Comparing shallow groundwater hydrodynamics in reference peatlands and the ditched Big Meadow Bog complex on Brier Island, Nova Scotia

By

Makeala Bridget Janvier MacIntyre

A Thesis Submitted to
Saint Mary's University, Halifax, Nova Scotia
in Partial Fulfillment of the Requirements for
the Degree of Environmental Science

April 2017, Halifax, Nova Scotia

Approved: Tony Bowron, Supervisor
Department of Environmental Science
Saint Mary's University

Approved: Dr. John Brazner, Supervisor
Nova Scotia Department of Natural Resources

Approved: Dr. Danika van Proosdij, Reader
Department of Geography
Saint Mary's University

Date: April 25, 2017

Comparing shallow groundwater hydrodynamics in reference peatlands and the ditched Big Meadow Bog complex on Brier Island, Nova Scotia

By: Makeala Bridget Janvier MacIntyre

ABSTRACT

Understanding characteristic hydrology is the first step toward assessing the degree of impairment in any wetland, including peatlands, and developing an effective approach for restoration. Pre-disturbance datasets are usually unavailable to use as a basis for establishing restoration targets, and there is limited research on peatlands in the province of Nova Scotia to serve as a reference for developing meaningful hydrologic performance measures on which to evaluate success. In the Big Meadow Bog wetland complex on Brier Island, Nova Scotia, a drainage ditch was excavated to increase arable land in 1958 and 1959. This study characterized the hydrodynamics of two Horizontal Fens, three Basin Bogs and a Domed Bog-Fen Complex to compare water level dynamics in different wetland types and to quantify the degree of hydrologic impairment of the ditched Big Meadow Bog complex. This study was also designed to examine relationships between hydrodynamics in the Big Meadow Bog complex and in the reference peatlands in relation to the known distribution of populations of the endangered Eastern Mountain Avens on the island.

All analyses completed for this study were based on hourly water level data collected by pressure transducer-based data loggers installed by Nova Scotia Department of Natural Resources. Water levels were used to characterize water table depths, monthly fluctuations, water table depth durations and the water table response to individual rainfall events. Horizontal Fens were characterized by a water table close to ground level and small fluctuations. The Domed Bog-Fen had a low water table, and was quite stable which was different from the higher water table and larger fluctuations observed in Basin Bogs. Consistent similarities in hydrologic characteristics led to the reclassification of one of the reference Basin Bogs as a Horizontal Fen. Disturbance associated with drainage ditches resulted in a lowered water table, larger amplitude of water level fluctuations, and greater frequency of water levels in dryer depth strata.

Hydrodynamic results suggest that Eastern Mountain Avens is most successful when water levels are concentrated in the shallow root zone, with regular fluctuations into the dryer depth stratum (20-40 cm below ground) for approximately 20-25% of the growing season. The results from this study characterize the typical hydrodynamics of peatlands on Brier Island and should be useful for developing targets to guide successful restoration of the Big Meadow Bog complex and increase the likelihood of sustaining populations of Eastern Mountain Avens in Nova Scotia.

Date: April 25, 2017

ACKNOWLEDGEMENTS

I would like to start by thanking both my supervisors, Tony Bowron and Dr. John Brazner, for all of their help and support. Thank you for taking the time to read through and critique my thesis. I appreciate the time you have set aside in your busy schedules to help me through this challenging process and for allowing me to gain valuable experience.

This project would not have been possible without the extensive data collected by Nova Scotia Department of Natural Resources. Thank you Dr. John Brazner for access to the data you have collected and for taking me to visit each site I have worked with. I'd also like to thank Wally de Vries, owner of the R.E Robicheau General Store for your accommodation on Brier Island. Special thanks to John Drage from the Nova Scotia Department of Natural Resources for access to data from the Big Meadow Bog complex and for assisting with data inquiries, it is very much appreciated. Thank you Dr. Nicholas Hill from Fern Hill Institute for the help you have provided in regards to the Eastern Mountain Avens, as well as Andrew Sharpe and Mike Parker from East Coast Aquatics Inc. for access to data from their rain gauge station.

Next, I would like to acknowledge Dr. Jason Clyburne and Roxanne Richardson from the Department of Environmental Science at Saint Mary's University for their support and the encouragement I needed to follow through with this project.

Last, but certainly not least, I would like to thank my friends and family. Thank you Nanae Kii, Kaitlyn Mackenzie and Liam Goulding for your constant support, patience and for supplying me with caffeine. To my truly amazing parents who, to say the least, have constantly supported and encouraged me, I appreciate and love you both.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION AND LITERATURE REVIEW

The Big Meadow Bog (BMB) wetland complex on Brier Island, Nova Scotia (NS) is one of many peatlands throughout the province that have historically been ditched in order to lower the wetland's water table and increase the quantity of land available for agricultural development. The hydrologic behavior of a wetland is an important parameter in determining the function and the biotic composition of the ecosystem (Richter *et al.* 1996). Understanding characteristic hydrology is the first step towards assessing the degree of impairment in any wetland. This project seeks to quantify the degree of hydrological alteration to BMB by examining the shallow groundwater hydrodynamics.

In order to successfully restore hydrological conditions to BMB, it is important to understand the original structure and hydrodynamics of the wetland complex. However, pre-disturbance groundwater datasets do not exist to help quantify the magnitude of impact resulting from ditching. Unfortunately, there is also limited research on peatlands in the province that could serve as a reference for meaningful hydrologic performance measures. Therefore, this project sought to characterize typical hydrologic behavior for bogs and fens on Brier Island that would not only help quantify the degree of hydrological alteration in BMB but also refine the characterization of typical bog and fen hydrodynamics in the area.

Lastly, the restoration of BMB wetland complex is of special ecological interest due to the presence of several metapopulations of the rare Eastern Mountain Avens (EMA), *Geum peckii*, a plant species found on the complex. EMA was listed as Endangered under Canada's Species at Risk Act (SARA) in June 2003 and under the NS Endangered Species Act in 2000 (Environment Canada 2008). This project sought to examine the relationship between shallow groundwater hydrodynamics and the distribution of EMA metapopulations on BMB and the reference peatlands containing populations of the plant.

1.1 PEATLANDS DISTURBANCE

The National Wetland Working Group (NWWG) (1997) define wetlands as "land saturated with water long enough to promote poorly drained soils, hydrophytic vegetation and biological activity adapted to a wet environment". The most basic requirement for a wetland to become established and be maintained is a consistent enough source of water to keep an area flooded at shallow depths (< 2 m) or saturated near the surface (< 30 cm) for several weeks during the growing season (Mitsch and Gosselink 2007). The Canadian Wetland Classification System recognizes five classes of wetlands; bogs, fens, swamps, marshes and shallow waters (NWWG 1997). Fens and bogs are categorized as organic wetlands based on the predominance of organic soils (peat depth >= 40 cm) (Zoltai and Vitt 1995). Organic wetlands are also referred to as peatlands (NWWG 1997), which represent over 90% of Canadian wetlands (Waddington *et al.* 2009). An inventory of wetlands in Nova Scotia (NS) in 2004 determined that 360 462 hectares of the province were freshwater wetlands, over three-quarters of which were peatlands (NSWCP 2011). This means approximately five percent of the land area in NS is occupied by peatlands.

It is estimated that wetlands provide $7.9 billion dollars in ecosystem services annually in NS, with an additional $12.5 million in economic opportunity (Wilson 2000). Ecosystem services that wetlands provide include habitat for native vegetation and animals, improved water quality, water storage capacitance and carbon sequestration (Bradford 2016). Nonetheless, the habitats have a history of exploitation, typically to increase the quantity of land available for agricultural development, afforestation, and to harvest peat for home heating and horticulture (Tiner 1999; Holden *et al.* 2011; Howie and Tromp-van Meervel 2011; Wilson *et al.* 2010).

The original area of wetlands in NS is unknown, but following European settlement, dyking by Acadians for agricultural purposes has caused considerable historical losses for certain types of wetlands (Kessel-Taylor 1984). Families of Acadian settlers had reclaimed marshland to expand farmsteads and to accommodate for growth in the community (Butzer 2002) and as a result, losses to salt marshes are estimated at 80% in the Bay of Fundy and at least 50% province-wide (Mackinnon and Scott 1984). Since Acadian colonization it is thought that 17% of freshwater wetlands have been lost (Wilson 2000), but this is likely a considerable underestimate because no comprehensive studies have been completed. Losses in some areas, such as the Halifax Peninsula, are known to have been severe. Pre-settlement estimates are that the Halifax Peninsula had a wetland cover of nearly 20%, but virtually all of that had been converted for other uses by the early 1900s (Reid 2012). Years of growth in urban and industrial development have increased the exploitation of peatlands and other wetland types for the expansion of urban and industrial areas and resource extraction (Landry and Rochefort 2012). It is estimated that wetland loss due to development costs the province of NS $2.3 billion dollars a year in lost ecological services (Wilson 2000).

1.2 IMPACTS OF DRAINAGE ON ECOSYSTEM DYNAMICS

The desired consequence of draining a wetland is ultimately to interrupt the natural succession of the land and artificially create a new ecosystem that is of use to human development. There is considerable evidence supporting the resulting changes to the natural biodiversity, water and soil quality of wetlands from drainage (Landry and Rochefort 2012; Price 1997; Wilson *et al.* 2010). Wetland hydrology is recognized as being a primary driver to wetland type and as the primary influence to the development and persistence of wetland ecology (Hunt *et al.* 1999). However, the most direct anthropogenic modification resulting from the drainage of a peatland is to the hydrology of the wetland. Most commonly peatlands are altered by creating a network of ditches, which provide a conduit for water to flow out and effectively lower the water table resulting in the consolidation of peat substrate (Price *et al.* 2003; Wilson *et al.* 2010). Modifications to hydrology cascade into alterations in peat structure, chemical composition of soil and water, and its general ecosystem dynamics (Landry and Rochefort 2012; Price *et al.* 2003; Holden *et al.* 2011; Waddington *et al.* 2009). Even small changes to the hydrology can result in significant biotic changes including species composition, richness and productivity (Mitsch and Gosselink 2007).

