layer was chosen as forested wetlands tend to have poorly drained soils (Tiner, 2016); the poorly drained soils allow the wetlands to retain a higher water table as the water drains through them more slowly. Additionally, the soils in the contributing watershed influence how the water is fed into the wetland. The data for the soils layer was downloaded from the National Soil Database (NSDB) 's soil surveys of Kings County (1966), Hants County (1978), Lunenburg County (1958), and Annapolis County (1969).

### 3.3.3 Wetland Topographic Position Index

The *wetland TPI* is a measure of slope and contributing watershed area which identifies convergent topography or small depressions in landscapes which can lead to the formation of wetlands(Riley et. al., 2017). The calculation of the TPI used the Nova Scotia provincial digital elevation model (DEM)  and watershed area of each wetland. The provincial DEM was obtained from the Department of Lands and Forestry (2006). To calculate the topographic position index, a model tool was built in ArcGIS Pro. The model, seen in Figure 7 consisted of two input parameters, an elevation input, and a neighborhood input. The elevation input used in the models was the Provincial DEM, and the neighborhood (number of cells to evaluate around focal cell) was determined to be a radius of 2 cells. A Focal Statistics tool was used to calculate the mean elevation within the neighborhood, then the Raster Calculator tool calculated the difference in elevation between the actual elevation and the mean elevation. The output raster, TPI was produced from the model (De Reu et al, 2012).

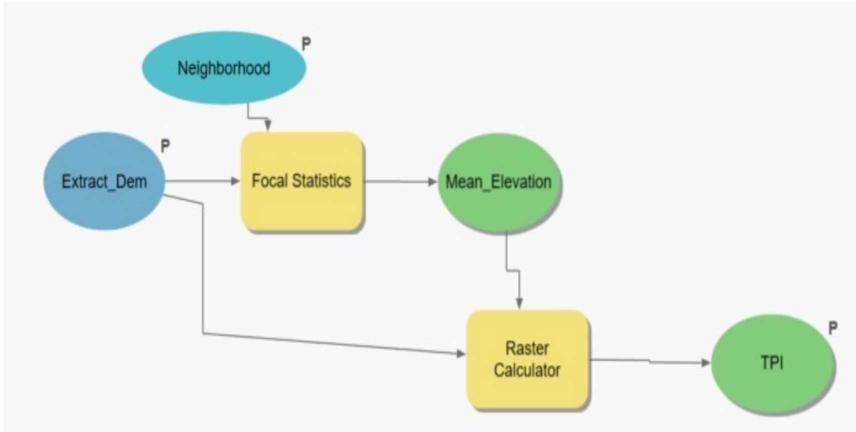


Figure 7: Topographic position Index (TPI) model tool used to calculate TPI for six wetland study areas.

Once the TPI raster was produced, the values could then be subdivided into morphological classifications based on topography. The classes were subdivided as per De Reu et al. (2012) and can be seen in Table 4.

Table 4: TPI classification into landscape position values (De Reu et al., 2012) where $Z_0$ is the value of each cell in the raster and SD represents the standard deviation of cell values in the raster.

| **Morphologic Class** | **Value** |
|---|---|
| Ridge | $Z_0 > SD$ |
| Higher Slopes | $SD \geq Z_0 > 0.5SD$ |
| Flat Slopes | $0.5SD \geq Z_0 > -0.5SD$ |
| Lower Slopes | $-0.5SD \geq Z_0 \geq -SD$ |
| Valley | $Z_0 < SD$ |

### 3.3.4 Wetland Topographic Wetness Index

The wetland TWI was developed by Beven and Kirkby (1979) and is a function of the local upslope drainage area ($a$) and slope ($\beta$) of the wetland. The relationship is defined as ln($a$/tanβ) (Beven & Kirkby, 1979). *TWI* is commonly used to determine the control of topography on hydrological processes, for example the larger the TWI, the more likely the area is to be saturated (Sørensen et al., 2006). The topographic wetness index was calculated in ArcMap version 10.5 using the Nova Scotia provincial DEM (Department of Lands and Forestry, 2006) and ArcHydro tools. The provincial DEM was used to calculate flow accumulation (FA) in the watershed (contributing drainage area, *a*) and slope (radians). The raster calculator tool was then used to calculate tanβ. The FA was scaled to the cell size of the DEM (25) using the raster calculator. Finally, the raster calculator tool was used to calculate the TWI for each cell in the raster as Ln(FAscaled)/ tanβ. The average value of the raster dataset was saved as the *wetland TWI.*

### 3.4 Statistical analysis

Inferential statistics were used to determine the baseline hydrologic conditions for each wetland type. The statistical analysis was limited to the dates where there was data from all 18 sites. The overall period of analysis was determined to be December 2018 to November 2019, however shorter time periods (Growing season (May to September 2019), Spring (May-June, 2019), Summer (July-August, 2019), and Fall (September-October, 2019)) were also examined. Boxplots and hydrographs were used to visually assess the hydrologic characteristics of each wetland type. For the piezometer nests, direction of vertical flow was determined by examining the differences between the water levels in the long and short piezometer wells.

For each site, six hydrologic descriptive statistics were calculated (*mean WL, median WL, maximum WL, minimum WL, Range in WL,* and *standard deviation in WL*) for each of the time periods listed above using Minitab statistical software (Minitab Inc., 2017). The overall percentage of time water tables were very dry (WL < -0.4 m), dry (-0.4 m ≤ WL ≤ -0.2 m), saturated ( -0.2 m ≤ WL ≤ 0 m) or inundated (WL > 0 m) was determined and summarized in a table. To determine whether there were differences among wetland types (wooded peatlands, shrub swamps, and treed swamps) and ecoregions (Western, Valley and Central Lowlands) two-way analysis of variance (ANOVAs) were completed with Tukey HSD post-hoc tests. These two-way ANOVAs were completed for each of the five time periods. As the shrub swamp wetlands were unevenly distributed by type across ecoregions (Table 1), a separate one-way ANOVA was completed for the Western Ecoregion to evaluate differences between wetland types over the five time periods.

The hydrologic metrics and watershed characteristics were evaluated using a Principal Components Analysis (PCA) to evaluate interactions between variables. The multivariate ecological data software, PC-Ord was used to perform the PCA (Wild Blueberry Media LLC, 2018). The PCA biplots were used to visually assess groupings among wetland types using the hydrologic descriptive statistics.

Finally, to examine the landscape characteristics that influence hydrologic regimes in forested wetlands, best subsets regression was employed to identify influential variables for predicting hydrologic metrics for each time period. The best subsets regression model considered the results of the seven spatial analysis variables (*watershed area, wetland area, %Forested, %anthropogenic, wetland TPI, wetland TWI, watershed soil drainage class*) and the results of the soils analysis (*peat depth*). Multiple linear regression models were then used to further analyse the results of the best subsets regression models for each time period. Level of significance for all analyses was $\alpha = 0.05$.

# 4 RESULTS AND DISCUSSION

## 4.1 Wetland and Watershed Characteristics

Key characteristics of the 18 study wetlands, and their watersheds, are summarized in Table 5, sorted by wetland type (wooded peatland, shrub swamp, treed swamp). Maps and visual representations of these results can be found in Appendix A.

The wetlands ranged in size from 1.7 to 43.5 ha, with watershed areas ranging between 6.0 and 1409.0 ha. As expected, the wooded peatlands had smaller watershed areas than the shrub swamps and treed swamps as these wetlands should be primarily groundwater- or precipitation-fed; while shrub swamps and treed swamps are typically part of a larger drainage network and receive their water from various water sources such as groundwater, precipitation, streamflow, and runoff (Mitsch & Gosselink, 2015).

The watersheds of wooded peatlands had the greatest variability in forested land cover, ranging from 12.6-88.9%, while the forest cover in the watersheds of shrub swamps and treed swamps ranged from 53.2-91.8% and 41.4-93.9%, respectively (Table 5). The percentage of forested area in a watershed influences the hydrology in terms of surface processes, evapotranspiration, hillslope runoff generation, and groundwater (Pike, 2010). Wooded peatlands had the lowest levels of anthropogenic disturbance in their watersheds, ranging from 0-35% (Table 5). *Dorey Rd. Bog* was an exception, with 51% of the watershed classified as anthropogenically influenced, due to the presence of roadways. Levels of anthropogenic disturbance in the watersheds of the treed swamps and shrub swamps ranged from 0.0-51.8%, and 0.4-44.7%, respectively.

*Cornwallis River Treed Swamp*, *Kingston TS,* and *Cornwallis River SS* had the highest values (44.9%,51.8%,44.7%, respectively) as the watershed areas of these wetlands are located within the town boundaries of Kentville and Kingston, NS.

According to the CWCS, peatlands must have a layer of peat greater than or equal to 0.40 m, measured in the centre of the wetland (National Wetlands Working Group et al., 1997). The depth of peat in the study wetlands ranged from 0.2 to 4.6m (Table 5), with 15 of the 18 wetlands having a peat layer deeper than 0.40 m. *Dorey Rd. Bog*, *Poor Farm Bog*, and *Highway 12 Shrub Swamp* had peat depth measurements of 0.2 m, which may be due to their geographic location in the Annapolis Valley Sand Barrens (Bush & Baldo, 2019). The Annapolis Valley Sand Barrens terrestrial habitat was created by glacial outwash deposits, and windblown sand and dunes, which could explain the shallower peat layers which are located over restrictive soil layers (poorly drained soils).

The drainage class of the dominant soil type in each of the watersheds spanned the full range of the soil drainage classification system (Table 5). Wooded peatlands generally possessed poorly to very poorly drained soils, with exceptions being *Meadowvale Bog, Aylesford Bog, Whitman Rd. Bog, and West Dalhousie Bog*. Soils in eight wetlands (*Cornwallis River SS, Cornwallis River TS, Kingston TS, North River Rd. TS, Highway 12 SS, Meadowvale Bog, Whitman Rd. Bog*) were classified as well drained or rapidly drained.

Between 32.9-55.3% of the wetland area in 17 of study wetlands was classified as a flat slope according to TPI values; the exception of *Payzant Rd. TS* in which 75% of the wetland was classified as flat slopes. This was expected as flat slopes would indicate depressional areas or floodplains where wetlands are typically located (Mitsch & Gosselink, 2015). The average TWI for the 18 wetlands ranged from 8.0-13.0 (Table 5).

Table 5a: Characteristics of study wetlands, grouped by wetland type.

| Study wetland | Wetland Area (ha) | Watershed Area (ha) | Wetland TPI: % Flat | Average Wetland TWI | Peat Depth (m) | Watershed Soil Drainage Class | % Forested | % Anthropogenic |
|---|---|---|---|---|---|---|---|---|
| *Wooded Peatlands* | | | | | | | | |
| Aylesford | 10.2 | 44.0 | 42.8 | 8.4 | 2.8 | Imperfect | 78.2 | 0.0 |
| Caribou | 31.1 | 43.4 | 36.8 | 9.5 | 4.5 | Very poor | 40.7 | 7.0 |
| Dorey Rd. | 21.6 | 79.5 | 44.8 | 9.7 | 0.2 | Poor | 12.6 | 51.0 |
| Meadowvale | 1.7 | 14.4 | 45.0 | 8.6 | 0.6 | Rapid | 70.0 | 21.2 |
| Old French | 21.1 | 26.6 | 53.5 | 9.7 | 2.4 | Very poor | 49.0 | 0.5 |
| Poor Farm | 43.5 | 115.6 | 48.8 | 9.0 | 0.2 | Poor | 20.0 | 35.0 |
| Red Shirt | 42.8 | 133.9 | 55.3 | 10.4 | 2.7 | Poor | 81.2 | 0.0 |
| West Dal | 2.0 | 6.0 | 48.1 | 8.0 | 1.4 | Imperfect | 88.9 | 5.4 |
| Whitman Rd. | 6.9 | 13.9 | 46.5 | 8.9 | 1.4 | Rapid | 39.8 | 14.5 |
| *Shrub swamps* | | | | | | | | |
| Cornwallis R. | 13.7 | 1409.0 | 48.1 | 12.2 | 1.2 | Well | 53.2 | 44.7 |
| Harmony | 4.1 | 264.0 | 43.4 | 9.9 | 2.6 | Well | 91.8 | 5.2 |
| Highway 12 | 8.5 | 23.6 | 39.0 | 9.5 | 0.2 | Rapid | 54.2 | 18.6 |
| Lakeview | 7.8 | 305.0 | 49.7 | 10.6 | 1.8 | Poor | 86.1 | 0.4 |

Table 5b: (continued) Characteristics of study wetlands, grouped by wetland type

| Study wetland | Wetland Area (ha) | Watershed Area (ha) | Wetland TPI (% Flat) | Average Wetland TWI | Peat Depth (m) | Watershed Soil Drainage Class | % Forested | % Anthropogenic |
|---|---|---|---|---|---|---|---|---|
| *Treed Swamps* | | | | | | | | |
| Cornwallis R. | 5.4 | 1398.0 | 48.2 | 11.8 | 1.5 | Well | 53.2 | 44.9 |
| Cloud Lake Rd. | 6.5 | 99.5 | 45.4 | 8.4 | 2.6 | Imperfect | 93.9 | 0.0 |
| Kingston | 26.8 | 157.5 | 37.1 | 9.5 | 1.9 | Rapid | 41.4 | 51.8 |
| North R. Rd. | 6.0 | 42.8 | 32.9 | 8.5 | 1.2 | Well | 80.5 | 19.4 |
| Payzant Rd. | 9.4 | 63.2 | 75.6 | 13.0 | 3.3 | Imperfect | 83.1 | 9.8 |

The key characteristics (*wetland area, watershed area, wetland TWI, wetland TPI, watershed soil drainage class, peat depth, % forested, % anthropogenic*) for the 18 wetlands were evaluated using a principal components analysis (PCA) examine whether there were particular characteristics associated with different wetland types (Figure 8). Interestingly, nearly all the sites in the Valley and Central Lowlands ecoregion are present on the left and the Western ecoregion sites are on the right; this suggests differences between ecoregions.

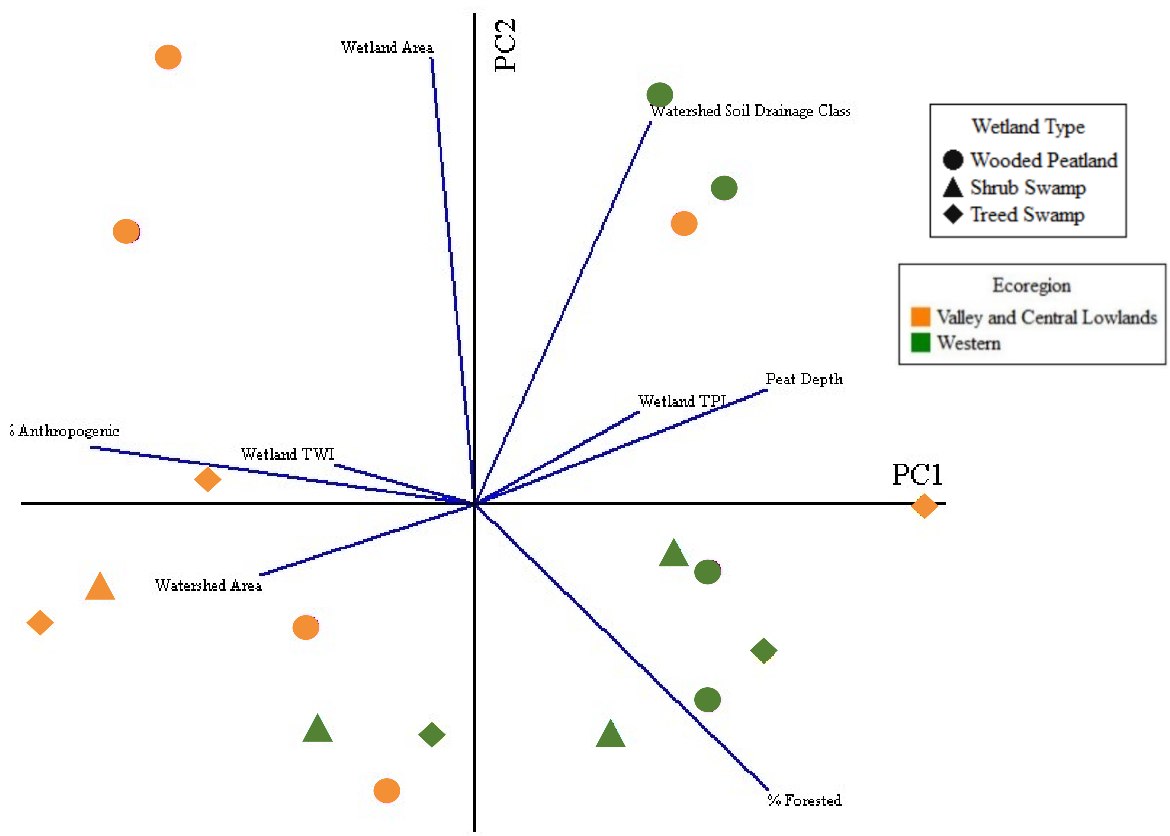


Figure 8: Biplot of PC1 vs. PC2, for key characteristics of 18 wetlands grouped by wetland type and ecoregion. PC1 represents 32% of total variation, while PC2 represents an additional 23%.

The peat depth in three wetlands was less than expected as most classification systems indicate that peatlands maintain at least 40 cm of peat (<0.40 m) (National Wetlands Working Group et al., 1997). Interestingly, all of the study wetlands have some level of anthropogenic disturbance in their watersheds (Table 5), which may influence their hydrology (Ehrenfeld et al., 2003). Previous studies have shown that disturbed and natural wetlands differ in terms of hydrological function (Moreno-Mateos et al., 2012; Zedler, 2003). *Cloud Lake Rd. TS* and *Caribou bog* are good examples as these watersheds do not have high percentages of anthropogenic disturbance classified during the spatial analysis; however, upon visiting these sites, there is evidence of nearby forestry activity and peat harvesting, respectively. This presents reliability issues with the forestry data layers used in the spatial analysis.

## 4.2 Hydrologic Regime of Forested Wetlands

The hydrologic regimes of each wetland type are presented in this section. All water level measurements are given with respect to the ground surface (0 m).

### 4.2.1 Wooded Peatlands

The wooded peatlands had water levels that were generally within -0.25 m of the ground surface, except *Caribou Bog* and *Meadowvale Bog* (Figure 9). The water levels in *Caribou Bog* were lower than the other wooded peatlands; this is due to disturbance caused by peat harvesting and associated ditching, which is occurring within 250 m of the central well. Conversely, the Meadowvale bog monitoring well was inundated for the entirety of the study period. It was noted that the site was surrounded by urban development, and this likely altered the hydrology of wetland. Due to these potential confounding factors, *Caribou Bog* and *Meadowvale Bog* were not included in further analyses of hydrology patterns.

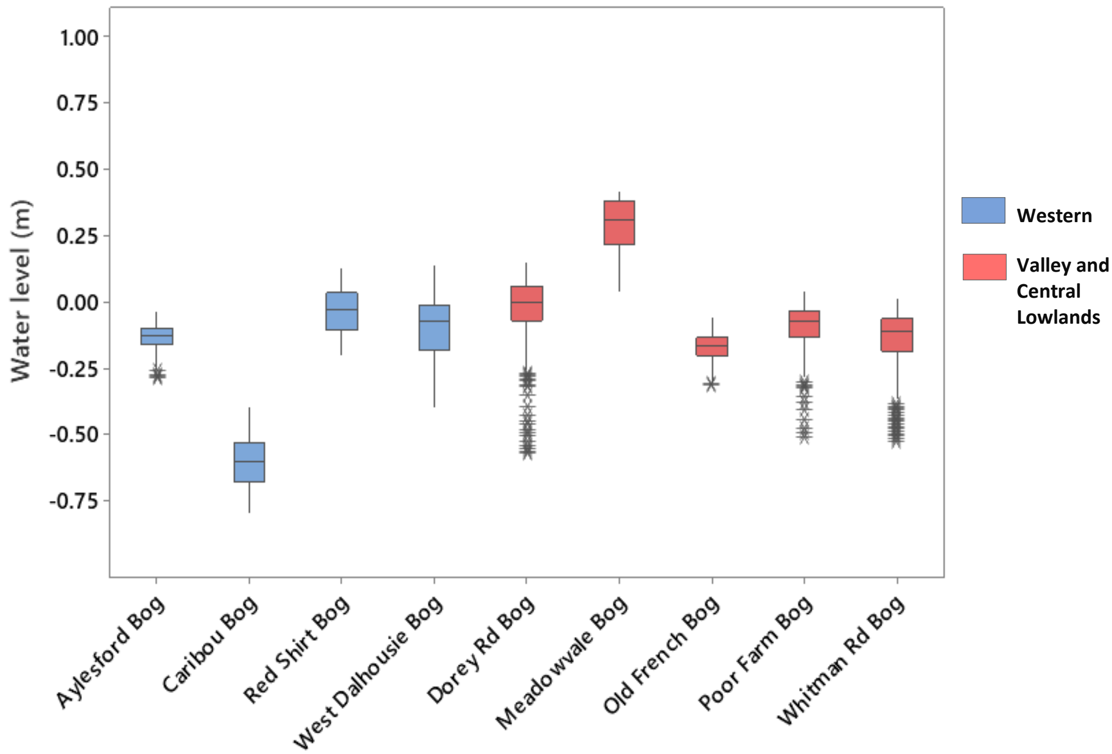


Figure 9: Boxplot of the mean daily water levels in wooded peatlands relative to ground surface (0 m) over the growing season (May-October 2019) grouped by Ecoregion. The "*" indicates outliers in the data, median values are represented by lines in the centers of boxes, and the interquartile ranges are represented by the boxes.

During the growing season, total water level ranges between 0.25 m (*Aylesford Bog*) to 0.75 m (*Dorey Rd. Bog*) were observed in the remaining seven wooded peatlands. Maximum water levels ranged from 0.04 m (*Old French Bog*) to 0.30 m (*Red Shirt Bog*) and typically occurred during early spring (March-May). Minimum water levels ranged from -0.58 m (*Dorey Rd. Bog*) to -0.20 m (*Red Shirt Bog*) and occurred during the summer months. As expected, the wooded peatland sites remained saturated (mean WL ≥ -0.2 m) – even during the summer months – with mean depths ranging between -0.17 m (*Old French Bog*) and -0.04 m (*Red Shirt Bog*). The percentage of time each wetland was inundated or saturated (WL ≥ - 0.20 m) ranged between 85 and 99% with respect to the entire time study period of analysis (Table 6).

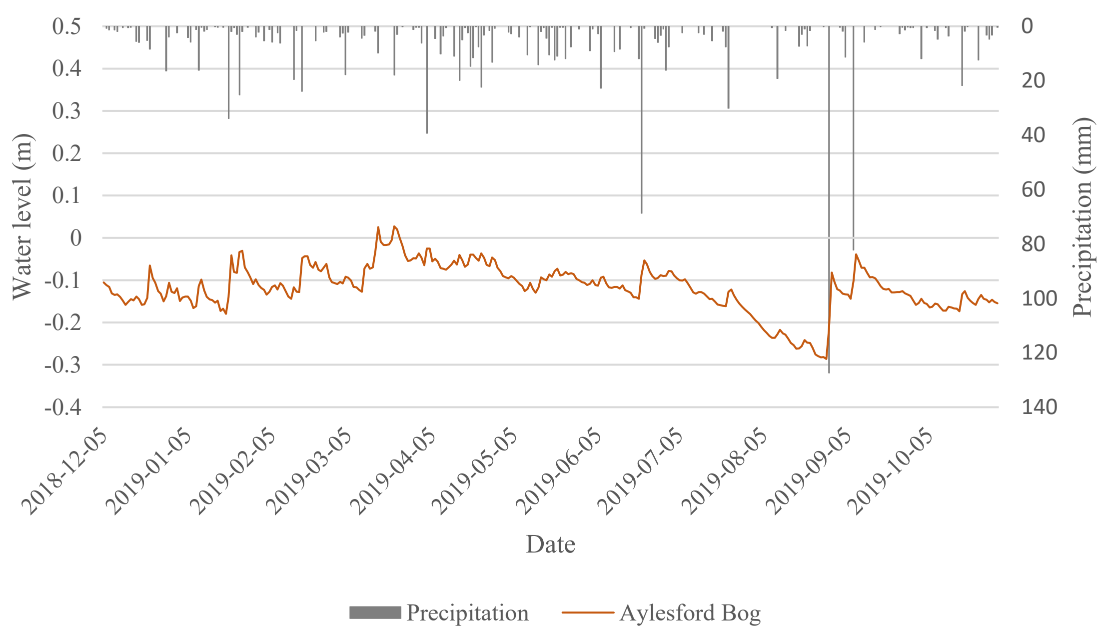


Figure 10: Hydrograph of Aylesford Bog based on daily mean water levels (m) relative to ground surface (0 m) and precipitation (mm) measured at the Greenwood Airport climate station over the entire period of analysis (December 2018-November 2019).

In summary, wooded peatlands in this study possessed water tables within – 0.20 m of the ground surface for the majority (85%+) of the year (Table 6), and experienced small (approx. 15 cm) decreases in water levels throughout the summer months (July-August) (Figure 10). It should be noted that there were two major rainfall events in August and September 2019. There was a 127 mm rainfall event on August 29/30, 2019, which was caused by the remnants of Tropical Storm Erin, and a 82 mm rainfall event on September 7, 2019 associated with Hurricane Dorian. These two rainfall events resulted in rapid restoration of saturated water levels in the wooded peatlands in the early fall.

Table 6: Percentage of water level measurements, during the entire period of analysis (December 2018-November 2019), in four depth strata. Classified by wetland type.

| **Study wetland** | **Very Dry** (WL ≤ -0.4m) | **Dry** (-0.4 m < WL ≤ -0.2m) | **Saturated** (-0.2 m < WL ≤ 0 m) | **Inundated** (WL ≥ 0 m) |
|---|---|---|---|---|
| *Wooded Peatlands* | | | | |
| Aylesford | 0.0% | 8.3% | 90.4% | 1.3% |
| Caribou | 94.5% | 4.9% | 0.5% | 0.1% |
| Dorey Rd. | 4.0% | 4.1% | 19.1% | 72.8% |
| Meadowvale | 0.0% | 0.0% | 0.0% | 100.0% |
| Old French | 0.0% | 14.8% | 84.8% | 0.4% |
| Poor Farm | 1.6% | 5.2% | 79.9% | 13.3% |
| Red Shirt | 0.0% | 0.7% | 37.1% | 62.2% |
| West Dalhousie | 0.4% | 11.1% | 55.3% | 33.3% |
| Whitman Rd. | 5.2% | 7.4% | 82.5% | 4.9% |
| *Shrub Swamps* | | | | |
| Cornwallis R. | 0.0% | 0.0% | 80.1% | 19.9% |
| Harmony | 0.0% | 0.0% | 33.6% | 66.4% |
| Highway 12 | 9.7% | 26.0% | 57.5% | 6.8% |
| Lakeview | 0.0% | 2.0% | 20.4% | 77.5% |
| *Treed Swamps* | | | | |
| Cornwallis R. | 0.0% | 6.0% | 88.1% | 5.9% |
| Cloud Lake Rd. | 0.0% | 0.0% | 71.1% | 28.9% |

| | | | | |
|---|---|---|---|---|
| Kingston | 0.0% | 0.0% | 70.1% | 29.9% |
| North River Rd. | 0.0% | 69.7% | 30.2% | 0.1% |
| Payzant Rd. | 0.0% | 4.4% | 36.9% | 58.7% |

### 4.2.2 Shrub Swamps

Mean water levels in the four shrub swamps ranged from -0.20 m *(Highway 12 SS*) to 0.05 (Lakeview SS). The water levels in three of the sites (*Cornwallis R SS, Harmony SS, Lakeview SS)* remained above -0.2 m for the entire period of analysis, the exception being *Highway 12 SS*, where water levels reached a minimum of -0.6 m (Figure 11). *Cornwallis*

*River SS* had the highest water level (0.93 m) which occurred just after Hurricane Dorian on September 9, 2019.

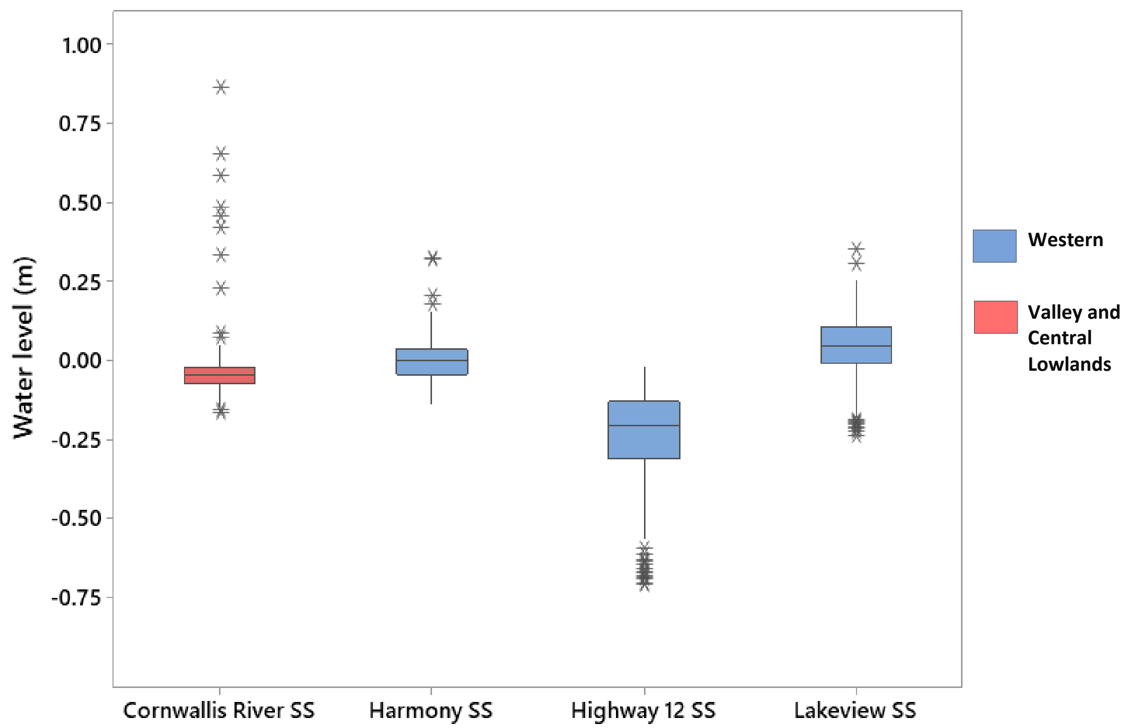


Figure 11: Boxplot of the mean daily water levels in shrub swamps (SS) relative to ground surface (0 m) over the growing season (May-October 2019) grouped by Ecoregion. The "*" indicates outliers in the data, median values are represented by lines in the centers of boxes, and the interquartile ranges are represented by the boxes.