1.2.1 Disruption to the natural Hydrologic Cycle

The main fluxes of water inputs and outputs common to most ecosystems are precipitation, evapotranspiration, surface water and groundwater (Waddington *et al.* 2009). These natural hydrologic inputs and outputs are changed by the construction of a drainage ditch (McCartney and Acreman 2009), which seeks to redirect the movement of surface water and groundwater out of the peatland. The magnitude of hydrological alteration can be quantified and observed through hydrologic characteristics; water level fluctuation, water table retention, annual loss and response to environmental stress such as periods of drought (Cole and Brooks 2000; Landry and Rochefort 2012; Holden *et al.* 2011; Van Seters and Price 2002).

Water table fluctuations can provide a useful reflection of the wetland water balance (Bragg 2002). Fluctuations increase with the installation and age of a drainage ditch (Holden *et al.* 2006). Intact wetlands typically have relatively high and constant water levels in the winter and spring seasons, followed by declining summer water levels (Tiner 1999). Minimum water levels are typically reached in late summer and rise once again in autumn (Mitsch and Gosselink 2007). Summer decline, often referred to as the drawdown (Mitsch and Gosselink 2007), can be attributed to higher temperatures, reduced precipitation and higher rates of evapotranspiration from vegetation (Gilman 1994). This natural cycle is heightened in a disturbed ecosystem. The magnitude of water table decrease and increase is greater during the natural seasonal cycle (Landry and Rochefort 2012). Water levels draw lower than is typical of the summer months, thus when the water level returns in autumn, the increase is more significant.

Fluctuations are also greater on a smaller scale in response to individual rainfall events (Holden *et al.* 2011). Storm responses in disturbed bogs include flashier regime of water input and discharge (Bragg 2002). Water levels will drop lower in disturbed peatlands in absence of precipitation and have a more significant rise as it returns (Van Seters and Price 2002). Since the water table is lowered by the drainage ditch there is greater storage capacity in disturbed peatland previous to a rainfall event (Holden *et al.* 2011). Therefore, it has a greater *initial* capacity to store precipitation. However, the rate at which the water table declines is typically greater as well (Holden *et al.* 2011). The added outlet for water flow created by the ditch augments the natural runoff and discharge cycle of a healthy peatland.

Overall the annual water loss is greater in a disturbed peatland. Water runoff, peak flows and base flows will increase through the ditch conduit during the annual water cycle and periods of extreme conditions, such as droughts and flood events (Price *et al.* 2003; Richter *et al.* 1996). Natural vegetation success is linked to the maintenance of a natural hydrologic cycle and retention of the water table (Richter *et al.* 1996). Hydrophobicity changes as a result of a lowered water table consolidating peat substrate (Holden *et al.* 2011). The new conditions generated by disturbance typically favor the growth of shrubs (Morgan-Jones *et al.* 2005), which have higher evapotranspiration rates than the naturally occurring vegetation (Price *et al.* 2003). Thus, the changing vegetation further affects the hydrological outputs and deficit to the water table (Morgan-Jones *et al.* 2005).

Although, the expected consequences are similar among drained peatlands, the degree of disturbance created by a ditch will be unique to the landscape based on the scale, effectiveness, age and the location of the drainage ditch in the landscape (Landry and Rochefort 2012). Therefore, site-specific assessments are required to determine the extent of disturbance.

1.2.2 Peat Degradation

Peat is partially decomposed plant material saturated with water found in organic wetlands. In intact peatlands, there is a diplotelmic structure, meaning there are two overlaid layers of peat which have distinct characteristics (Mitsch and Gosselink 2007). Together they regulate water table storage and discharge processes (Morgan-Johns *et al.* 2005; Price *et al.* 2003; Holden *et al.* 2011). The permeable upper layer of peat, the acrotelm, is characterized by large pore space and high hydraulic conductivity when saturated with water (Price 1997; Holden *et al.* 2011). The hydraulic conductivity controls the facility with which water moves throughout the peat layer (Landry and Rochefort 2012). When the acrotelm has full function, its regulatory properties include stabilizing the water table close to the surface, regulating surface water runoff and minimizing evaporative loss (Price 1997; Ketcheson and Price 2011). The layer beneath the acrotelm is the catotelm, which is not typically exposed. The more highly decomposed peat in this layer has different properties that include smaller pore space and lower hydraulic conductivity than the acrotelm (Holden *et al.* 2011).

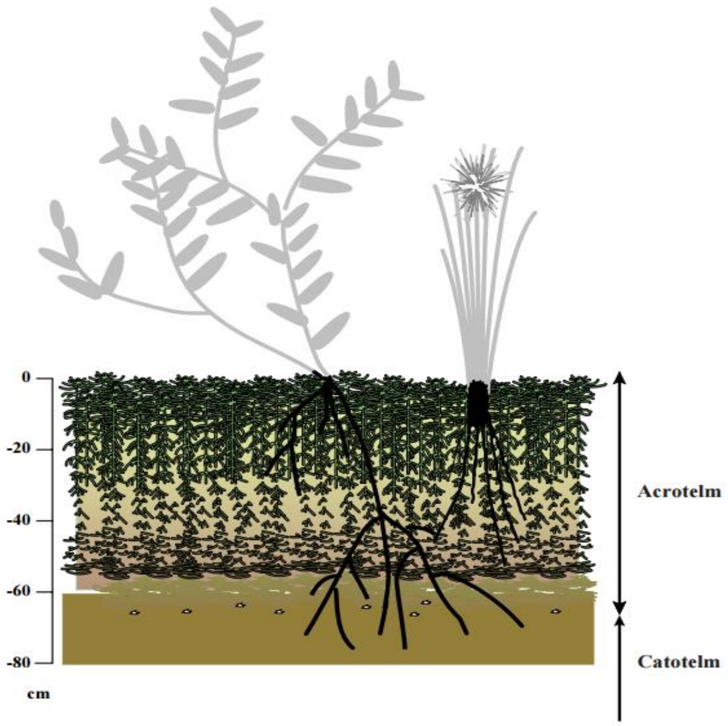

Figure 1. Diagram of the structure of acrotelm and catotelm peat layers (Quinty and Rochefort 2003).

Drainage and harvesting remove the acrotelm layer exposing denser and more decomposed peat in the catotelm (Price 1997). When the water level is lowered to the catotelm layer, the soil no longer has the properties to retain the water table and vegetation (Price *et al.* 2003; Ketcheson and Price 2011). A drainage ditch in combination with the removal of the acrotelm layer leads to peat degradation resulting in a habitat no longer suitable for typical peatland vegetation (Price *et al.* 2003). Removal or degradation of the top layer of vegetation in turn leads to significantly faster surface water flow over the bare peat (Grayson *et al.* 2010; Morgan-Jones *et al.* 2005).

In absence of a high water table, exposed and drier upper layers of peat will shrink and oxidize (Ketcheson and Price 2011). When the peat begins to degrade the landscape structure is lost to subsidence in the upper layers and compaction in the lower layers (Ketcheson and Price 2011; Howie and Tromp-van Meervel 2011; Price *et al.* 2003; Price 1997). Unless mitigated, permanent structural changes may result from the loss of healthy diplotelmic peat layers

(Ketcheson and Price 2011). In peatlands, the natural supporting relationship between the diplotelmic layers, overlying vegetation and hydrologic cycle becomes crippled by a landscape that is continuously draining.

1.3 PEATLANDS RESTORATION

The affects to the structure and dynamics of a peatland generated by a drainage ditch do not typically regenerate without intervention (Howie and Tromp-van Meervel 2011). Abandoned drainage sites need over 25 years for minimal natural recolonization to occur (Ketcheson and Price 2011; Van Seters and Price 2002). Aber *et al.* (2012) refer to restoration as a return to a previous state. As interest in conservation has grown, so has attention to restoration of altered habitats (Gorham and Rochefort 2003). Drained peatlands have received considerable attention in restoration work (Grayson *et al.* 2010; Holden *et al.* 2011; Wilson *et al,* 2010). In recent years' restoration efforts in NS have been driven by the wetland conservation policy promoting compensation for wetland loss to development to prevent net loss and long-term net gain in wetland types that have experienced high historic losses (NSWCP 2011).

The two main peatland active restoration techniques used at present are rewetting and revegetating. However, the former is typically a prerequisite for revegetation by sphagnum moss (Howie and Tromp-van Meervel 2011). The usual management approach is to raise the water table by blocking drainage ditches (Ketcheson and Price 2011; Wilson *et al.* 2010). This slows the discharge of water from the peatland thus raising both the water table and residency time of water (Wilson *et al.* 2010). Returning the water table to natural levels favors the return of previously naturally occurring vegetation, which encourages peat accumulation, and the retreat of encroaching vegetation (Landry and Rochefort 2012). The long-term goals of restoration of a disturbed wetland site should be resilience and persistence, along with the reestablishment of biophysical interactions (Middleton 1999).

Before restoration can be initiated, it is critical to determine appropriate hydrological restoration targets. These are often designed to resemble the original conditions of the drained peatland. Long-term pre-restoration datasets help capture climatic variability and an estimate of typical hydrologic dynamics of a site (Moorhead *et al.* 2008). However, pre-disturbance datasets are typically unavailable to establish baseline hydrological characterization and unfortunately, there is also a lack of assessment dedicated to identifying general hydrologic characteristics of wetlands with similar classification (Cole and Brooks 2000). Undisturbed peatlands in the region can resolve this problem by serving as reference ecosystems to set restoration goals and to monitor success of a project (Moorhead *et al.* 2008). Therefore, in absence of pre-disturbance datasets, a contemporary reference site or sites can be used as a proxy for meaningful hydrologic performance measures.

By expanding a hydrological assessment to a broader scale of intact, or reference wetlands, it allows for the characterization of typical hydrologic behavior and ecological response (Cole and Brooks 2000). Cole and Brooks (2000) suggest that rather than focusing on a single wetland, groups of reference wetlands should to be incorporated. Assessments based on larger number of reference wetlands create a more accurate depiction of hydrologic behavior for restoration targets (Cole and Brooks 2000).

Nonetheless, reference wetlands need to have similar biological and hydrological function to provide intact parameters for the disturbed habitat. Within the five wetland classes designated by the Canadian Classification system (NWWG 1997), there are also several forms differentiated by surface form, relief and proximity to water bodies (Tiner 1999). In addition, the Tiner (1999) classification system recognizes seventeen bog forms and seventeen fen forms. Due to ecosystem variability and the availability of reference ecosystems, they may vary in size, landscape position and vegetation composition. For the purpose of this project, I have focused on the Horizontal and Basin Fen classes, and the Domed and Basin Bog forms (NWWG 1997).

1.3.1 Natural Progression of Peatlands

The class of peatlands referred to as fens have had a slow development of peat in nutrient and base rich waters (NWWG 1997). The slow formation of peat is derived from fallen leaf litter and dead stems of plants such as sphagnum and brown mosses (Tiner 1999). Constant nutrient rich flooding prevents succession to a more acidic environment (Gilman 1994). Fens are classified as having minerogenous hydrology (NWWG 1997). This means that the water table is fed by groundwater or surface water in combination with precipitation (NWWG 1997). The minerogenous hydrology of fens allows for water rich in dissolved minerals to enter the system, especially in areas with particular types of surficial geology, such as limestone, dolomite or basalt (NWWG 1997). Water tables in fens typically fluctuate by only a few centimeters above or below the surface throughout a year (NWWG 1997). Dominant vegetation is dependent on the water table’s depth and chemical composition, but is typically dominated by ericaceous shrub, and graminoid species (Tiner 1999; NWWG 1997). It is not uncommon for fens to be dominated by just a few species (Gilman 1994) but rich fens can be quite diverse (Slack *et al.* 1980).

The build up of peat over fens can give rise to minor hummock structures which become isolated from the ground surface and thus the groundwater over time (Gilman 1994; Howie and Tromp-van Meerveld 2011). The isolation from the nutrient rich ground surface flooding leads to an increased importance of rainfall as a water supply (Gilman 1994). Separation from base rich groundwater promotes the development of bog vegetation communities (Gilman 1994). Bogs are classified by having a rapid development of peat in acidic, nutrient and base poor water (Tiner 1999).

The continuous rapid development of peat can lead to the development of a Domed Bog (Gilman 1994) in one of seventeen forms (NWWG 1997). The form is classified by a large convex structure where water drainage radiates outward (NWWG 1997). The shape of the bog surface will be determined by the wetland's ability to maintain rainfall inputs (Keddy 2000). Due to the frequent fog and high moisture surplus characterizing the coastal areas of NS, hummocks and raised bog structures tend to develop high above the original ground surface (Damman and Dowhan 1981).

A secondary bog form is the Basin Bog (NWWG 1997). Basin Bog features are defined by the confinement to a basin area which maintains a relatively flat surface on the bog (NWWG 1997). When the peat accumulates, the surface does not raise higher than the adjacent terrain (NWWG 1997). The basin feature essentially closes the drainage (NWWG 1997).

Both the Basin Bog and Domed Bog forms are categorized as having ombrogenous hydrology (NWWG 1997). This means they have a precipitation-fed water table and are isolated from lateral inflow or upward seepage due to their position in the landscape (NWWG 1997). Both landscape position and the properties of peat limit water and solute inputs into bogs, so that in true bogs all water is derived from precipitation (Price *et al.* 2003). Fully developed bog vegetation is chemically separated from the mineral soil. Separation occurs through the development of a deep peat soil layer near the surface (Gilman 1994). Thus, there is a shift from control exerted by the local site ecology to control exerted from climatic factors (Keddy 2000).

Bogs are characterized by a water table that is higher than the groundwater table in the adjacent terrain (NWWG 1997). Water table is typically at or slightly below the bog surface (NWWG 1997), but this can be quite different in domed types (Howie and Tromp-van Meerveld

2011). There is correlation between the stability of water levels and the development of a peat (Keddy 2000). Being sustained by precipitation, bogs are typically nutrient poor. Precipitation, fog and snowmelt are mildly acidic due to dissolved carbonic acid and usually contain few dissolved minerals (NWWG 1997). Ion exchange by sphagnum leaves will accumulate cations and release hydrogen ions in the peat, further amplifying the natural acidity of the peat (NWWG 1997). The pH typically associated with bogs lies between 4.0 and 4.8 (NWWG 1997).

1.3.2 Importance of the Transitional Lagg-Fen

An added feature often present along the perimeter of bogs is a transition zone, commonly referred to as a lagg, which is affected and formed by runoff from the surrounding mineral topography and the bog proper (Howie and Tromp-van Meerveld 2011; Langlois *et al.* 2015). When peat accumulation leads to a domed structure, a fen complex often develops on the adjacent margins of the bog (Howie and Tromp-van Meerveld, 2011). The influence from the underlying mineral soil associated with fens will stay restricted to the bog margin, where it is sometimes fed by the outward radiating drainage from the dome structure (Howie and Tromp-van Meerveld 2011). Water levels will typically be lowest in the center of a raised bog and highest in the lagg (Howie and Tromp-van Meerveld 2011).

The lagg margin is not always distinct, but it is more evident when transition between the raised bog structure and the upland is gradual (Howie and Tromp-van Meerveld 2011; Langlois *et al.* 2015). The hydrological and hydrochemical gradients in a lagg take qualities from both the adjacent bog and mineral terrain, but are usually categorized as minerotrophic (Howie and Tromp-van Meerveld 2011; Langlois *et al.* 2015; Whitefield *et al.* 2006). Vegetation in the lagg must adapt to fluctuating water levels due to low summer flow and high winter runoff from the bog and adjacent upland (Howie and Tromp-van Meerveld 2011).

According to Howie and Tromp-van Meerveld (2011), there has been a lack of research on the lagg due to the difficulty in identifying the feature in the landscape. However, the high-water table in the lagg is a key factor in maintaining the water table in bogs (Howie and Tromp-van Meerveld 2011; Morgan-Jones *et al.* 2005; Langlois *et al.* 2015). Thus, in order to properly understand the hydrology and ecological function of a raised bog, there also needs to be an understanding of the transition lagg-fen (Whitfield *et al.* 2006; Howie and van Meerveld 2013).

1.4 BIG MEADOW BOG WETLAND COMPLEX

The BMB wetland complex located on Brier Island, NS is a diverse wetland comprised of a central raised bog and a peripheral lagg-fen, with much of the complex surrounded by adjacent stunted black spruce sloping swamp (Figure 1; Hill *et al.* 2016). The complex is currently a Basin Bog 350 to 450 m in width and stretching approximately 1800 m from the community of Westport in the northeast to Big Pond in the southwest (Hill *et al.* 2016). The wetland is estimated to be 59 ha.

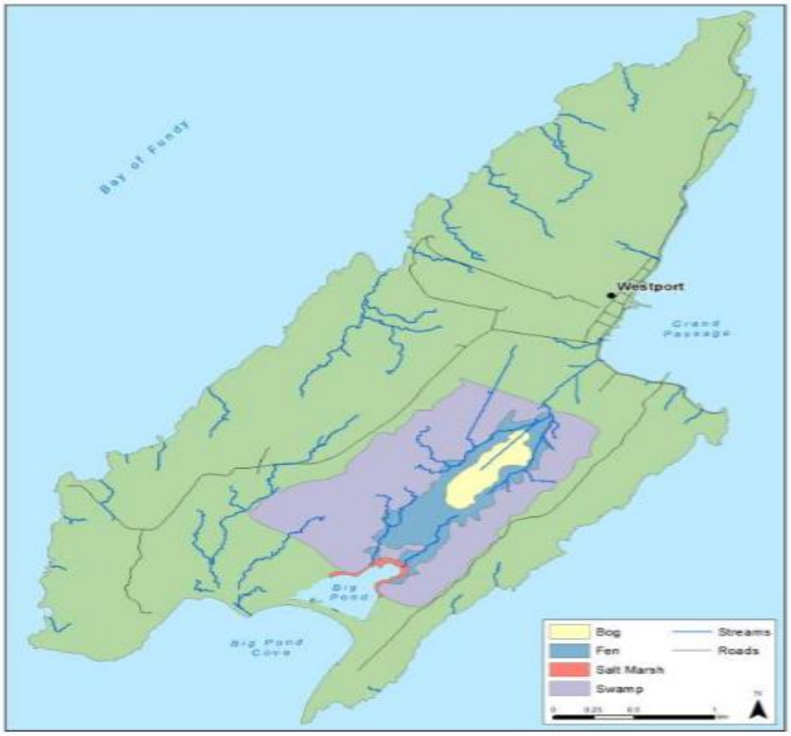

Figure 2. Historic wetland distribution at BMB interpreted from aerial photographs before 1958 (Hill *et al.* 2016).