Total water level ranges varied between 0.61 m (*Harmony SS*) and 1.13 m (*Cornwallis River SS*) over the growing season (May-October 2019). The maximum water levels occurred during the fall months after large rain events, while the minimums occurred during the summer months (July-August). The shrub swamps were saturated or inundated between 64-100% of the study period (Table 6). The water level regime in *Highway 12 SS* was markedly different from the other three shrub swamps, with periods where the water levels were -0.4 m below ground surface (very dry). Drainage channels associated with a previous attempt to establish an orchard in the area are the likely cause of these dryer conditions.

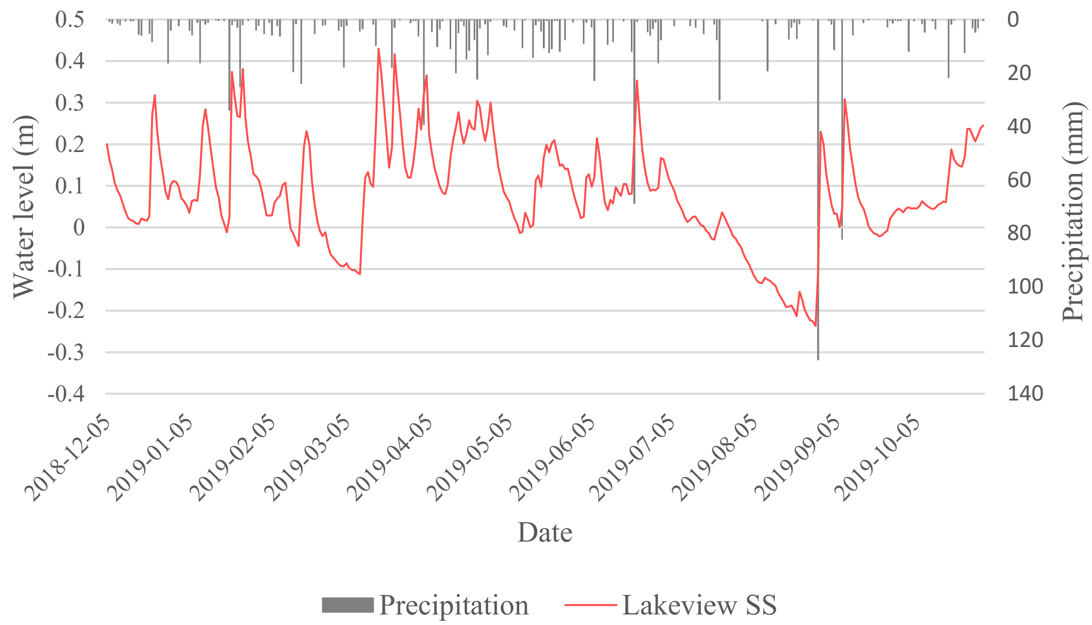


Figure 12: Hydrograph of Lakeview SS based on daily mean water levels (m) relative to ground surface (0 m) and precipitation (mm) from the Greenwood Airport climate station over the entire period of analysis (December 2018-November 2019)

In general, the hydrologic regime of shrub swamps was observed to be flashier than that of wooded peatlands with greater water level responses to rainfall events (Figure 12). The shrub swamps were saturated, with water tables above -0.20m, for the majority (64%+) of the study period, but during periods without precipitation, water levels decreased by 0.20 – 0.40 m (Figure 12).

### 4.2.3 Treed Swamps

Water levels in all treed swamps were within -0.30 m of the ground surface (0 m) during the growing season (Figure 13). Total ranges in water levels varied between 0.23 m (Kingston TS) and 1.12 m *(Cornwallis River TS*), and mean water levels varied between -0.23 m (*North River Rd. TS*) and -0.19 m (*Kingston TS*). *North River Rd. TS* had the lowest water levels of the five treed swamps, reaching a minimum of -0.37 m, while the highest water levels were recorded in *Cornwallis River TS* at 0.83 m.

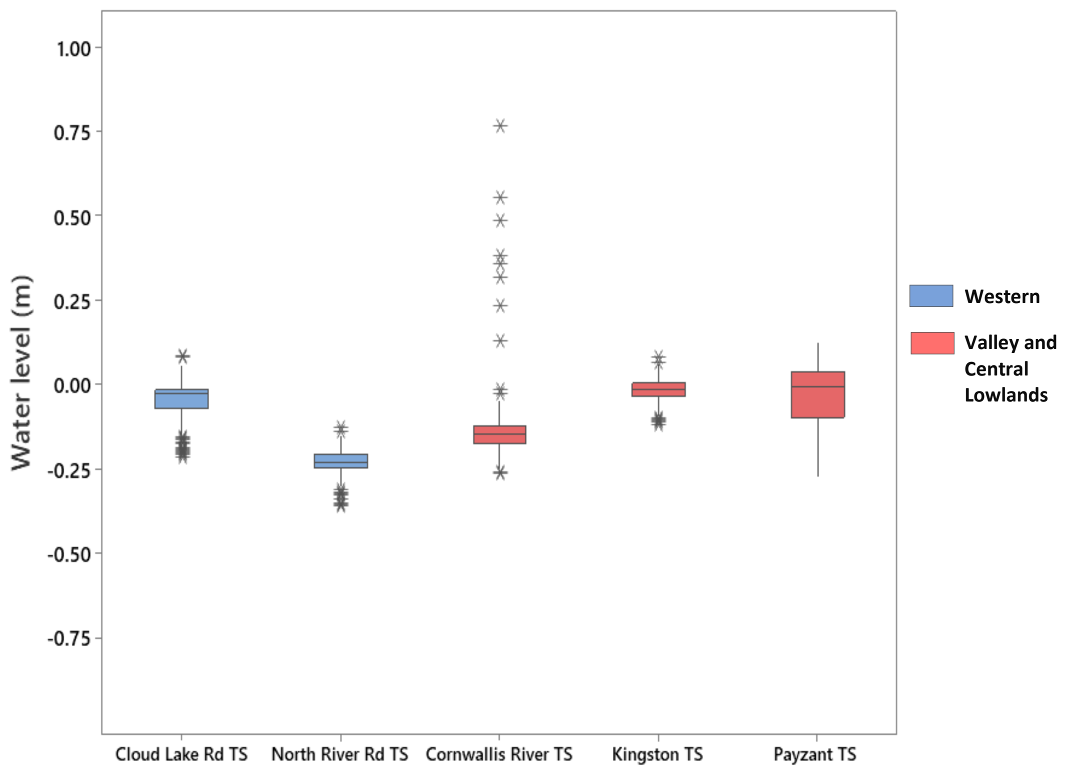


Figure 13: Boxplot of the mean daily water levels in treed swamps (TS) relative to ground surface (0 m) over the growing season (May-October 2019) grouped by Ecoregion. The "*" indicates outliers in the data, median values are represented by lines in the centers of boxes, and the interquartile ranges are represented by the boxes.

Similar to the shrub swamps, the water levels in the treed swamps fluctuated more than wooded peatlands throughout the year (Figure 14). The maximum water levels were observed during the early spring (March-April) during periods of snowmelt and precipitation. The minimum water levels occurred during the summer months, when all five wetlands became dry (-0.2 m > WL ≥ -0.40 m). Saturated or inundated (WL ≥ -0.2 m) conditions existed between 94% (*Cornwallis River TS)* and 100% (*Kingston TS*) of the time. The exception was *North River Rd. TS* (30.3%) as it was dry (-0.2 m > WL ≥ -0.40 m ) for the majority (67%) of the year (Table 6).

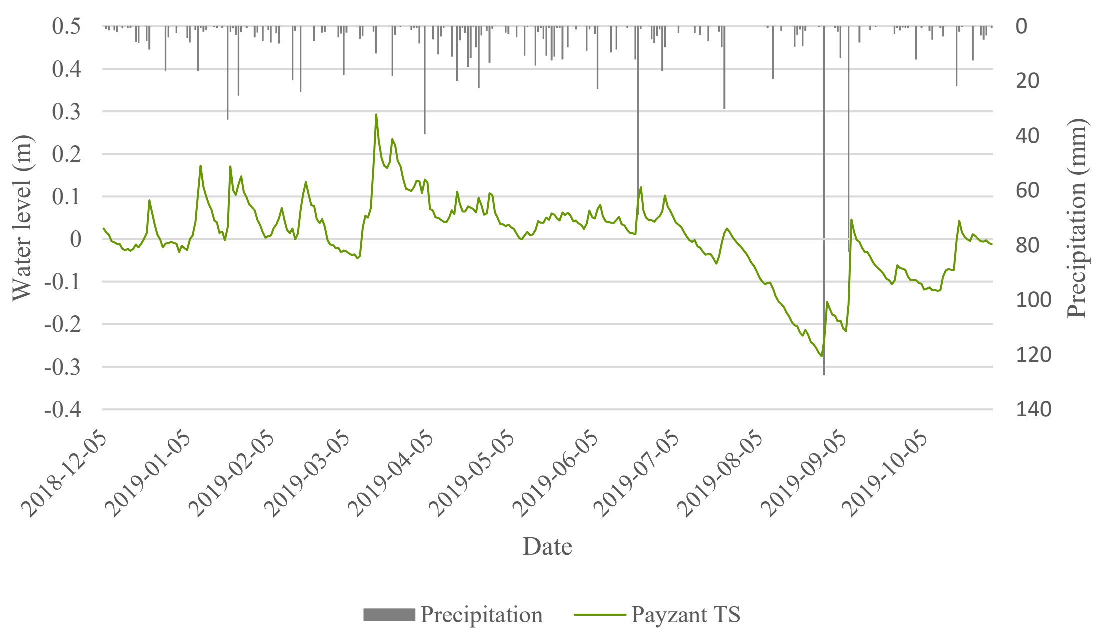


Figure 14: Hydrograph of Payzant TS based on daily mean water levels (m) relative to ground surface (0 m ) and precipitation (mm) from the Kentville CDA climate station over the entire period of analysis (December 2018-November 2019)

Treed swamps possessed a dynamic water level regime, influenced by precipitation events, with mean water levels around -0.15 m over the growing season. During time periods without appreciable rainfall, water levels decreased by 30 - 40 cm; this occurred during mid-summer (July-August). Water levels typically returned to within -0.20 m of the ground surface after large rainfall events in the fall and remained at this level for the remainder of the winter.

### 4.2.4 Characterization of Vertical Hydraulic Gradients

Six wetlands were instrumented with piezometer nests adjacent to the central well (*Aylesford Bog, Old French Bog, Cornwallis River SS, Harmony SS, Cornwallis River TS,* and *Cloud Lake Rd TS)* to determine the direction of vertical groundwater flow in the centre of the wetlands. Five wetlands displayed upward vertical hydraulic gradients (groundwater discharge) for the majority (73%+) of the study period (*Cornwallis River SS, Harmony SS, Cornwallis River TS, Cloud Lake Rd. TS,* and *Old French Bog*). *Aylesford Bog* was the exception, displaying downward vertical hydraulic gradient (groundwater recharge) for the majority of the study period. A dominant groundwater recharge regime would be expected for a bog wetland (National Wetlands Working Group et al., 1997), with shrub and treed swamp wetlands expected to display a combination of both recharge and discharge periods depending on antecedent hydrologic conditions. The dominant upwards vertical hydraulic gradient in *Old French* was unexpected and would indicate that this wetland may be more accurately characterized as a fen as it is minerotrophic (predominantly groundwater-fed) for the majority (99.5%) of the year. *Old French Bog* is also located in the sand barrens (Bush & Baldo, 2019), which may explain the upward hydrologic gradient as the surrounding surficial geology causes faster drainage during dry periods. The hydrology in the remainder of the wetlands – the swamps – is as expected for these wetland types (Table 7) (Cole & Brooks, 2000).

Table 7: Piezometer nest results for six wetlands over the entire study period.

| Wetland | Dominant Direction of Vertical Flow | Percent of Time |
|---|---|---|
| Aylesford Bog | Downwards | 99.9% |
| Old French Bog | Upwards | 99.5% |
| Cornwallis River SS | Upwards | 97.1% |
| Harmony SS | Upwards | 99.8% |
| Cornwallis River TS | Upwards | 99.9% |
| Cloud Lake Rd. TS | Upwards | 73.3% |

## 4.3 Comparisons by Wetland Type and Eco Region

In the previous sections it was apparent that shrub swamps and treed swamps had more dynamic hydrologic behaviour compared to wooded peatlands (Figures 10, 12, 14). Water levels in wooded peatlands had the least amount of fluctuation throughout the study period while shrub swamps had the greatest. This observation was expected as swamps would typically receive greater amounts of surface runoff, with greater hydrologic inputs during large precipitation and snowmelt events (Cameron, 2009).

The differences in hydrologic behaviour between the three wetland types and two ecoregions (Western, Valley and Central Lowlands) were examined using inferential statistical methods. A two-way ANOVA revealed no statistically significant differences between wetland types or ecoregions when four of six hydrologic metrics were evaluated (*Mean WL, Median WL, Standard deviation in WL,* and *Minimum WL*). *Range in WL* and *Maximum WL* were the exceptions. For these two variables, statistically significant differences were detected among wetland types or between ecoregions for all of the evaluated time periods ($p \leq 0.05$). The two-way ANOVAs performed on *Range in WL,* and *Maximum WL* metrics did not result in significant interaction terms between the wetland types and ecoregions ($p > 0.05$) for the evaluated time periods. Therefore, wetlands of the same type in different ecoregions were not significantly different ($p >0.05$).

*Range in WL* was statistically significant different among wetland types and between ecoregions.. Specifically, wetlands in the Western Ecoregion had significantly different ranges in WL than those in the Valley and Central Lowlands Ecoregion during the Fall [$F (1,10) = 5.215$, $p = 0.045$] *Range in WL* was significantly different among wetland types during the Spring ([$F (2,10) = 6.279$ $p = 0.017$], and Fall [$F (2,10) = 5.383$ $p =0.026$]. This difference was driven by lower *Range in WL* in Wooded Peatlands compared to Shrub Swamps (Tukey's HSD, $p \leq 0.05$). No other paired comparisons for Range in WL were significant ($p \geq 0.05$) for either the Spring or Fall time periods (Figures 15 & 16).

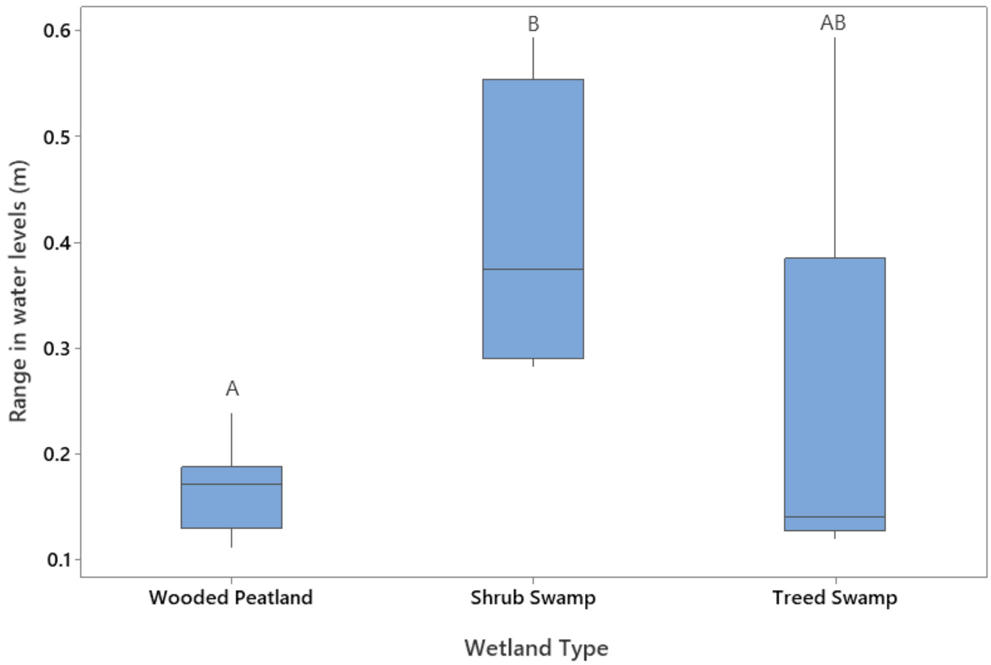


Figure 15: Boxplot of Range in water levels (m) relative to ground surface (0 m) grouped by wetland type during the Spring season (May-June 2019). Groups that do not share a letter are significantly different ($p \leq 0.05$).

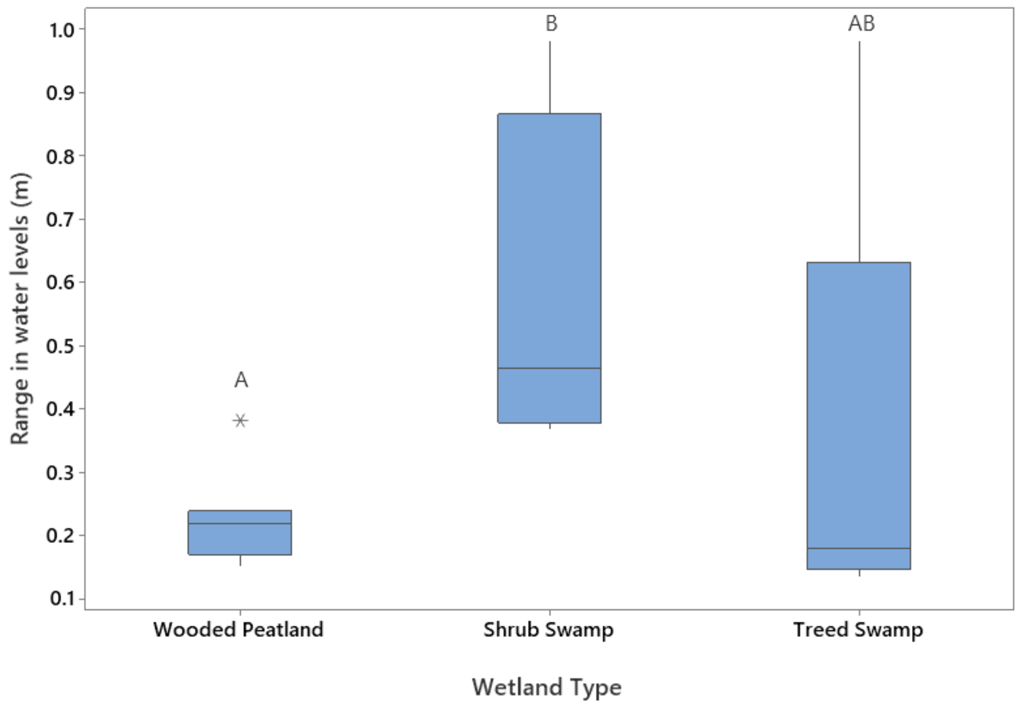


Figure 16: Boxplot of Range in water levels (m) relative to ground surface (0 m) grouped by wetland type during the Fall season (September-October 2019). Groups that do not share a letter are significantly different ($p \leq 0.05$). "*" indicates outliers in the data.

*Maximum WL* also differed by ecoregion and wetland type during every period of analysis (Entire study period, Growing season, Spring, Summer, and Fall). The *Maximum WLs* of wetlands in the Western ecoregion were significantly different than the *Maximum WLs* of the wetlands in the Valley and Central Ecoregion over the Entire study period [$F_{(1,10)} = 6.046$, $p=0.034$], Growing season [$F_{(1,10)} = 5.546$, $p=0.040$], Summer [$F_{(1,10)} = 6.070$, $p=0.033$], and Fall [$F_{(1,10)} = 6.242$, $p=0.032$]. *Maximum WL* was also significantly different among wetland types for every study period: Entire study period [$F_{(2,10)} = 7.193$, $p= 0.012$], Growing season [$F_{(2,10)} = 6.183$, $p =0.018$], Spring [$F_{(2,10)} = 5.526$, $p = 0.024$], Summer [$F_{(2,10)} = 6.222$, $p = 0.018$], Fall [$F_{(2,10)} = 5.968$, $p = 0.02$]. These results were driven mainly by the lower maximum levels in wooded peatlands relative to shrub swamps ($p \leq 0.05$;Figure 17). No other paired comparisons between wetland types were significant.

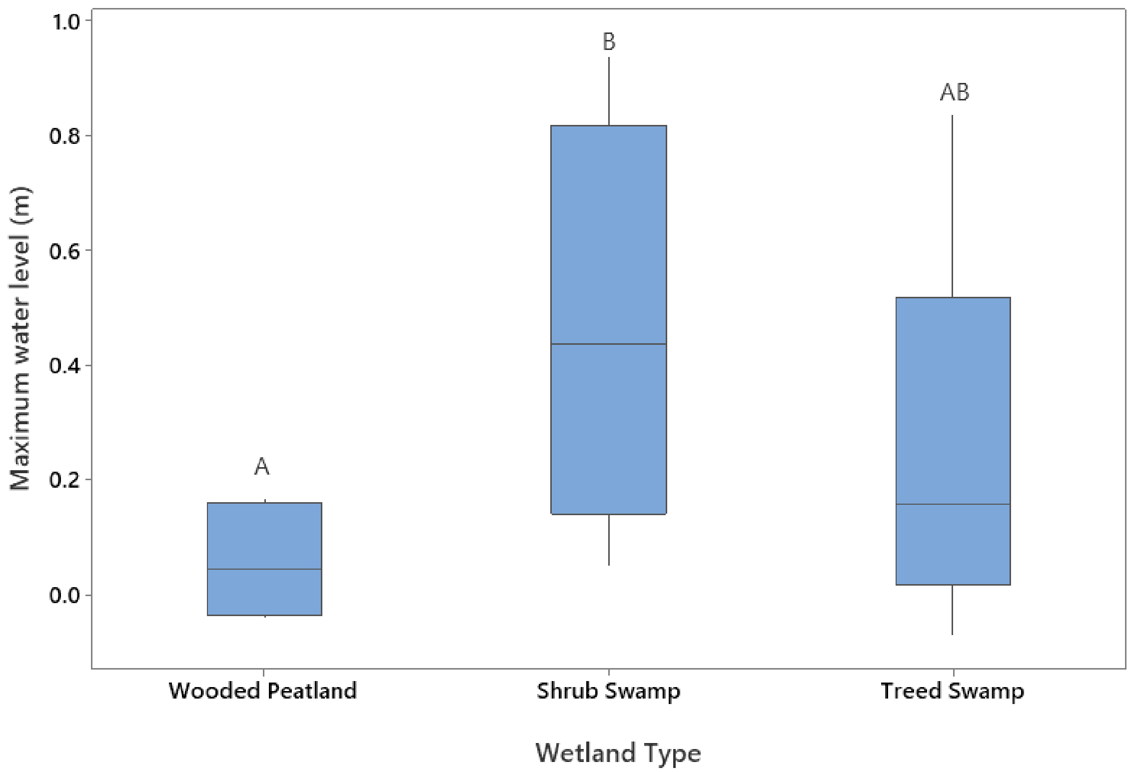


Figure 17: Maximum water levels (m) relative to ground surface (0 m) grouped by wetland type during the growing season (May-October 2019). Groups that do not share the same letter are significantly different ($p \leq 0.05$).

The results of this study differ from past research as significant differences between wetland types were previously observed using the *Median WL* or *Standard deviation in WL* metrics (Cole & Brooks, 2000; Merkey, 2006). Both Cole & Brooks (2000) and Merkey (2006) used the HGM classification of wetlands instead of grouping by wetland type. It is possible that the wetlands in Nova Scotia would be grouped differently if the HGM classification method was used and resulted in different hydrologic patterns being detected among wetland types or ecoregions.

### 4.3.1 Western Ecoregion

A separate analysis was conducted on the hydrologic metrics of the wetlands in the Western Ecoregion to assess differences between wetland types within the same Ecoregion. A one-way ANOVA was performed on the six hydrologic metrics (*Mean WL, Median WL, Standard deviation in WL, Minimum WL, Maximum WL,* and *Range in WL).* Statistically significant differences were found only for the *Range in WL* hydrologic metric but were consistent over four of the five time periods of analysis, the exception was during the Summer period. There was a statistically significant difference between wetland types in the Western ecoregion during the Entire period of analysis [$F(2,5) = 6.576$, $p=0.040$], Growing season [$F(2,5) = 6.252$, $p= 0.044$], Spring [$F(2,5) = 9.230$, $p = 0.021$], and Fall [$F(2,5) = 5.832$, $p = 0.049$]. When a Tukey HSD post hoc test was used, wooded peatlands were found to be significantly different than shrub swamps in all time periods evaluated ($p \leq 0.05$), while no significant differences were found between shrub swamps and treed swamps or wooded peatlands and treed swamps (Figure 18).

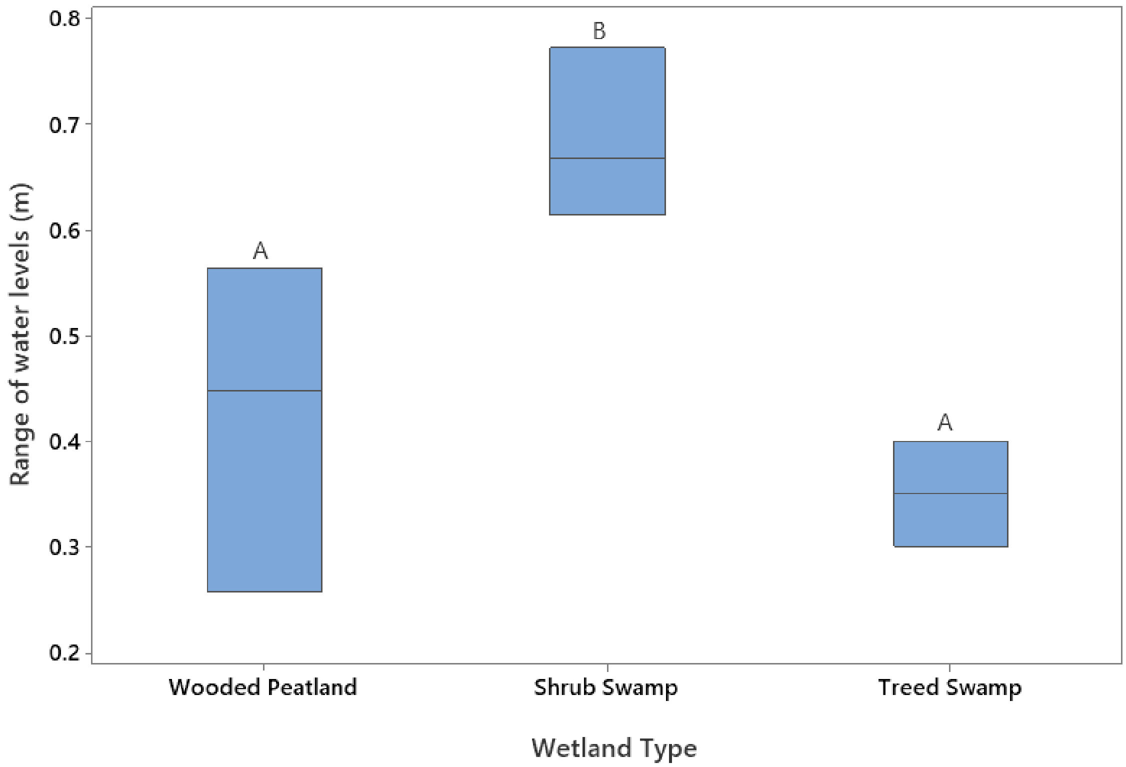


Figure 18: Total range in water levels (m) grouped by wetland type for the Western Ecoregion over the growing season (May-October 2019). Groups that do not share a letter are significantly different ($p \leq 0.05$).

### 4.3.2 Principal Components Analysis of Hydrologic Metrics

A PCA was also used to reduce dimensionality and help visualize variability in hydrologic response among the wetland types and ecoregions. Biplots of the 1$^{st}$ and 2$^{nd}$ principal components, grouped by wetland type and ecoregion generally confirmed the results of the ANOVA analysis, illustrating that Shrub Swamps were grouped separately from Wooded Peatlands and Treed Swamps, with no distinct groupings based on Ecoregion (Figure 19).

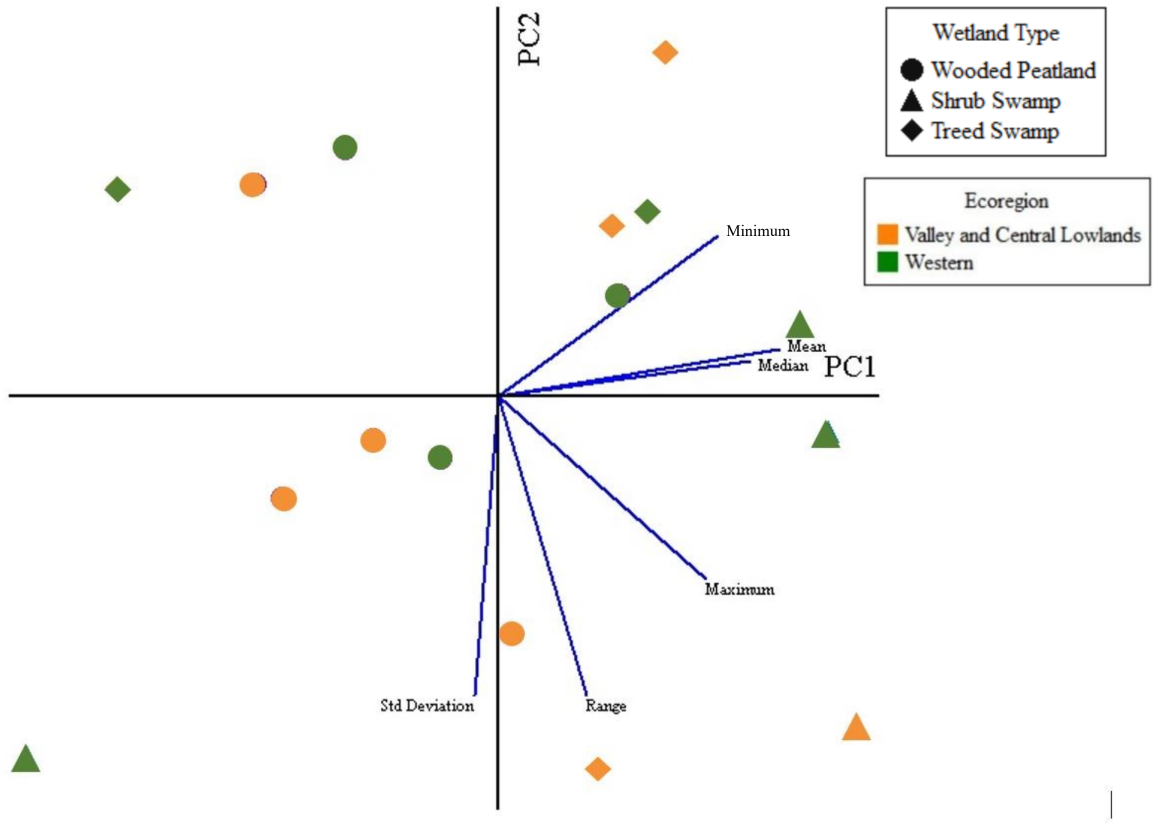


Figure 19: Biplot of PC1 vs. PC2, for hydrologic metrics of 16 wetlands grouped by wetland type during the Growing season (May-October 2019). PC1 represents 42% of total variation, while PC2 represents an additional 27%.