In 1958 and 1959, a total of 3700 linear meters of ditching was excavated in hopes of creating suitable land for agricultural crops (Hill *et al.* 2016). Originally, BMB was thought to have a domed shape which has been reduced due to the lowered water table and peat subsidence (Kennedy *et al.* 2015). The character of the vegetation for much of BMB now resembles an old field. In response to dryer conditions on BMB there has been encroachment of trees and shrubs and the establishment of the largest colony of herring gulls in the Maritimes with over 4000 nesting pairs (Hill *et al.* 2016). In addition, excrement from the gull colony has resulted in an increase in nutrient concentrations in BMB. Increased nitrogen from the gulls has led to increased phosphorous availability and dramatic decreases in sphagnum coverage across BMB. The increase in nutrient availability has led to faster growing, nutrient demanding plants throughout BMB (Hill *et al.* 2016).

The restoration plan for BMB (2016) submitted to Nova Scotia Environment as part of a Wetland Alteration Approval describes a ditch blocking approach intended to return groundwater to levels approximating historic conditions across BMB. Unfortunately, apart from estimations based on aerial photography, a pre-disturbance hydrological baseline does not exist. Therefore, baseline data from relatively unaltered wetlands were selected as reference sites for comparison with conditions in BMB and developing restoration targets. There is the possibility of anthropogenic disturbance to reference sites such as foot and ATV traffic or climate change, which are beyond the scope of this study. Therefore, apart from Lighthouse Bog, which has a distinct road side ditch disturbance, reference peatlands are assumed to be intact and with minimal or no anthropogenic disturbance. I will compare the hydrodynamics of wells in the reference peatlands to those in the central bog as well as the lagg-fen in BMB to determine the relative degree of hydrological impairment.

1.4.1 Baseline hydrological impairment assessment

Some impacts of ditching to the sites hydrology have been detected through baseline studies completed by researchers that have been working in BMB since 2012 (NCC 2015). Preliminary baseline hydrological monitoring has been completed from monitoring wells along three longitudinal transects running Northwest to Southeast across the wetland complex (Figure 2; Kennedy *et al.* 2015).

Preliminary baseline hydrology studies demonstrated exaggerated water level change in the centre of each transect, within 50 m of the central drainage ditch (Kennedy *et al.* 2015). Although visual observations of the central drainage ditch would suggest that it does not behave as an efficient drain, water level variability indicate that it sustains a continuous discharge of base flow groundwater (Kennedy *et al.* 2015). The most pronounced impact from the central ditch was along Transect 1 and Transect 3, especially during periods of high moisture deficiency (Figure 2; Kennedy *et al.* 2015). However, the greatest water level variability was observed at Transect 1.

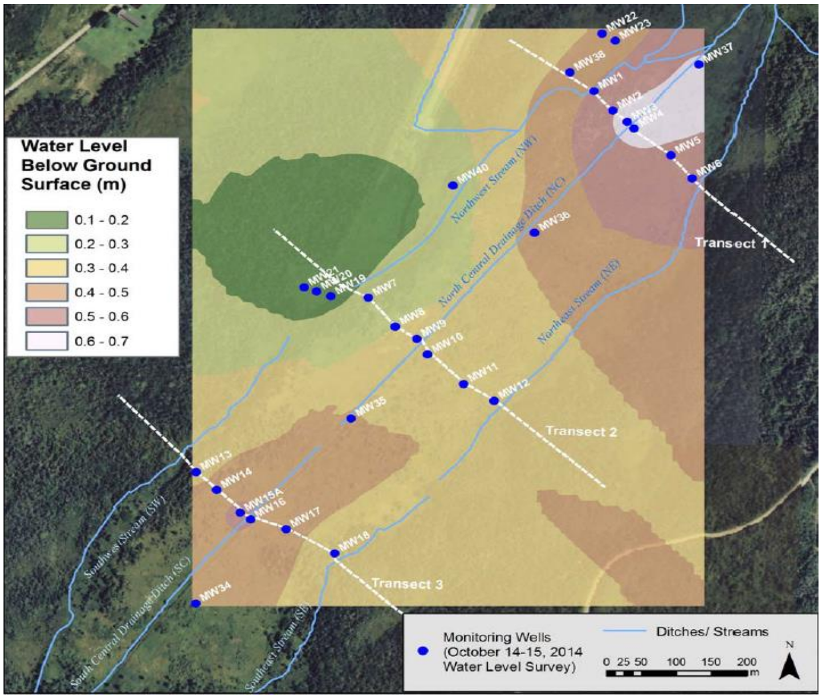

Figure 3. Interpolated depth to water level below ground surface for October 2014, showing location of monitoring wells, longitudinal transects and ditches and streams. The peripheral streams/ditches define the approximate extent of the Basin Bog (Kennedy et al. 2015).

In the intact setting, surface water from upslope pathways on the northwestern end of BMB was thought to have been an important natural source of water to Transect 1, which has since been intercepted and redirected by an airport runway ditch above BMB towards Transect 2. Transect 2 also appears to have the highest and most stable water levels among the three transects (Kennedy *et al.* 2015). The greater stability of water levels in Transect 2 is thought to be due to a regular supply of water from the runway drainage ditch that is distributed as radial groundwater flow towards the centre of the raised bog of the complex (see Kennedy *et al.* 2015 for more detail). However, the magnitude of water level impacts are difficult to quantify without the availability pre-disturbance water level data (Kennedy *et al.* 2015).

1.4.2 Eastern Mountain Avens

EMA has been found in 5 wetlands on Brier Island, which includes the BMB complex. Otherwise, the only other known locations of this perennial, rhizatomous herb are in a fen adjacent to Harris Lake on the Digby Neck, NS and in the White Mountains in New Hampshire (Sperduto and Nichols 2004).

In the BMB complex the only habitat where EMA currently occurs is in the lagg-fen where drainage from adjacent swamps maintains wetter conditions. However, the metapopulation is believed to be threatened by the drainage disturbance in the complex (Hill *et al.* 2016). It is believed that by blocking the ditches and increasing the groundwater level will eventually result in a return of plant communities that are adapted to the low-nutrient boggy conditions that were typical in the past, and provide conditions that will favour EMA (Hill *et al.* 2016). Although there is still considerable uncertainty about exactly what conditions EMA requires to thrive, it is assumed that the central raised bog portion of BMB needs to be returned to an ombrotrophic state and that the wetter hydrology of the lagg must be maintained where it still occurs and returned to areas where it has been lost (Hill *et al.* 2016). The preferred habitat of the EMA in BMB seems to be the perimeter lagg-fen, but the lack of basic life history knowledge of this species creates considerable uncertainty about exact targets for restoring habitat.

1.5 METRICS FOR HYDROLOGIC ASSESSMENTS

Understanding the hydrology is the starting point to any wetland impact assessment (Bradford 2016). Despite its recognized importance, hydrology is frequently omitted in studies of wetlands, thus there is no standard method for characterizing wetland hydrology (Mitsch and Gosselink 2007). The difficulty of effectively and efficiently sampling has likely contributed to the lack of extensive hydrological assessments (Schaffer et al. 2000), but the development of relatively inexpensive and easy to deploy digital water level logging sensors has made this less of an issue in recent years.

The most straightforward time series data to collect as a measure of physical hydrology, and often the only data available, are water levels (Schaffer *et al.* 2000). Measurements of the water level can give insight to seasonal variation, which demonstrates the natural water regime and response to natural and artificial influences (Mitsch and Gosselink 2007). Several variables can be extrapolated and interpreted based on water level data. The three most important determining factors of wetland type are water level fluctuations, mean water levels and range of water table fluctuations (Keddy 2000).

The data collected from water level sensors can be used to quantify the magnitude, duration, timing, rates of change and frequency of water levels as broad metrics of the hydrologic regime of a wetland (Bradford 2016). Hydrographs, plots of water level against time, are commonly used as a first indication of temporal changes (Richter *et al.* 1996). Combined with other quantifying measures of water level, one can demonstrate the overlying hydrologic character of the wetland. A hydroperiod is defined as a temporal analysis of high and low water table (Moorhead *et al.* 2008). Measuring hydroperiod is useful for characterizing intra-annual variability of conditions in a wetland (Bradford 2016).

Threshold water level data is important to the understanding of the distribution of vegetation (Schaffer *et al.* 2000). Thresholds are often quantified in relation to the root zone of plants, which is typically considered to be 30 centimeters below ground level (Cole and Brooks 2000). The distribution of water level in different depth stratum above the water level threshold can also be used to classify and compare different kinds of wetlands. Determining the occurrence and duration of water levels above a specified threshold have been shown to vary between intact wetlands and mitigated wetlands (Schaffer *et al.* 2000).

Median depths and monthly mean water levels are good indications of temporal variations (Cole and Brooks 2000; Schaffer *et al.* 2000). Means represent a good average hydrologic character, however, with extensive data sets there is a high likelihood of outliers which can substantially skew mean values, thus obscuring general hydrologic character (Cole and Brooks 2000). Medians are also typically unchanged by the frequency of measurements (Cole and Brooks 2000; Schaffer *et al.* 2000), which is useful for comparisons that span over longer time periods or a number of systems. Median or mean water level and threshold water level can also be used to characterize the movement of water into and out of a wetland, otherwise known as the flashiness of the system (Cole and Brooks 2000).

2. SIGNIFICANCE AND RELEVANCE OF RESEARCH

Due to a limited amount of research on freshwater wetlands in NS, baseline physical, chemical and biological conditions are not well known (Brazner *et al.* 2015). By expanding on the scientific understanding of the structure and function of these habitats when they are intact, we can quantify reference conditions that characterize typical hydrologic behavior for wetlands in a particular geographic area (Cole and Brooks 2000). Characterizing typical hydrologic behaviour is also critical to creating restoration targets.

One of the goals of this project was to characterize differences in the hydrodynamics of peatlands on Brier Island, NS that have been relatively unaltered by direct anthropogenic impacts to assess the degree of hydrological impairment that exists in the BMB complex. Reference ecosystems on the Island will provide quantitative comparisons from which the hydrological alteration of BMB can be estimated. This hydrological characterization of the reference ecosystem can be used to develop restoration targets for the ditched BMB complex.