## 4.4 Relationships Between Wetland-Watershed Characteristics and Hydrologic Metrics

Relationships between hydrologic metrics and wetland and watershed characteristics were explored to determine which key characteristics have the greatest influence on the hydrologic regime of the study wetlands. The hydrologic metrics *Range in WL* and *Maximum WL* were chosen as the response variables in the regression analyses, as they were two metrics which displayed the greatest differences among the wetland types (Section 4.3).

Best subsets regression was first employed to identify influential variables for predicting *Range in WL* and *Maximum WL* for each time period. The results of the best subsets regression models showed that the key factors that consistently influenced the hydrologic metrics were *watershed area*, *%forested*, *peat depth, wetland TPI* and *%anthropogenic* (Table 8).

A series of multiple linear regressions were then carried out to identify the best-fitting models which could predict *Range in WL* or *Maximum WL* for each of the five time periods (Table 8). All regressions resulted in statistically significant models ($p \leq 0.05$). *Watershed area, wetland TPI,* and *%Forested* were key characteristics that were identified as statistically significant predictor variables. *Peat depth* was a significant predictor mainly for *Maximum WL. Watershed area* contributed significantly to all models ($p \leq 0.05$) and positively influenced the hydrologic metrics, indicating watershed size increased the range of water levels of these forested wetlands. This finding has important implications for assessing how proposed developments may impact wetland form and function. When proponents and regulators are conducting and evaluating environmental assessments involving wetland alterations, potential impacts should be evaluated at the watershed scale; alterations to effective watershed drainage capacity such as dams or urban development will affect the wetland hydrology, and thus influence the overall function of the wetland (Mitsch & Gosselink, 2015).

Table 8a: Multiple linear regression results of the ability of key wetland and watershed characteristics to predict Range in WL over five time periods.

| Hydrologic metric | Time period | $R^2$ | Adj $R^2$ | p-value | Regression equation |
|---|---|---|---|---|---|
| *Range in WL* | Growing Season | 74.1 | 66.1 | 0.001 | Range = 1.003 + 0.2703(*Watershed Area*) [A] – 0.1277*(% Forested*) [A] |
| | Entire Period | 87.3 | 82.1 | 0.000 | Range = -0.411 + 0.2432(*Watershed Area*) [A] + 0.0803*(% Forested*) [A] – 0.0790(*Peat Depth*) [A] |
| | Spring | 75.5 | 68 | 0.001 | Range = 0.323 + 0.1602(*Watershed Area*) [A] |
| | Summer | 60.5 | 52 | 0.004 | Range = 0.759 + 0.1192(*Watershed Area*) [A] - 0.1024*(% Forested*) [A] |
| | Fall | 82.7 | 77.4 | 0.000 | Range = 0.505 + 0.2672(*Watershed Area*) [A] |

[A] – indicates the variable significantly contributed to the model.

Table 8b: Multiple linear regression results of the ability of key watershed and wetland characteristics to predict Maximum WL over five time periods.

| Hydrologic metric | Time period | $R^2$ | Adj $R^2$ | p-value | Regression equation |
| --- | --- | --- | --- | --- | --- |
| *Maximum WL* | Growing Season | 86.6 | 82.4 | 0.000 | Maximum = -0.189 + 0.2561(*Watershed Area*) [A] + 0.0814 (*%Forested)* [A] - 0.0737(*Peat Depth)* [A] |
| | Entire period | 86.2 | 82.0 | 0.000 | Maximum = -0.192 + 0.2567(*Watershed Area*) [A] + 0.0747 (*%Forested*) [A] - 0.0753(*Peat Depth*) [A] |
| | Spring | 67.4 | 57.4 | 0.004 | Maximum = -0.226+ 0.1211(*Watershed* Area) [A] + 0.0648 *(%Forested)* - 0.0840(*Peat Depth)* [A] |
| | Summer | 74.6 | 69.1 | 0.000 | Maximum = -0.0431 + 0.1906 (*Watershed Area*) [A] |
| | Fall | 85.2 | 82.0 | 0.000 | Maximum = -0.0169 + 0.2651(*Watershed Area*) [A] + 0.0718(*%Forested*) [A] - 0.0779(*Peat Depth*) [A] |

[A] – indicates the variable significantly contributed to the model.

Similarly, the *%forested* characteristic was also identified as a consistently significant predictor variable, being both negatively and positively related to response variables, depending on the time period. Numerous previous studies have shown that increasing forest cover in a watershed results in dampened event hydrographs, greater rates of infiltration, and more evapotranspiration (ET) which all impact the temporal distribution and magnitude of water yield to wetlands (Bosch & Hewlett, 1982; Brown et al., 2013; J. Lu et al., 2006; Moore & Wondzell, 2005). Even though infiltration rates and ET were not measured in this study, the wetland hydrographs indicated the wetlands with greater percentages of forest cover (treed swamps) had lower fluctuations in event hydrographs than wetlands with lower percentages of forest cover (wooded peatlands) (Figures 10, 12, 14).

There are relatively few comparable studies in the literature that have explicitly examined the relationship between wetland-watershed characteristics and hydrologic response. In Pennsylvania, Schaffer (1999) evaluated the relationship between wetland hydrologic regime and land use, soils, wetland area, and presence of a water retention structure; however, significant relationships were found only between wetlands with/without a water retention structure. In the Southern High Plains (SHP), USA, similar research was conducted on the influence of land use and playa characteristics on water loss rate and periods of inundation in 33 playa lakes (similar to vernal pools in the CWCS) (Tsai et al., 2007). Although the wetland type and climate differ from those of forested wetlands in Nova Scotia, Tsai et al. (2007) found significant relationships between several characteristics (land use, percent vegetation cover, and soil texture) and hydrologic metrics (water loss rate and periods of inundation); however, watershed size and playa size were not found to be significant predictors of hydrologic response.

To the authors knowledge, this research was the first attempt to examine the landscape characteristics that influence hydrologic regimes in forested wetlands in Canada. Understanding how physiographic and climatic characteristics influence wetland hydrology will greatly benefit wetland restoration and protection efforts in the region. For example, as the relationship between range in water levels and forest cover (%) is negative, as you increase forest cover you will decrease fluctuation or range in water levels in the wetland. The relationships between physiographic features and wetland hydrology differ by hydrologic metric, however the relationships need to be understood for wetland management practices as it is shown that one must also consider how alterations to the watershed such as urban development will affect the hydroperiod of the wetland. This methodology should provide a framework for investigating controls on wetland hydrologic regime for other wetland types, and ecoregions, in the province.

# 5 RECOMMENDATIONS FOR FUTURE WORK

As the scope of this study was limited to a short study period, there were limitations to the analysis. First, it may be worthwhile to examine a larger suite of wetlands or wetlands across all the ecoregions of the province of Nova Scotia. The examination of wetland hydrology using a larger data set, allows for more accurate prediction of future water levels (Amatya et al., 2020). In addition, the expansion of the dataset to include all wetland types in the province might provide a greater contrast of hydropatterns among wetland types that were not seen in this study. The larger the dataset or wetland inventory, the more accurate and useful it would be at determining typical hydrologic behaviour of wetlands in the province of NS.

As this study has shown relationships between the wetland and watershed features, other hydrologic indicators could be analyzed and compared by wetland types such as rates of ET, infiltration, and duration of inundation or saturation. Determining infiltration rates by wetland type, for example, would aid in the determination of substrate material for wetland construction. The duration of inundation (number of consecutive days a wetland well remains inundated or saturated) has been used in Cole & Brooks (2000) study where the average duration of inundation and saturation was 81%, therefore it would be interesting to see how Nova Scotia's wetlands would compare.

When compared to similar studies such as Cole & Brooks (2000), Ehrenfeld et. al. (2003), and Grabas & Rokitnicki-Wojcik (2015), the wetlands in this study are classified using the Canadian Wetland Classification system as opposed to Brinson's (1993) HGM classification. Inherently, there is the possibility that more differences between wetland types may be seen if a different wetland classification method was used, however, this would require a re-examination and re-classification of all wetlands in the province.

All in all, the main focus of future research should be to expand and broaden the scope of this study to provide a more holistic view of the hydrologic patterns in Nova Scotia's wetlands.

# 6 CONCLUSION

Characterizing the hydrology is the first step in assessing the health of any wetland, and aids in the development of restoration practices. The characterization of the hydrology of these 18 FW in the Annapolis Valley will aid in management practices for altered FW sites, and in the development of wetland compensation requirements.

This study has determined that FW in the Annapolis Valley have fluctuating hydroperiods that vary, in some respects, depending on type. The water levels in FW of all types were saturated or inundated throughout the winter months (WL > -0.2 m), while during the summer months or growing season, the water tables would fluctuate more frequently because of fewer precipitation events and transpiration. When compared, wooded peatlands and treed swamps do not differ in hydrologic behaviour or by geographic location. However, wooded peatlands and shrub swamps evaluated in this study do have significantly different maximum water levels ($p<0.05$). Although this difference was only shown using the maximum and range in water level metrics, further analysis using a larger data set may help further identify differences in hydrologic behaviour between wetland types.

Overall, the above study presents data that can be used as a reference in the restoration of wooded peatlands, shrub swamps, and treed swamps in the Annapolis Valley of Nova Scotia. Wooded peatlands had relatively stable hydrographs with most sites having water levels in the saturated zone throughout the study period (WL > 0.2 m); Shrub swamps were sensitive to precipitation events (flashy hydrograph) and experienced drier water tables during the hot summer months; Finally, treed swamps were less sensitive to precipitation events than shrub swamps, however treed swamps were drier during the summer months, likely due to transpiration by larger wooded species.

The key characteristics that influence the hydrology in wooded peatlands, shrub swamps and treed swamps were determined to be amount of forested area, watershed size and wetland topographic position index. Understanding the impacts these key characteristics have on wetland hydrology can aid in management practices.

In future wetland restoration projects, it is important to remember that you cannot manage what you have not measured. Therefore, using the results of this study and the established wetland compensation requirements, target water levels can be established for FW types in Nova Scotia. The features of the hydroperiods determined in this study can serve as restoration targets in wetland management. The use of restoration targets will ensure wetland function is not lost and wetlands are restored, created, enhanced, or expanded to be as close to "natural" conditions as possible.

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# APPENDIX A: Spatial Analysis Results

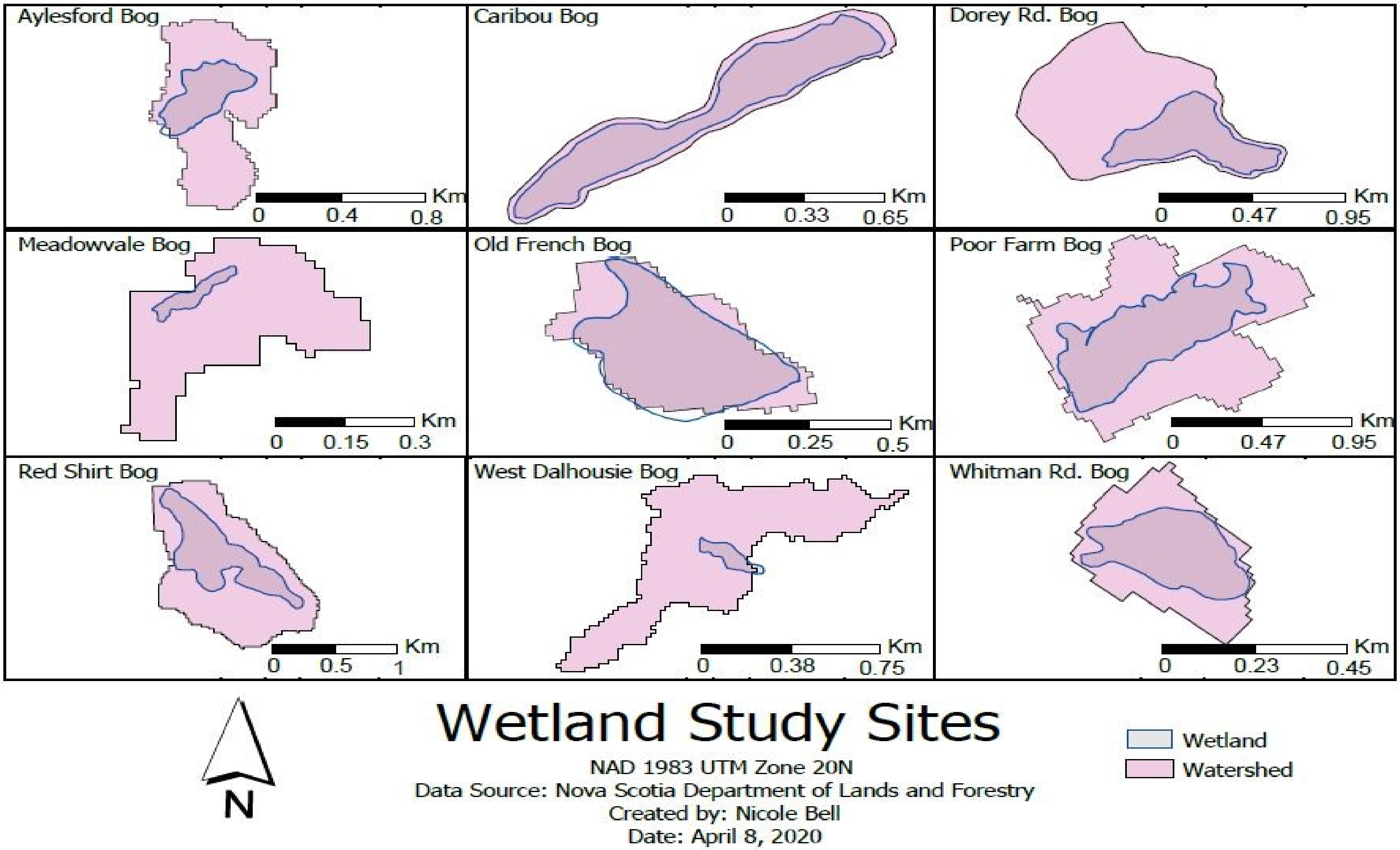


Figure 20: Wetland and Watershed areas for the wooded peatland sites.

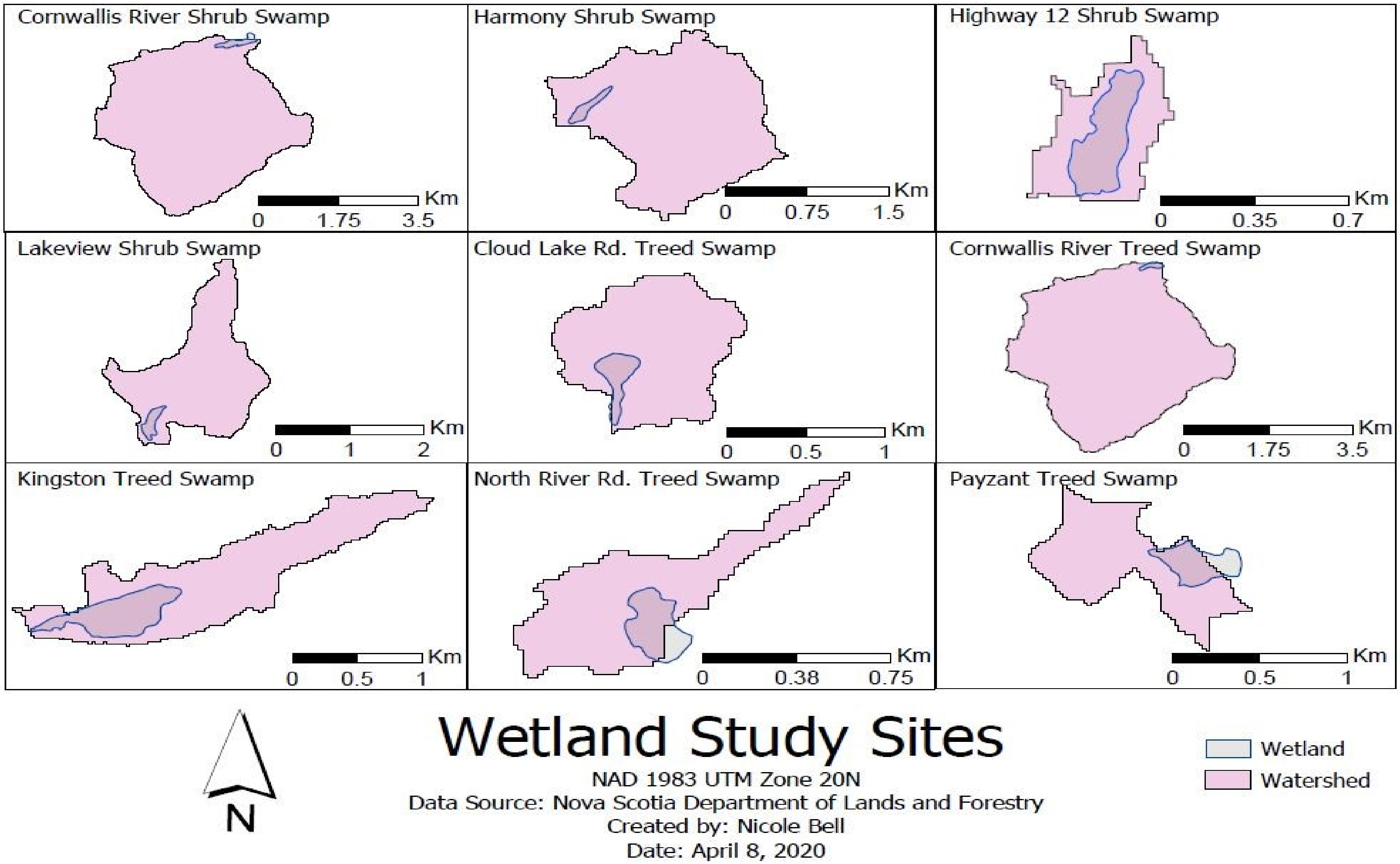


Figure 21: Wetland and watershed areas for shrub swamp and treed swamp sites.

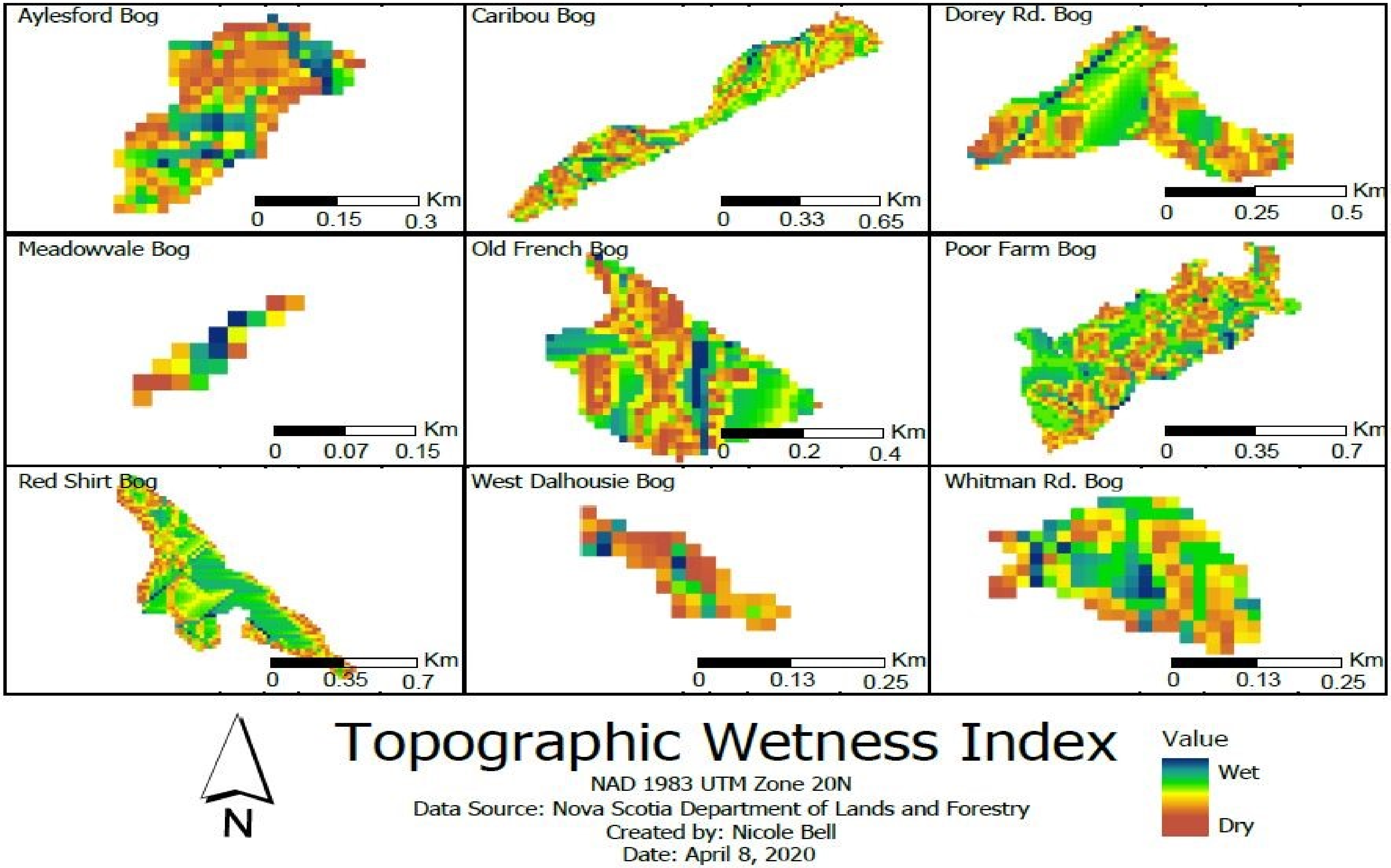


Figure 22: Wetland topographic wetness index (TWI) for the wooded peatland sites.

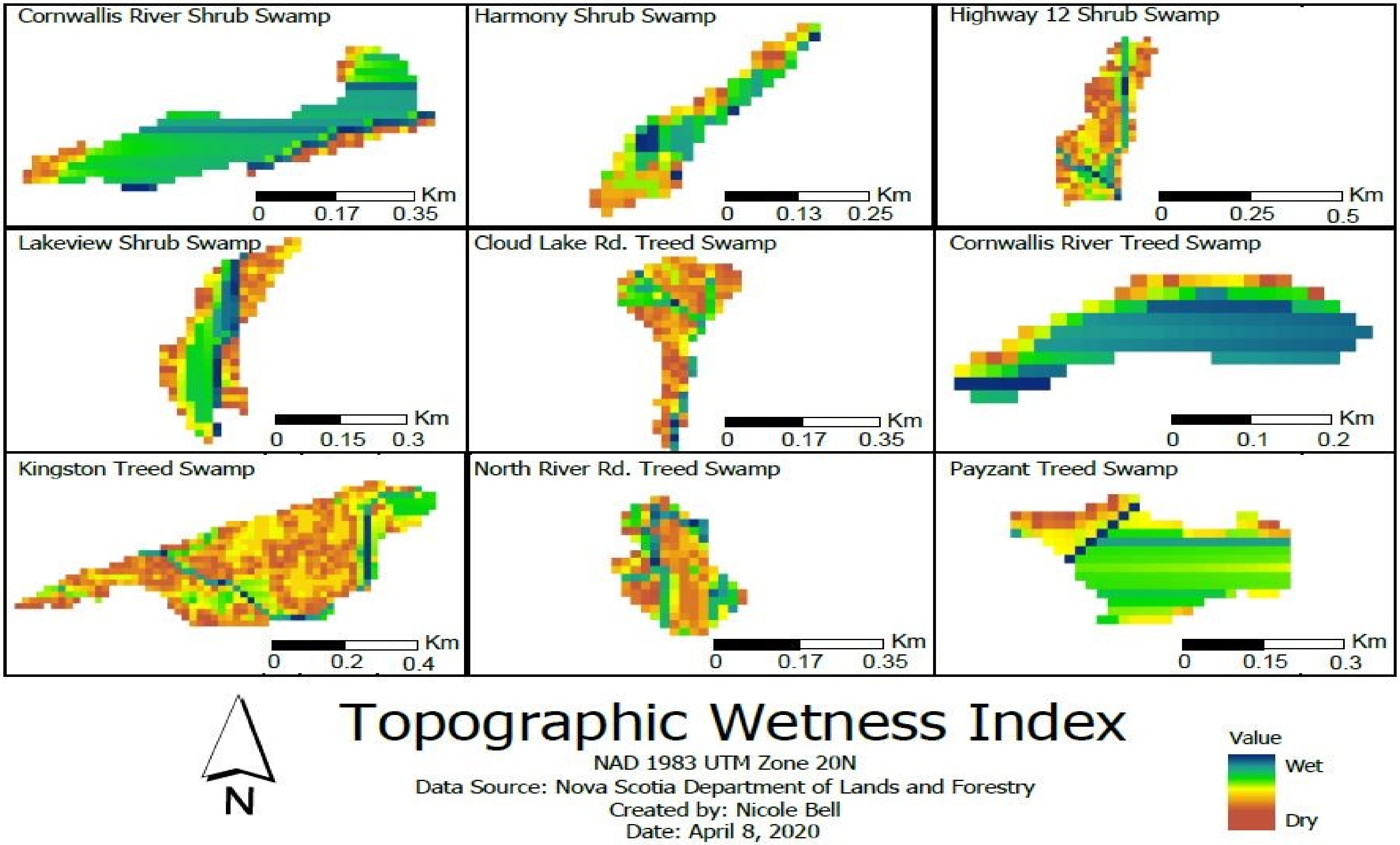


Figure 23: Wetland topographic wetness index (TWI) for the shrub swamp and treed swamp sites

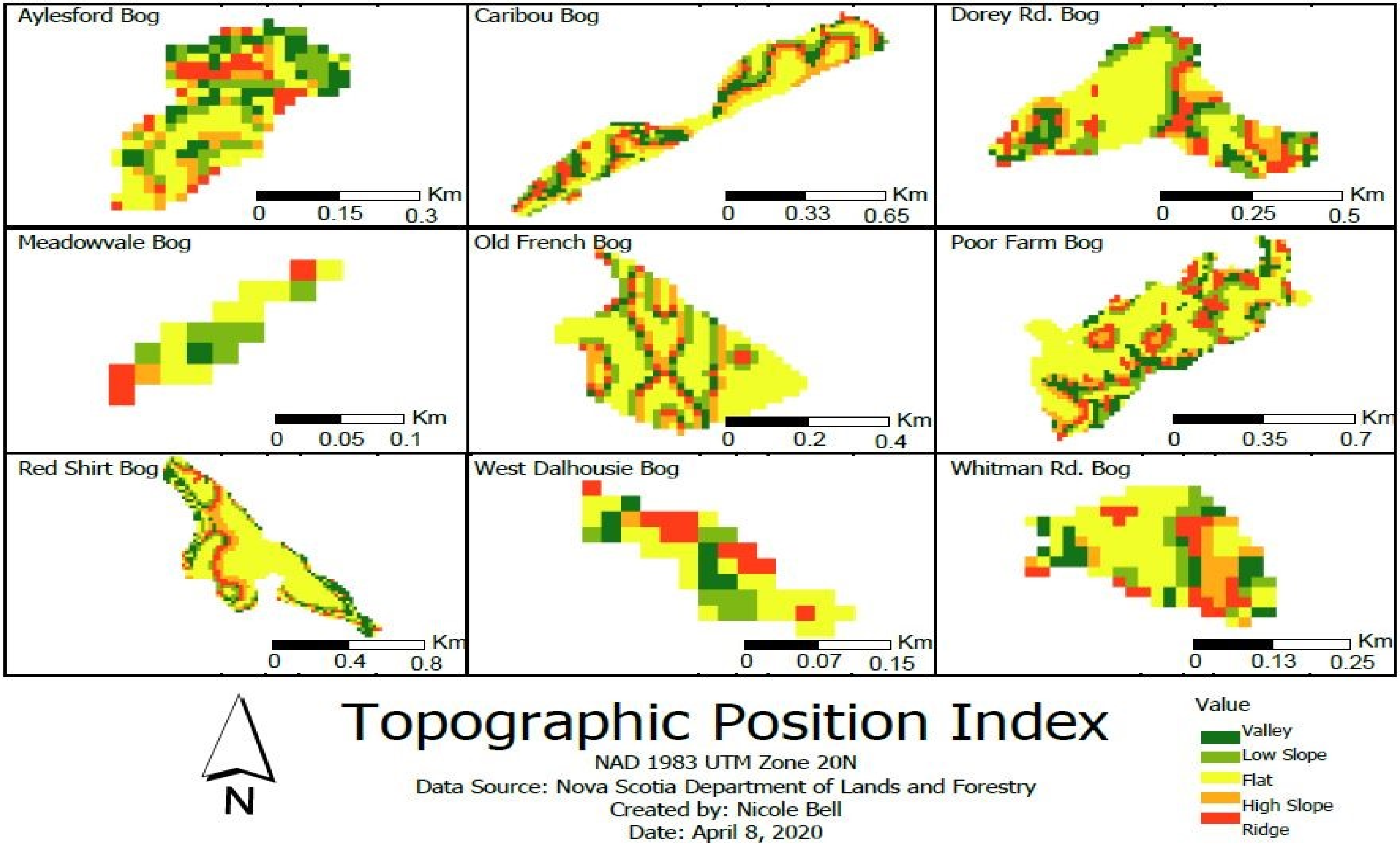


Figure 24: Wetland topographic position index (TPI) for the wooded peatland sites.