Without more detailed topographical and hydrologic surveys, which was beyond the scope of this study, it was not possible to be certain about the proper classifications for the reference peatlands. However, we anticipated that hydrologic data collected for this study would help in refining the classifications for these sites.

Since BMB is a wetland complex and the overall project incorporates monitoring in both the bog and lagg-fen, reference peatlands included both fens and bogs to allow differences in typical hydrodynamics of these wetland classes to be quantified. In addition, I wanted to estimate the potential influence of hydrology on the current distribution of EMA.

EMA is known to be present at low to high abundance in four of the reference peatlands and in several sites in the BMB complex. I expected that by examining the known distribution and abundance of EMA populations in relation to the hydrodynamics of these sites, the potential significance of wetland hydrodynamics on EMA success could be quantified.

3. STUDY SITES

Analyses for this study were based on eight study sites located on Brier Island, NS (Figure 3), a small 1700 ha island located off the western tip of the Digby Neck in the Bay of Fundy. Seven of the study sites were reference peatlands. Two of the reference sites were originally classified as fens, three were classified as Basin Bogs and the last was classified as a Domed Bog-Fen (see Table 1 for more site detail).

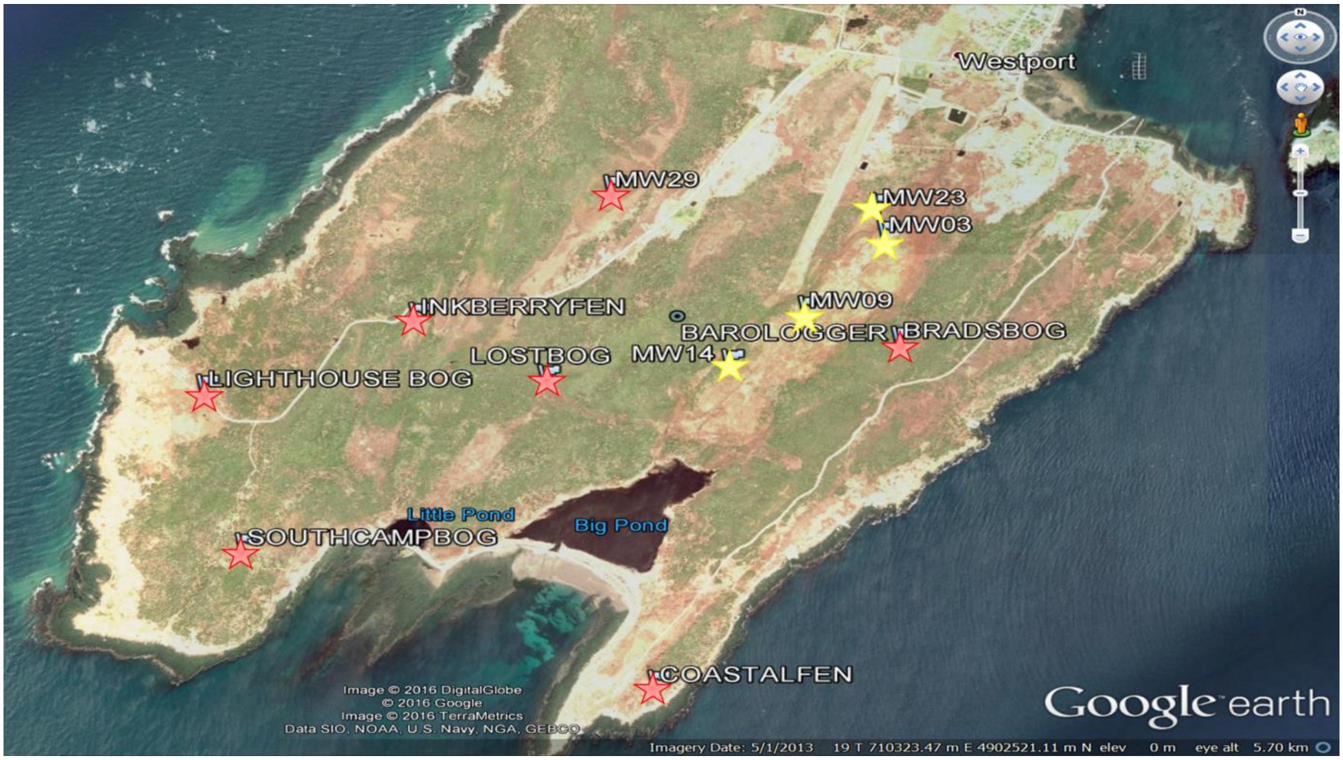

Figure 4. Locations of Big Meadow Bog complex monitoring wells (yellow stars) and reference peatland wells (red stars) (Google Earth March 2013, September 2016).

3.1 BRIER ISLAND CLIMATE

Brier Island has narrow mean annual temperature and daily temperature ranges (~16^{o}C and 8^{o}C, respectively) relative to the rest of NS (Mills and Laviolette 2011). The island has very mild winters with average temperatures in January being approximately 2^{o}C and the longest frost-free period in the Maritimes (Mills and Laviolette 2011). The summers are usually cool with average temperatures in July falling below 18^{o}C (Elliot-Fiske 1988).

The limited variation in climate on the island is due to the surrounding sea temperatures in the Bay of Fundy having no more than a few degrees in change throughout the year (Petrie *et al.* 1996). Tidal mixing and strong Labrador currents cool ocean upwelling and fast tidal streams of the Bay of Fundy that surround Brier Island (Brown 1988; Mills and Laviolette 2011). Sea surface temperature in the outer Bay of Fundy will typically not be any higher than 12^{o}C in the summer and 7^{o}C in the colder months (Mills and Laviolette 2011).

Cool sea temperatures result in frequent fog cover and well distributed precipitation (Damman and Dowhan, 1981). Precipitation is mostly rain with higher monthly averages reached in late fall (115-155 mm) and low monthly averages in the spring (74-85 mm). The average monthly total is 101 mm (Hill *et al.* 2016).

3.2 BMB COMPLEX MONITORING WELLS

For the purpose of this study I will be focusing on groundwater-level monitoring wells at a number of sites around the island, four of which were placed along the three longitudinal transects in the BMB complex. Monitoring Wells 3 and 9 were located in the central bog area and Monitoring Wells 14 and 23 were located on the peripheral lagg-fen where EMA populations are found (Figure 3). The wells were located at various distances from the central drainage ditch and along different transects, therefore having different degrees of disturbance based on location (see Table 1 for more site detail).

- Monitoring Well 3 (MW3) (44.253413, -66.3578334) was located in the central bog along the first transect. The well was located 3.78 m from to the west of the central drainage ditch.

- Monitoring Well 9 (MW9) (44.250055, -66.3614195) was located in the central bog along the second transect. The well was 7.81 m west of the central drainage ditch. MW9 was also believed to be influenced by a ditch (Kennedy et al. 2015) excavated for a private airport runway located adjacent to BMB. The end of the runway was approximately 350 meters northwest of the well.

- Monitoring Well 14 (MW14) (44.247687, -66.3648813) was located near the treeline along the western fen margin/lagg in Transect 3. The well was 56 m from the central drainage ditch. This well was near a population of 100 EMA plants (Toms 2015).

- Monitoring Well 23 (MW23) (44.254624, -66.3581186) was located in the western fen margin approximately 100 m northeast of the western end of Transect 1. The well was located in the lagg of the complex. This is currently the only place where a healthy EMA population occurs in BMB with a population of 747 plants (Toms 2015).

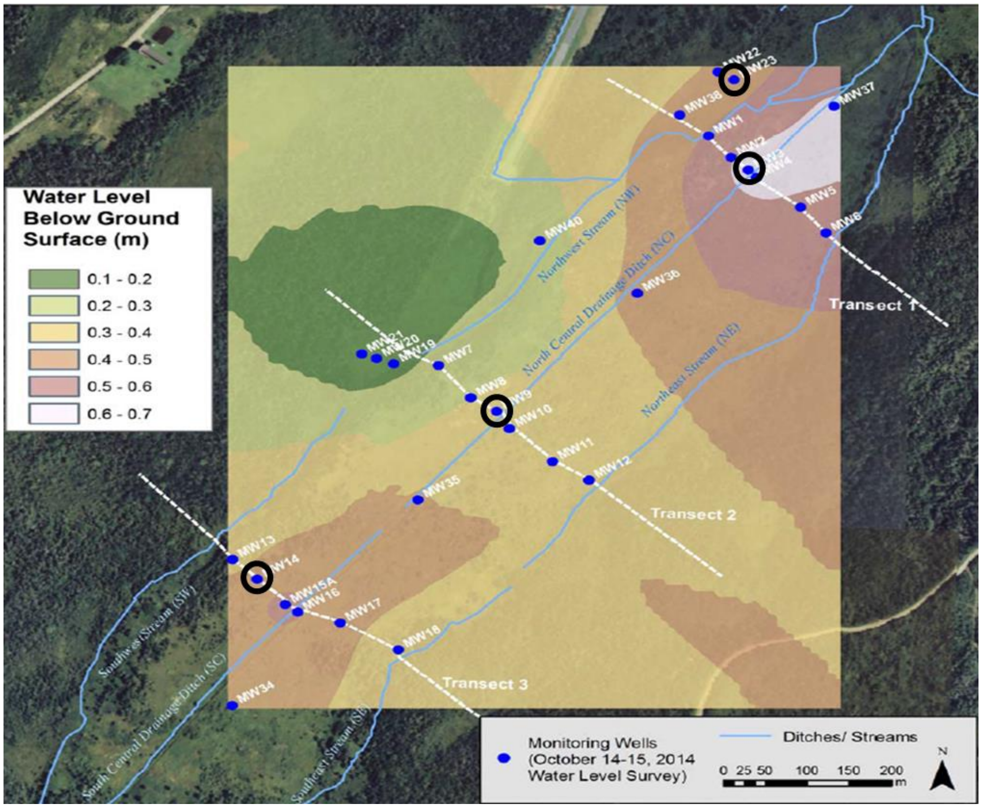

Figure 5. Interpolated depth to water level below ground surface for October 2014 (Kennedy et al. 2015). Monitoring wells used in the project are circled in black.