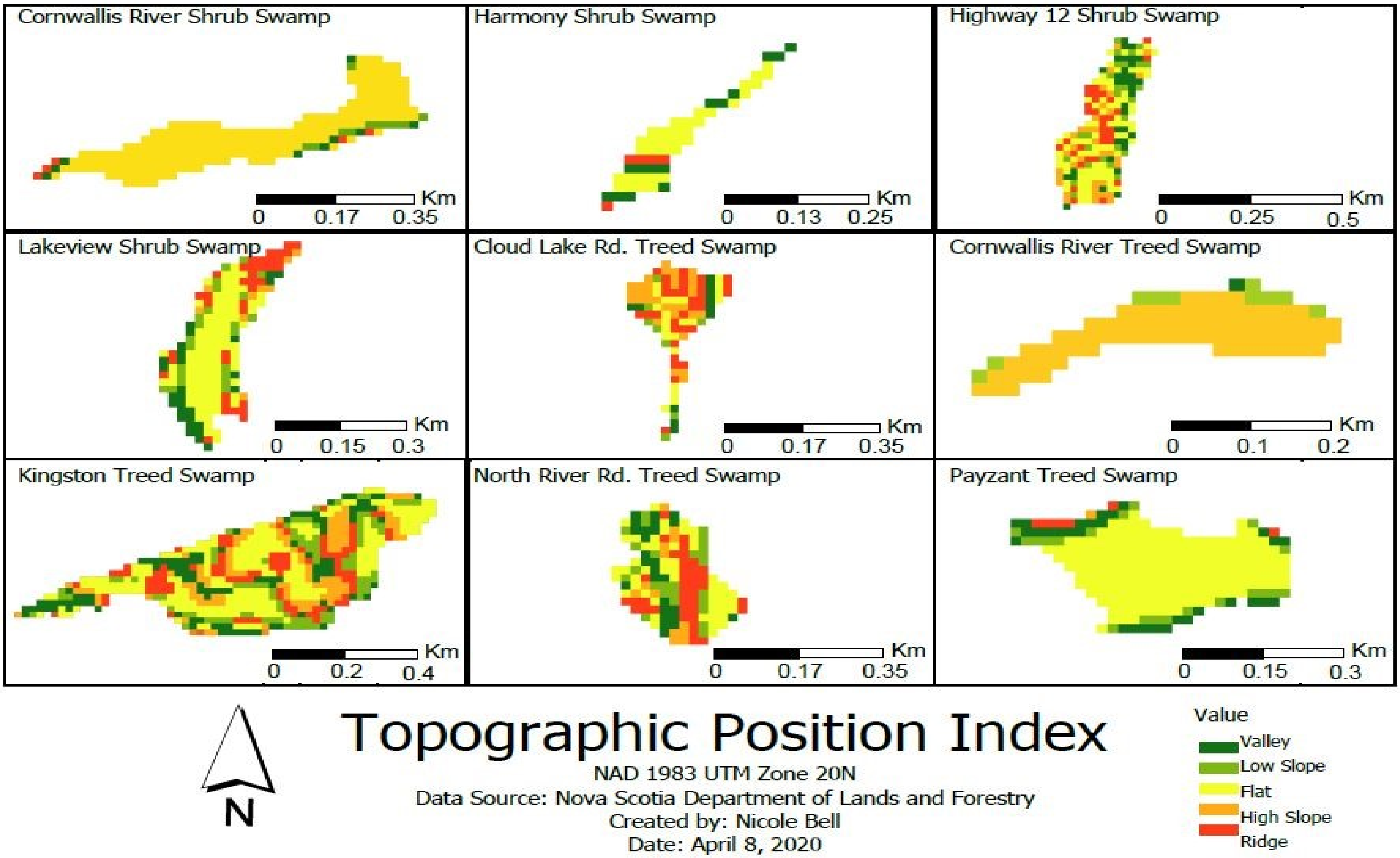


Figure 25: Wetland topographic position index (TPI) for the shrub swamp and treed swamp sites.

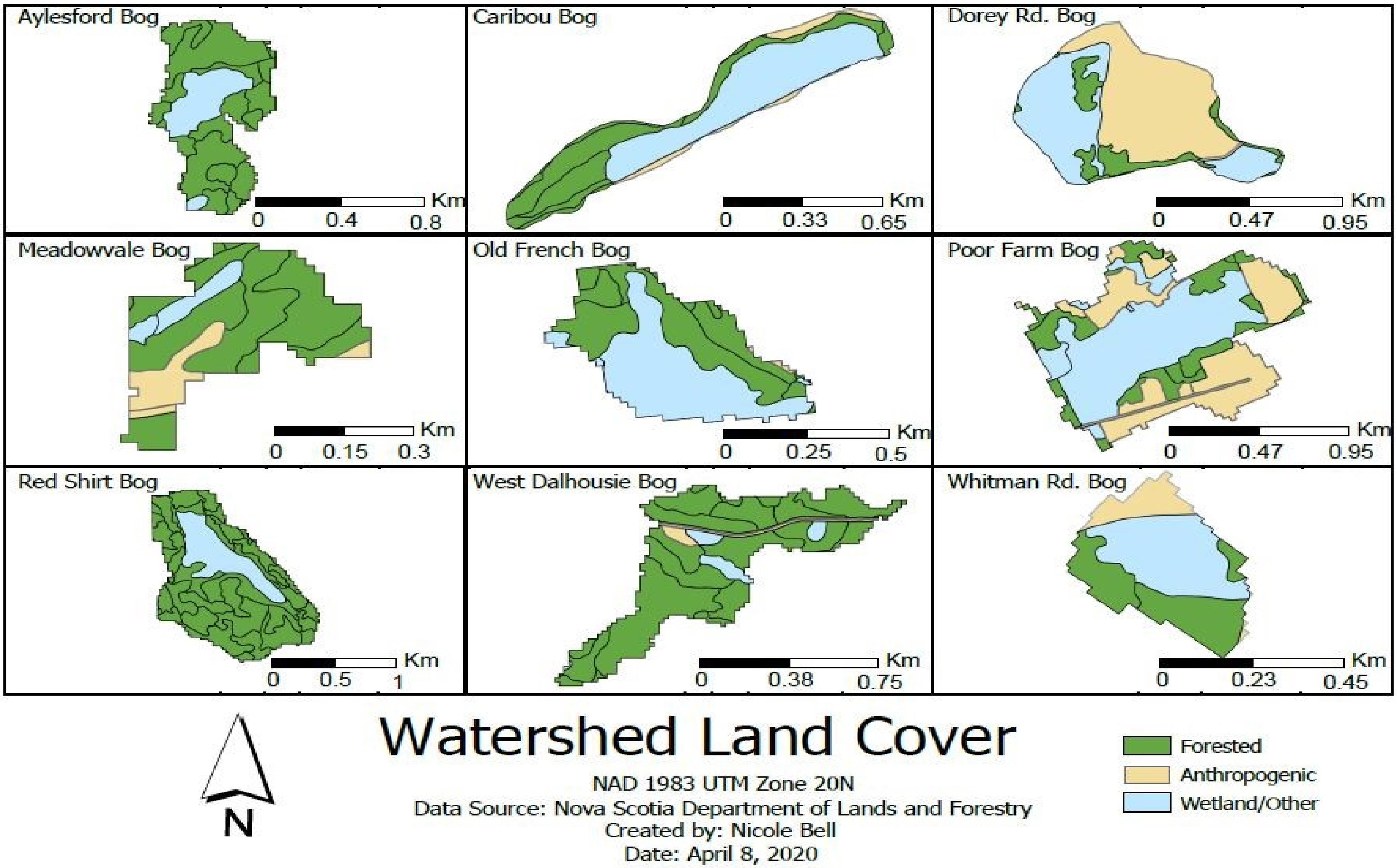


Figure 26: Watershed land cover for the wooded peatland sites.

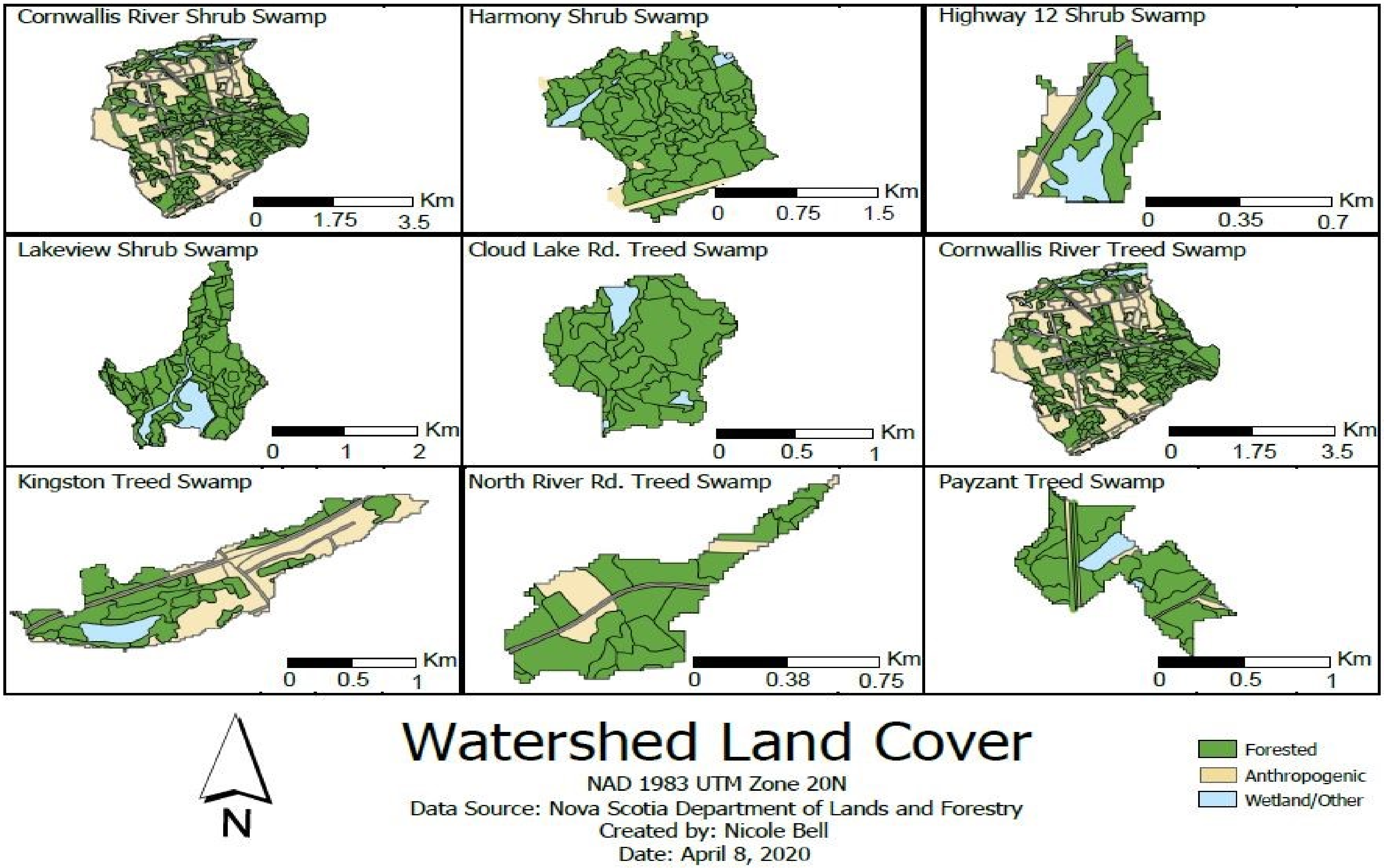


Figure 27: Watershed land cover for the shrub swamp and treed swamp sites.

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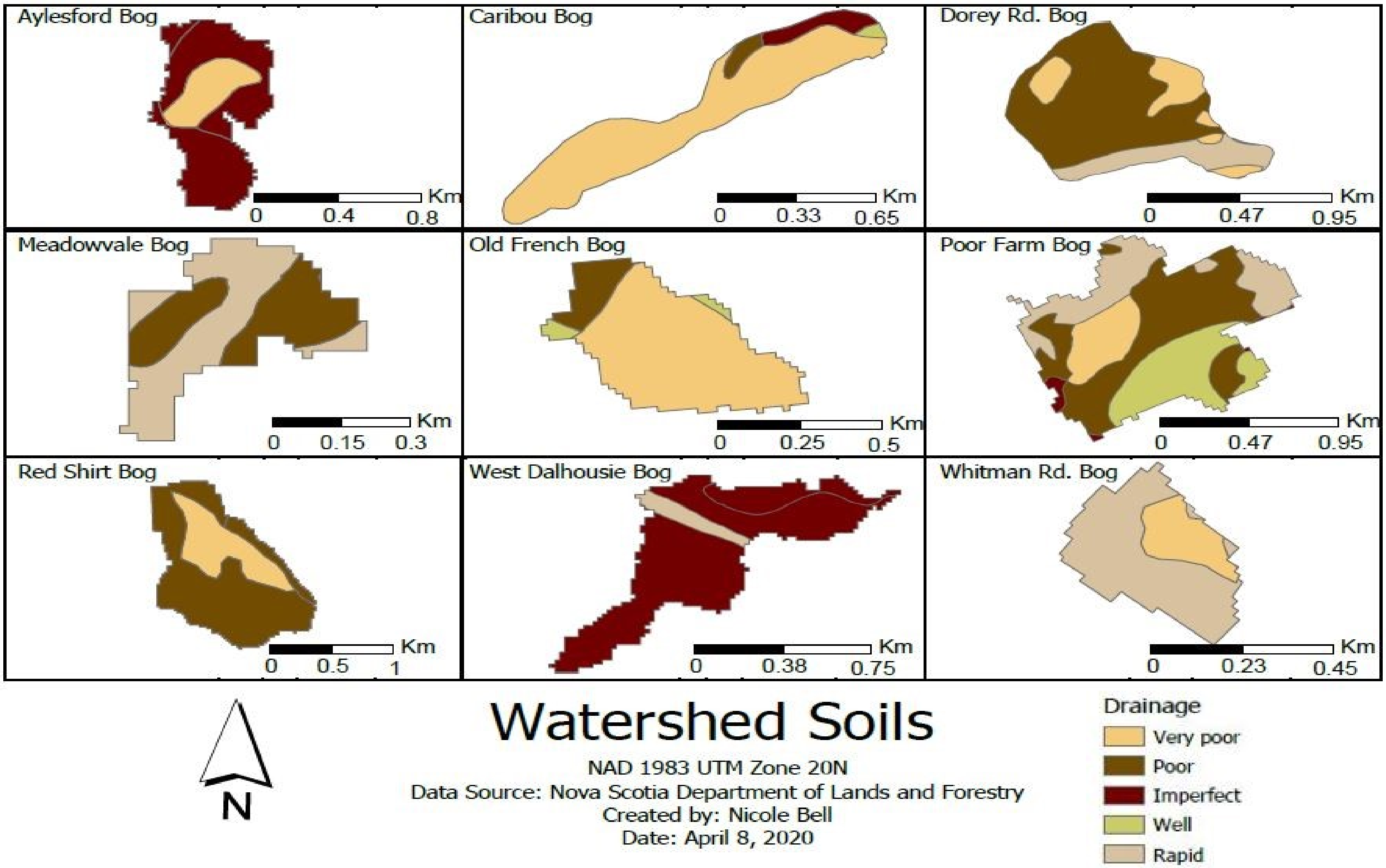


Figure 28: Watershed soils for the wooded peatland sites.

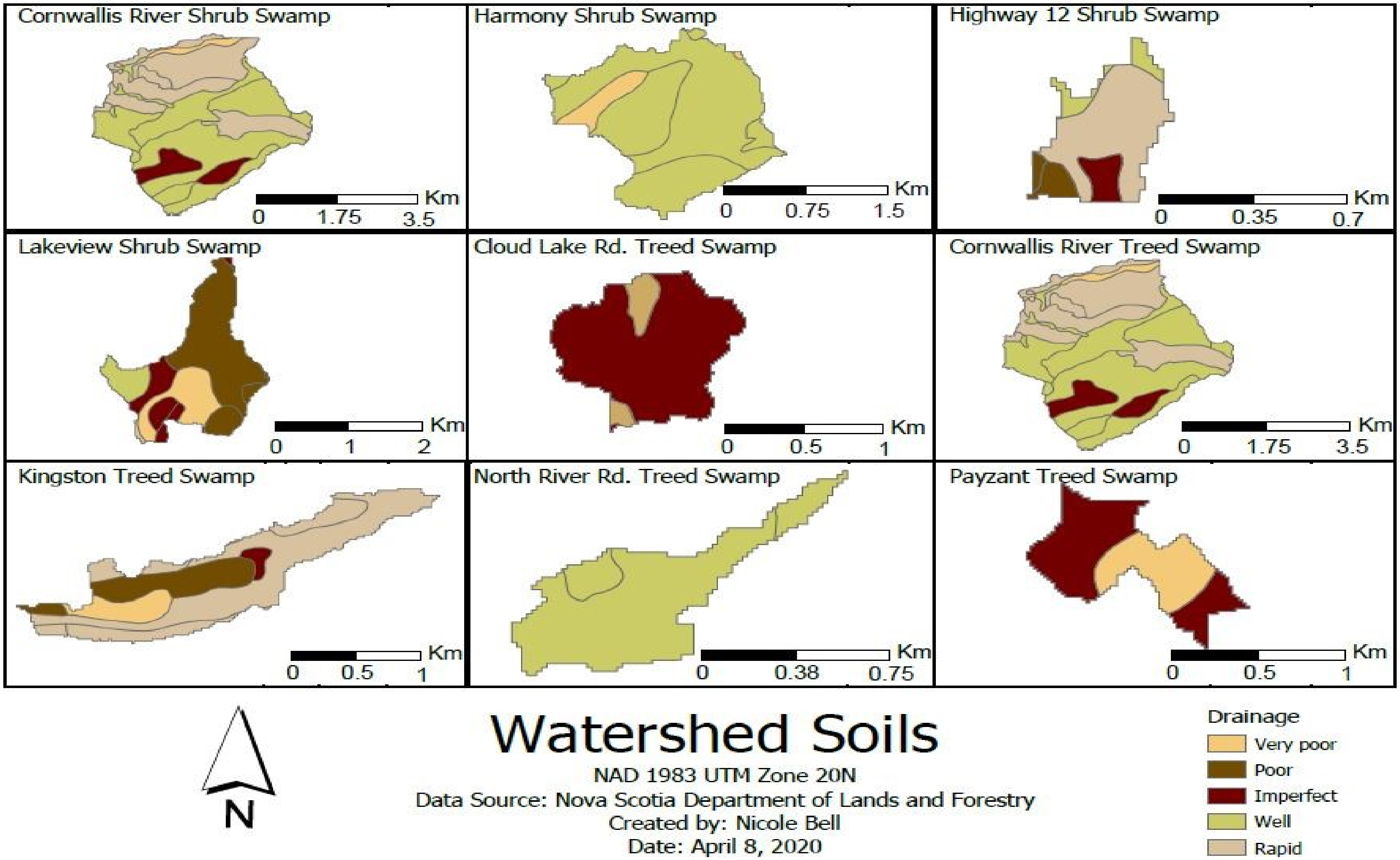


Figure 29: Watershed soils for the shrub swamp and treed swamp sites.

# APPENDIX B:

## Two-way ANOVA Results and Statistics

**ENTIRE STUDY PERIOD**

Table 9: ANOVA results testing mean water level over the entire study period (December 2018-November 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | p |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.004 | 0.432 | 0.661 |
| Ecoregion (B) | 1 | 0.001 | 0.138 | 0.718 |
| A×B | 2 | 0.004 | 0.432 | 0.660 |
| Error | 10 | 0.009 | | |

Note.—MS=Mean squares, *p<0.05.

Table 10: ANOVA results testing median water level over the entire study period (December 2018-November 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | p |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.003 | 0.391 | 0.667 |
| Ecoregion (B) | 1 | 0.000 | 0.047 | 0.832 |
| A×B | 2 | 0.004 | 0.420 | 0.668 |
| Error | 10 | 0.009 | | |

Note.—MS=Mean squares, *p<0.05.

Table 11: ANOVA results testing maximum water level over the entire study period (December 2018-November 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | p |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.275 | 7.193 | 0.012* |
| Ecoregion (B) | 1 | 0.231 | 6.046 | 0.034* |
| A×B | 2 | 0.125 | 3.271 | 0.081 |
| Error | 10 | 0.038 | | |

Note.—MS=Mean squares, *p<0.05.

Table 12: ANOVA results testing minimum water level over the entire study period (December 2018-November 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.032 | 1.191 | 0.344 |
| Ecoregion (B) | 1 | 0.001 | 0.047 | 0.833 |
| A×B | 2 | 0.045 | 1.665 | 0.238 |
| Error | 10 | 0.027 | | |

Note.—MS=Mean squares, *p<0.05.

Table 13: ANOVA results testing range in water level over the entire study period (December 2018-November 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.193 | 3.766 | 0.060 |
| Ecoregion (B) | 1 | 0.198 | 3.873 | 0.077 |
| A×B | 2 | 0.020 | 0.395 | 0.084 |
| Error | 10 | 0.051 | | |

Note.—MS=Mean squares, *p<0.05.

Table 14:ANOVA results testing standard deviation water level over the entire study period (December 2018-November 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.003 | 2.104 | 0.173 |
| Ecoregion (B) | 1 | 0.001 | 0.545 | 0.477 |
| A×B | 2 | 0.000 | 0.293 | 0.752 |
| Error | 10 | 0.001 | | |

Note.—MS=Mean squares, *p<0.05.

**GROWING SEASON**

Table 15: ANOVA results testing mean water level over the growing season (May 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.004 | 0.377 | 0.695 |
| Ecoregion (B) | 1 | 0.003 | 0.306 | 0.592 |
| A×B | 2 | 0.004 | 0.396 | 0.683 |
| Error | 10 | 0.010 | | |

Note.—MS=Mean squares, *p<0.05.

Table 16: ANOVA results testing median water level over the growing season (May 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.002 | 0.231 | 0.798 |
| Ecoregion (B) | 1 | 0.001 | 0.116 | 0.740 |
| A×B | 2 | 0.002 | 0.262 | 0.775 |
| Error | 10 | 0.009 | | |

Note.—MS=Mean squares, *p<0.05.

Table 17: ANOVA results testing maximum water level over the growing season (May 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.318 | 6.183 | 0.018* |
| Ecoregion (B) | 1 | 0.285 | 5.546 | 0.040* |
| A×B | 2 | 0.128 | 2.491 | 0.132 |
| Error | 10 | 0.051 | | |

Note.—MS=Mean squares, *p<0.05.

Table 18: ANOVA results testing minimum water level over the growing season (May 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.043 | 1.662 | 0.238 |
| Ecoregion (B) | 1 | 0.004 | 0.161 | 0.697 |
| A×B | 2 | 0.041 | 1.605 | 0.249 |
| Error | 10 | 0.026 | | |

Note.—MS=Mean squares, *p<0.05.

Table 19: ANOVA results testing range in water level over the growing season (May 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.219 | 3.494 | 0.071 |
| Ecoregion (B) | 1 | 0.220 | 3.515 | 0.090 |
| A×B | 2 | 0.026 | 0.418 | 0.669 |
| Error | 10 | 0.063 | | |

Note.—MS=Mean squares, *p<0.05.

Table 20: ANOVA results testing standard deviation water level over the growing season (May 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.003 | 1.718 | 0.228 |
| Ecoregion (B) | 1 | 0.001 | 0.769 | 0.401 |
| A×B | 2 | 0.000 | 0.036 | 0.965 |
| Error | 10 | 0.002 | | |

Note.—MS=Mean squares, *p<0.05.

**SPRING**

Table 21: ANOVA results testing mean water level over the spring season (May 2019 – June 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.004 | 0.392 | 0.686 |
| Ecoregion (B) | 1 | 0.000 | 0.037 | 0.852 |
| A×B | 2 | 0.005 | 0.535 | 0.601 |
| Error | 10 | 0.009 | | |

Note.—MS=Mean squares, *p<0.05.

Table 22: ANOVA results testing median water level over the spring season (May 2019 – June 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.003 | 0.368 | 0.701 |
| Ecoregion (B) | 1 | 0.000 | 0.010 | 0.921 |
| A×B | 2 | 0.005 | 0.537 | 0.600 |
| Error | 10 | 0.009 | | |

Note.—MS=Mean squares, *p<0.05.

Table 23: ANOVA results testing maximum water level over the spring season (May 2019 – June 2019); excludes Caribou Bog and Meadowvale Bog

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.105 | 5.526 | 0.024* |
| Ecoregion (B) | 1 | 0.080 | 4.197 | 0.068 |
| A×B | 2 | 0.043 | 2.250 | 0.158 |
| Error | 10 | 0.019 | | |

Note.—MS=Mean squares, *p<0.05.

Table 24: ANOVA results testing minimum water level over the spring season (May 2019 – June 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.000 | 0.041 | 0.960 |
| Ecoregion (B) | 1 | 0.005 | 0.487 | 0.501 |
| A×B | 2 | 0.002 | 0.217 | 0.808 |
| Error | 10 | 0.011 | | |

Note.—MS=Mean squares, *p<0.05.

Table 25: ANOVA results testing range in water level over the spring season (May 2019 – June 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.095 | 6.279 | 0.017* |
| Ecoregion (B) | 1 | 0.044 | 2.939 | 0.117 |
| A×B | 2 | 0.031 | 2.051 | 0.179 |
| Error | 10 | 0.015 | | |

Note.—MS=Mean squares, *p<0.05.

Table 26: ANOVA results testing standard deviation water level over the spring season (May 2019 – June 2019); excludes Caribou Bog and Meadowvale Bog

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.002 | 5.416 | 0.025* |
| Ecoregion (B) | 1 | 0.001 | 1.749 | 0.215 |
| A×B | 2 | 0.000 | 1.163 | 0.351 |
| Error | 10 | 0.000 | | |

Note.—MS=Mean squares, *p<0.05.

**SUMMER**

Table 27: ANOVA results testing mean water level over the summer season (July 2019 – August 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.006 | 0.463 | 0.642 |
| Ecoregion (B) | 1 | 0.005 | 0.428 | 0.580 |
| A×B | 2 | 0.012 | 0.929 | 0.426 |
| Error | 10 | 0.013 | | |

Note.—MS=Mean squares, *p<0.05.

Table 28: ANOVA results testing median water level over the summer season (July 2019 – August 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.003 | 0.260 | 0.776 |
| Ecoregion (B) | 1 | 0.005 | 0.361 | 0.562 |
| A×B | 2 | 0.008 | 0.622 | 0.557 |
| Error | 10 | 0.013 | | |

Note.—MS=Mean squares, *p<0.05.

Table 29: ANOVA results testing maximum water level over the summer season (July 2019 – August 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.191 | 6.222 | 0.018* |
| Ecoregion (B) | 1 | 0.186 | 6.070 | 0.033* |
| A×B | 2 | 0.067 | 2.176 | 0.164 |
| Error | 10 | 0.031 | | |

Note.—MS=Mean squares, *p<0.05.

Table 30: ANOVA results testing minimum water level over the summer season (July 2019 – August 2019); excludes Caribou Bog and Meadowvale Bog

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.030 | 1.132 | 0.361 |
| Ecoregion (B) | 1 | 0.002 | 0.070 | 0.796 |
| A×B | 2 | 0.047 | 1.741 | 0.225 |
| Error | 10 | 0.027 | | |

Note.—MS=Mean squares, *p<0.05.

Table 31: ANOVA results testing range in water level over the summer season (July 2019 – August 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.120 | 3.232 | 0.083 |
| Ecoregion (B) | 1 | 0.151 | 4.067 | 0.071 |
| A×B | 2 | 0.003 | 0.071 | 0.932 |
| Error | 10 | 0.037 | | |

Note.—MS=Mean squares, *p<0.05.

Table 32: ANOVA results testing standard deviation water level over the summer season (July 2019 – August 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.003 | 1.231 | 0.333 |
| Ecoregion (B) | 1 | 0.001 | 0.293 | 0.600 |
| A×B | 2 | 0.001 | 0.421 | 0.668 |
| Error | 10 | 0.002 | | |

Note.—MS=Mean squares, *p<0.05.

**FALL**

Table 33: ANOVA results testing mean water level over the fall season (September 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.009 | 1.053 | 0.385 |
| Ecoregion (B) | 1 | 0.010 | 1.112 | 0.316 |
| A×B | 2 | 0.002 | 0.233 | 0.796 |
| Error | 10 | 0.009 | | |

Note.—MS=Mean squares, *p<0.05.

Table 34: ANOVA results testing median water level over the fall season (September 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.005 | 0.570 | 0.583 |
| Ecoregion (B) | 1 | 0.004 | 0.483 | 0.503 |
| A×B | 2 | 0.001 | 0.144 | 0.868 |
| Error | 10 | 0.009 | | |

Note.—MS=Mean squares, *p<0.05.

Table 35: ANOVA results testing maximum water level over the fall season (September 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.328 | 5.968 | 0.020* |
| Ecoregion (B) | 1 | 0.343 | 6.242 | 0.032* |
| A×B | 2 | 0.127 | 2.307 | 0.150 |
| Error | 10 | 0.055 | | |

Note.—MS=Mean squares, *p<0.05.

Table 36: ANOVA results testing minimum water level over the fall season (September 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.006 | 0.538 | 0.600 |
| Ecoregion (B) | 1 | 0.010 | 0.859 | 0.376 |
| A×B | 2 | 0.002 | 0.161 | 0.853 |
| Error | 10 | 0.012 | | |

Note.—MS=Mean squares, *p<0.05.

Table 37: ANOVA results testing range in water level over the fall season (September 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.244 | 5.383 | 0.026* |
| Ecoregion (B) | 1 | 0.236 | 5.215 | 0.045* |
| A×B | 2 | 0.102 | 2.251 | 0.156 |
| Error | 10 | 0.045 | | |

Note.—MS=Mean squares, *p<0.05.

Table 38: ANOVA results testing standard deviation water level over the fall season (September 2019 – October 2019); excludes Caribou Bog and Meadowvale Bog.

| Source | df | MS | F | P |
|---|---|---|---|---|
| Wetland Type (A) | 2 | 0.006 | 4.091 | 0.051 |
| Ecoregion (B) | 1 | 0.009 | 6.380 | 0.030* |
| A×B | 2 | 0.004 | 2.707 | 0.115 |
| Error | 10 | 0.001 | | |

Note.—MS=Mean squares, *p<0.05.