3.3 REFERENCE PEATLANDS MONITORING WELLS

Reference peatlands were selected based on similarity to wetland classes present in the BMB wetland complex, and also because they supported a range of EMA population sizes. Reference peatlands consist of two Horizontal Fen class wetlands, three Basin Bogs and a Domed Bog-Fen wetland (see Table 1 for more site detail).

- Coastal Fen (CF) (44.233418, -66.368235) was classified as a Horizontal Fen estimated to be 2.9 ha. The site has medium abundance of *Geum peckii* (156 plants in 2013).

- Inkberry Fen (IF) (44.249759, -66.379080) was classified as a Horizontal Fen estimated to be 4.6 ha. The site does not have any populations of *Geum peckii*.
- Lost Bog (LoB) (44.246996, -66.373223) was classified as a Basin Bog and is estimated to be 11 ha. The site does not have any populations of *Geum peckii*.

- Brad’s Bog (BB) (44.248703, -66.357186) was classified as a Basin Bog and was estimated to be 0.79 ha. The site has a high abundance of *Geum peckii* (1205 plants in 2013).

- South Camp Bog (SB) (44.239517, -66.386956) was classified as a Basin Bog and is estimated to be 0.5 ha. The site has medium abundance of *Geum peckii* (805 plants in 2013).

- Lighthouse Bog (LiB) (44.246562, -66.388719) was classified as a Basin Bog and is estimated to be 3.4 ha. The site has a low abundance of *Geum peckii*. There is only one *Geum peckii* plant found on site.

- Reference Bog - Monitoring Well 29, (RB) (44.255396, -66.3702686) is located northwest of BMB (Figure 3). It was classified as a Domed Bog and is part of a peatland complex that includes an adjacent fen (Hill *et al.* 2016). The complex has similar dimensions to BMB (Hill *et al.* 2016). The Fen-Bog peatland complex was estimated to be 20.2 ha. There is no EMA in RB.

Table 1. General site description of reference fens, reference bogs and the four monitoring wells in Big Meadow Bog complex based on field measurements and observations from November 3rd and 4th, 2016 (Acronym is the abbreviation used for each site in the text; Geum counts most recent reported by Toms 2015; low shrub cover ≤ 2 m height, tall shrub cover ≥ 2 m height; surface wetness was a subjective assessment of wetness underfoot at the time each site was visited).

Monitoring Well	**Acronym**	***Geum peckii*** **Count (# plants)**	**Dominant Vegetation (% cover by taxa)**	**Mean Shrub Height (cm)**	**Sphagnum Cover (%)**	**Ground-water pH**	**Conductivity (umhos/cm)**	**Surface Wetness**
Coastal Fen	CF	156	*Carex* spp. (80-90), cranberry (30), bog laurel, bayberry, cinnamon fern, golden rod and raspberry (1-5).	32.75	40-50	5.28	202	Wet
Inkberry Fen	IF	None	Low shrub cover (30), including common junifer (5-10), inkberry (10-15) and black spruce (15). Graminoid (55); scattered reindeer lichen, crowberry, cotton grass and pitcher plants (1-5)	30.5	60	5.07	143	Wet
Lost Bog	LoB	None	Low ericaceous shrub includes huckleberry (30), crowberry (15), lambkill (5-10), *Carex* spp. (10-20), scattered common juniper, low black spruce and bog laurel (1-5). Scattered herbaceous; golden rod, cotton grass and pitcher plant (~1). Tall black spruce (>2m) and white birch (5-10)	85.5	80	4.83	127	Wet
Brad's Bog	BB	1336	Low shrub cover (60), including common juniper (30) lambkill (5) low black spruce (5-10), scattered crowberry, dwarf raspberry, bog rosemary, bog laurel, leatherleaf (1-5). Tall black spruce (5-10)	-	30-40	4.92	157	Damp
South Camp Bog	SB	805	Sedges (25), common juniper (10), black spruce (5-10), with scattered lambkill, leatherleaf, Labrador tea, speckled alder and witherod (1-5)	37	50-60	5.24	130	Damp
Reference Bog	RB	None	Low shrub cover (95), including common juniper (5-10), crowberry (10-20), leather leaf (5-10), lambkill (10-20), black spruce and Labrador tea (1-5). Reindeer moss, Carex spp., bunchberry and pitcher plant (1-5).	31.5	10-20	3.82	132	Dry
Lighthouse Bog	LiB	1	Ericaceous shrub cover (90), *Carex* spp. (10), dwarf raspberry (10) , with scattered crowberry, Labrador tea, Canada holly, cinnamon fern and black spruce (1-5)	41	5-10	4.72	215	Dry
BMB - MW3	MW3	None	No herbaceous. Raspberry thicket (80-90), dense patch of bayberry (1-5), black spruce along ditch (1)	152.5	0	4.8	190	Dry
BMB - MW9	MW9	None	*Juncus* spp. (40), raspberry (5-10), blackberry (10-20) meadowsweet (5), scattered wood/cinnamon fern, golden rod, unidentified grass. Tall shrub on ditch edge (witherod – 10%).	105	0	3.6	182	Damp
BMB - MW14	MW14	100	Labrador tea (40), leatherleaf (5), lambkill (5-10), bog laurel, marsh fern, *Carex* spp. (1-5), tall shrub; witherod and black spruce (1-5)	96.75	75	3.94	113	Wet
BMB - MW23	MW23	747	Low shrub (80-90) lambkill, huckleberry, Labrador tea, dwarf raspberry. Low (<2m) black spruce (5) tall (>2m) black spruce (1-5), *Carex* spp. (1-5)	60.4	1-5	4.31	230	Dry

4. HYPOTHESES

Based on the current understanding of differences in hydrodynamics between bog and fen/lagg habitats as well as current knowledge about the ecology of EMA summarized above, key hypotheses were made based on the relevance of the project.

4.1 CHARACTERIZING TYPICAL HYDROLOGIC BEHAVIOUR

i. As described by the Canadian Wetland Classification system, a fen's water levels are typically close to land surface throughout the year (NWWG 1997). Thus, greater seasonal stability was expected in the reference peatlands classified as fens relative to those classified as bogs since their hydrodynamics are driven by more consistent sources than the rain-fed bogs.

ii. Significant hydrological differences were expected between the two bog forms. Water levels in the Domed Bog were expected to be lower on average than in Basin Bogs, due to their geomorphological differences. The greater accumulation of peat to the convex structure of a Domed Bog may result in a true bog, completely reliant on precipitation (Price *et al.* 2003).

4.2 QUANTIFYING HYDROLOGICAL IMPAIRMENT

i. The baseline study conducted by Kennedy *et al.* (2015) found the greatest amount of hydrologic impairment within 50 m of the central drainage ditch. Thus, Monitoring Wells 3 and 9 were expected to have the greatest hydrological variability due to their proximity to the central drainage ditch on the raised bog portion of the BMB complex.

ii. Lighthouse Bog was expected to have the most similar hydrodynamics to those wells near the central ditch in the BMB complex due to the ditching along the road at this site. The general hydrological impairments expected in drained peatland should also be observed in this bog; greater water level fluctuations and a lowered water table (Landy and Rochefort 2012).

iii. If periods of low water levels are sustained too long, the invasion of taller shrub species is favored (Morgan-Jones *et al.* 2005). Encroaching shrub species would outcompete EMA. Thus, Monitoring Well 23 was expected to have the least variable hydrodynamics due to its position on the lagg-fen with the highest abundance of EMA.

4.3 HYDROLOGIC INDICATIONS OF EMA SUCCESS

i. Since there is significant correlation between the mean water table and the dominant vegetation in bogs and fens (Johansen *et al.* 2017), sites with higher abundances of EMA were expected to have higher water tables. The expected depth of saturation required for sustaining EMA populations is -20 cm (N. Hill, personal communication, Oct. 26th 2016).

5. METHODS

5.1 INSTRUMENTATION USED FOR WATER LEVEL DATA

Groundwater-level recorders were instrumented in the reference peatlands and in the BMB wetland complex in 2013. The research was conducted using existing monitoring well data collected by the Nova Scotia Department of Natural Resources in 2014 and 2015. Two separate types of loggers were used to collect groundwater-level measurements. Hourly water level data from Monitoring Wells 3, 9, 14, 23 in BMB complex and Monitoring Well 29 in RB were provided by John Drage at NSDNR. Data was collected using Solinst level loggers (Solinst, Georgetown, ON, CA). Hourly water level data from wells in BB, CF, IF, LoB, LiB and SB were provided by John Brazner at NSDNR. Data was collected using Hobo pressure transducer-based dataloggers (Hobo U20L-04, Onset Corp., Bourne, MA, USA).

Although, the two sets of hourly water level data were collected using different groundwater-level recording devices, installation was similar and data collected was compatible. For both devices, wells were 1.5 m in length and installed in hand-augered boreholes (Brazner *et al.* 2015; Kennedy *et al.* 2015). Wells used for Solinst recording devices were constructed from 25 mm PVC pipes that were perforated starting 30 cm from the top of the well to the bottom with 5 mm diameter holes at 5 cm intervals (Kennedy *et al.* 2015). To prevent the well from filling with peat when installed the bottom was capped with a PVC pipe cap (Figure 4).

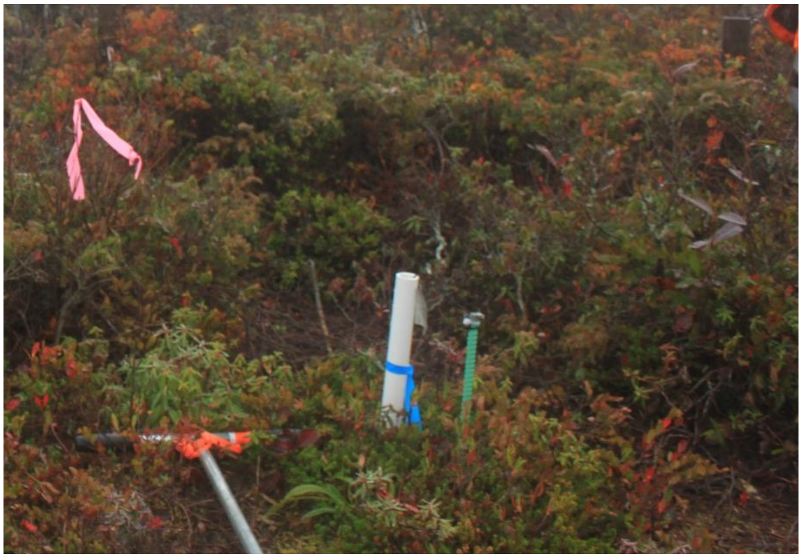

Figure 6. Monitoring Well 29 located in Reference Bog, using Solinst groundwater-level recording device (November 3rd 2016).

Wells instrumented with Hobo recording devices were constructed from 38 mm ABS pipes with one hundred 5 mm diameter holes drilled in the lower 1m of the pipe. The bottom of each well was closed with a plastic pipe cap (Brazner *et al.* 2015). The submerged portion of each well was wrapped with a 2 mm mesh landscape fabric to prevent peat in-filling during installation and to reduce peat sediment in water samples. Hourly water level was measured in relation to ground surface (see Brazner *et al.* 2015 for details; Figure 5).

Figure 7. Well installation for a Hobo groundwater-level recording device (Brazner et al. 2015)

The data from the well loggers was corrected for differences in barometric pressure using an additional Hobo logger installed above ground at Brad's Bog ("barologger").

Daily precipitation records from July 2014 to May 2016 were obtained from the Environment Canada climate station (ID 8200604) on the northern tip of Brier Island. Hourly precipitation data was collected by East Coast Aquatics Inc. Rainlogger station (Solinst, Georgetown, ON, CA) from September 8th to December 3rd, 2015 on Brier Island.

5.2 GENERAL SITE DESCRIPTION

A general site habitat characterization within a 5 m radius of the area around each well on November 3rd and 4th 2016. A YSI 1030 sonde unit (Xylem, Yellow Springs, Ohio, USA) was used to collect a single groundwater pH and conductivity measurement from inside the monitoring well. Surface wetness was assessed subjectively as wet, damp or dry based on examination of augered peat samples next to the monitoring well (Figure 6).

Figure 8. Hand augered peat in South Camp Bog for surface wetness assessment (November 3rd, 2016).

The average shrub height was calculated from four measurements taken within 5 m of every well, one measure in each cardinal direction. Percent cover of low shrub, tall shrub, herbaceous and sphagnum cover was visually estimated in the same area as the shrub height measurements. Low shrub cover was designated as percent cover of all woody species ≤ 2 m in height. Tall shrub cover was designated as percent cover of all woody species ≥ 2 m in height.

5.3 STATISTICAL ANALYSIS OF DATA

Utilizing the extensive data sets provided by NSDNR for the BMB complex and reference peatlands in the surrounding landscape on Brier Island, I examined patterns in the hydrology of these wetlands to determine if there were differences in hydrodynamics associated with differences in human disturbance or wetland type at these sites. However, in order for the two sets of loggers to be directly comparable, water level datasets had to be correctly processed.

Data from MW3, MW9, MW14 and RB were originally recorded as meters above sea level (mAsl). Elevation surveys were conducted by NSDNR in 2014 using a Leica Viva GS14 Global Navigation Satellite System to give wetland surface elevation in relation to sea level (see Kennedy *et al.* 2015 for more details). Values were converted to centimeters below ground level by subtracting the ground surface elevation specific to each well from the original mAsl values.

Data from CF, IF, BB, LoB, LiB and SB were processed and made comparable to the Solinst groundwater-level recorders by using Hoboware graphing and analysis software (Onset Corp, MA, USA). During each download and redeployment, water levels were measured manually using a tape measure rigged electronically to beep when in contact with water. The distance between ground level and the top of the well casing was subtracted from the distance between the water level and the top of the well casing to provide the final estimate of water elevation. The manual water level measurements were used for calibration when processing the downloaded data using Hoboware graphing and analysis software. The barologger data from BB for the corresponding time series was used to correct barometric pressure in the graphing and analysis software. The software processed the downloaded data and converted it into hourly temperature and water levels for each corresponding well.

Once the water levels were correctly processed from both types of groundwater-level recorder, water levels were compiled by the hour for all available dates. However, monitoring wells were not simultaneously recording at all times. Available data from the HOBO loggers was from July 15th 2014 00:00 AM until December 1st 2014 12:00, when they were removed due to the possibility of freezing, and from May 27th 2015 17:00, when the loggers were reinstalled, until May 24th 2016 13:00. The availability of data for the Monitoring Wells was from August 11th 2014 19:00 until November 16th 2015 17:00, except for MW23, which was removed on June 8th 2015 15:00 for the groundwater-level recorder to be used in another monitoring location.

Statistical comparisons were restricted to dates where there was data from all wells. The time series in which all wells were recording was from August 11th 2014 19:00 to December 1st 2014 12:00 and May 27th 2015 17:00 to November 16th 2015 17:00 and is hence forth referred to as the *period of analysis*. Due to MW23 shorter record period, it was often left out of the statistical comparisons. Nonetheless, at times when it was included the well does not have data after June 8th 2015 15:00.

To facilitate certain statistical comparisons, sites were grouped by disturbance and wetland type. Undisturbed Fens were designated as CF, IF and LoB. LoB was reclassified into the Undisturbed Fens group after data processing based on the similarity of water level dynamics at this site to the other two reference wetlands classified as fens. Based on these results, it was assumed the original designation as a bog was a misclassification. MW14 and MW23, the two monitoring wells located on the peripheral lagg-fen of the BMB complex were designated as Disturbed Fens, BB, SB and RB were designated as Undisturbed Bogs. RB was excluded from the Undisturbed Bog group for some of the grouped analyses that involved comparison of median water levels due to the raised peat structure at this site and the inherent difference in water levels that results from this geomorphology. Disturbed Bogs were designated as MW3 and MW9, in the central raised bog of the BMB complex, and LB due to its roadside ditch disturbance.

All mean water level characteristics were statistically compared with one-way analysis of variance (ANOVA) using Minitab Statistical Software (Minitab, State College, PA, USA) to test for significant differences among the means of various water level dynamics characteristics (details below) Tukey’s honest significant difference method was used to test for significant pairwise differences in all ANOVAs. A p-value less than 0.05 was considered significant for all statistical tests.

For each well, I determined mean, standard deviation, interquartile range, median, maximum, minimum water table depths by using Minitab software’s descriptive statistics. Range of water level fluctuations for the period of analysis was calculated as the difference between the maximum and minimum water table depths.

At a finer scale, monthly fluctuations were calculated as the difference between the highest and lowest water level depths for the corresponding month in each well. Summer means were calculated for each disturbance and wetland group and statistically compared. Pairwise comparisons were also made for fall means and the period of analysis. Summer was designated as June, July and August. Fall was designated as September and October.

The amount of time water levels in each well were within various depth intervals was quantified from the original hourly dataset by summing the number of measurements in a particular depth stratum and converting to a percentage of time for the period of analysis. Depth strata were designated as > 0 cm, in the shallow root zone (0 to -20 cm), between -20 cm and -40 cm, and below 40 cm. Hydrologic behavior within the shallow root zone was of particular importance since it is the approximate depth of saturation recommended for the success of EMA populations (N. Hill, personal communication, Oct. 26th 2016). Water levels that were >0 cm were designated as inundated, between 0 cm and -20 cm was designated as saturated and between -20 cm and -40 cm was designated as dry. Each depth stratum was statistically compared between disturbance and wetland group.

Medians are a useful approach to assessing water level (Cole and Brooks 2002). Daily water level medians were calculated for each day that data was available for every well. A hydrograph of daily medians with daily precipitation from Environment Canada’s climate station (ID 8200604) was used to visualize hydrologic characterises, water level fluctuations and water table depth durations for the period of analysis. Values were also statistically compared and plotted in a boxplot.

A hydrograph was also included for summer of 2015 to aid in the visualization of differences in the magnitude of drawdown occurring in the growing season between wells. Values were also statistically compared and plotted in a boxplot.

Monitoring Wells and Hobo loggers were not recording during the same winter season. The Monitoring Wells were recording during December 2014 through March 2015 whereas the Hobo loggers which were removed for the 2015 winter months were re-installed and allowed to record during the 2016 winter months. For this reason, I could not include these dates in the statistical comparisons. However, to capture any hydrological characteristics that may not have been included in the period of analysis, I chose to represent the entire segment of data available as a daily median hydrograph with daily precipitation from Environment Canada's climate station. The hydrograph includes all daily median water levels available from July 15th 2014 to May 24th 2016.

Water table responses to three large rainfall events from September 8th to December 3rd 2015 were examined using the hourly precipitation data. Due to the limited amount of hourly precipitation data, a period of rainfall greater than 30 mm within 24 hours was designated as a large precipitation event to observe a distinct change to the water table and to focus on simple rainfall events rather than complex events lasting several days (Holden *et al.* 2011). For every well, I calculated the total rise in water table height, and converted it to a percentage of total quantity of rainfall for each individual event. Additionally, a 12-hour water table recession was calculated as the percentage of the water table rise that was lost within 12 hours of the wells having reached their peak water table height (e.g. minimum depth) for the corresponding rainfall event. Mean percentage of water level rise and 12-hour recession was statistically compared among the four wetland disturbance classes.

6. RESULTS

6.1 WATER TABLE CHARACTERISTICS

6.1.1 Water Table Descriptive Statistics

Undisturbed Fens had similar mean water levels (Table 2) which were typically within 5 cm of ground level (Figure 7). The mean water table depths in Undisturbed Fens were significantly closer to ground level than the remaining wetland disturbance groups (Table 2; Figure 8, $p > 0.05$). Maximum water levels were over 10 cm above ground level and minimums did not surpass 17.7 cm in depth (Table 2). The range of values varied slightly between 28 and 32 cm (Table 2), which was generally the smallest range among the four disturbance and wetland groups (Figure 8).

Compared to the Undisturbed Fens, MW14 and MW23's mean and median water table depth was typically 10 cm lower (Table 2). Additionally, maximum and minimum water levels were over 15 cm lower (Figure 7). MW14 water table depth was generally the closest to ground level out of the BMB well and its range was similar to the Undisturbed Fens.

During the period of time data was available for MW23, the range in values was ~20 cm greater than the Undisturbed Fens and MW14 and more comparable to Undisturbed Bogs (Table 2). Maximum water level was greater than MW14. However, the minimum water level was over 30 cm lower than the Undisturbed Fens.

Table 2. Hydrologic characteristics of hourly water level data (in cm) of eight peatlands on Brier Island for the period of analysis. Period of analysis is from August 11th to December 1st, 2014 and May 27th to November 16th, 2015. Monitoring well means that do not share a letter as superscripts are significantly different ($p \leq 0.05$). Because the logger for MW23 was removed during the period of analysis, data for MW23 was not included in statistical comparisons. N is the number of times water levels were recorded for each well; IQR is the interquartile range; Range refers to the difference between the highest and lowest water level depths; Geum peckii count refers to the number of plants located on each site.

Monitoring Well	N	Mean	St. dev.	IQR	Maximum Depth	Median Depth	Minimum Depth	Range	*Geum peckii* count
Undisturbed Fens									
CF	6817	-4.60^{A}	3.63	5.1	16.40	-4.7	-12.3	28.7	156
IF	6817	-4.19^{A}	3.50	4.9	14.30	-3.5	-12.3	26.6	-
LoB	6817	-4.10^{A}	3.64	4.7	13.80	-3.6	-17.7	31.5	-
Disturbed Fens									
MW14	6817	-14.96^{C}	14.95	11.3	0.38	-13.9	-30.5	30.9	100
MW23	2951	-20.81^{-}	14.95	29.3	3.85	-21.8	-46.2	50.0	747
Undisturbed Bogs									
BB	6817	-13.35^{B}	7.40	10.8	15.10	-10.5	-38.0	53.1	1336
SB	6817	-17.21^{D}	3.18	4.6	-5.20	-17.2	-25.1	19.9	805
RB (MW29)	6817	-47.16^{G}	6.81	10.7	-19.56	-47.5	-62.8	43.2	-
Disturbed Bogs									
LiB	6817	-30.46^{E}	11.75	22.2	-3.50	-33.1	-56.0	52.5	1
MW3	6817	-40.03^{F}	20.18	32.5	7.23	-40.5	-78.1	85.3	-
MW9	6817	-17.53^{D}	12.48	22.9	9.88	-16.4	-40.3	50.1	-

RB had the lowest values for the majority of hydrologic characteristics (Table 2). Low water level behaviour was likely attributed to the raised peat structure at this site. In addition, the location of the single monitoring well, which was at the highest point of elevation within the site (top of the dome), also contributed to the low values observed (Figure 7). Water level depth varied by 43.2 cm overall, which was 10 cm smaller than the other Undisturbed Bog, BB (Table 2).

Water levels at the other Undisturbed Bogs, SB and BB, varied more than in Undisturbed Fens. Differences between mean water levels was 3.86 cm, but the largest difference was between maximums and water level range. BB had the second highest water level maximum (15.10 cm) and a lower minimum tan SB (-38.0 cm). Where as SB had one of the lowest maximums (-5.20 cm) and a higher minimum (- 25.1 cm). Thus, SB had a lower range (19.9 cm), the lowest of all other wells (Figure 7). The range in values at BB was over 30 cm larger than SB, however, its maximum and minimum levels were closer to ground level (Figure 7).

The difference between SB and MW9 mean water table depth was not considered significant (Table 2, $p > 0.05$). However, the range of values in MW9 was ~30 cm greater. MW9's mean, median, maximum, and minimum water levels were nearly 15 cm closer to ground level than LiB. Mean, median and minimum water levels in LiB were over 10 cm lower than the other Basin Bogs (Table 2). However, the maximum value at LiB (- 3.50 cm) was greater than SB (Table 2), but still never rose above ground level (Figure 7).

Among the disturbed wells, MW3 had the most wide-ranging water levels (Table 2). Mean and median water levels were the lowest of all wetland disturbance groups (Table 2). Minimum depth was 78.1 cm, which was lower than RB (Figure 7), but the maximum water level was above ground level (7.23 cm). The range for this well (85.3 cm) was over 30 cm greater than the next closest well, LiB (Figure 7).

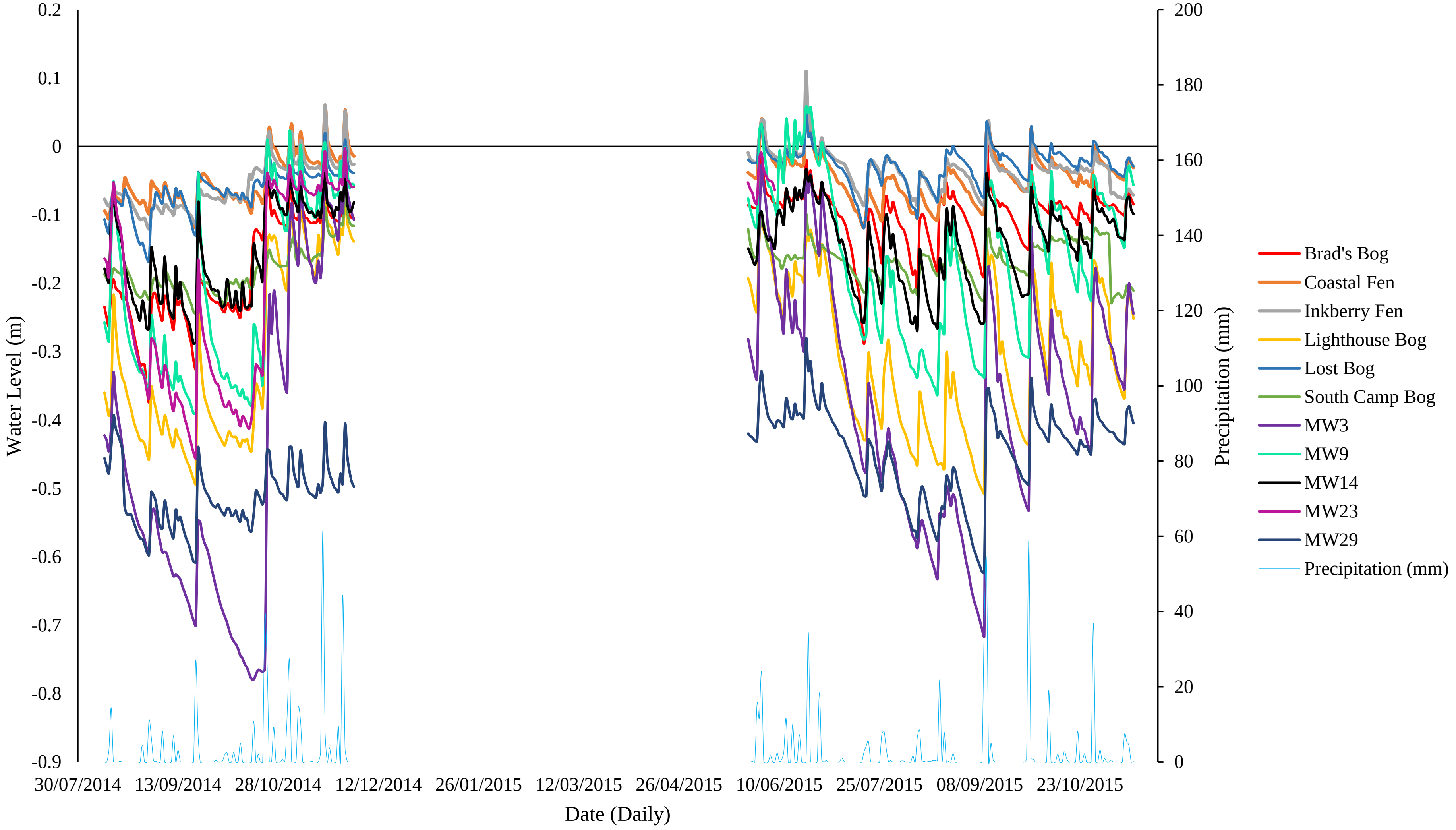

Figure 9. Hydrograph of all wells based on daily water level medians (m) with precipitation (mm; light blue lines) from August 11 to December 1 2014 and May 27 to November 16 2015 – referred to as Period of Analysis in other Tables and Figures. It includes data during which all monitoring wells were simultaneously recording. The data logger at MW23 was removed June 8, 2015. Data plotted was included in statistical analysis. Water level is relative to ground surface (0 m).

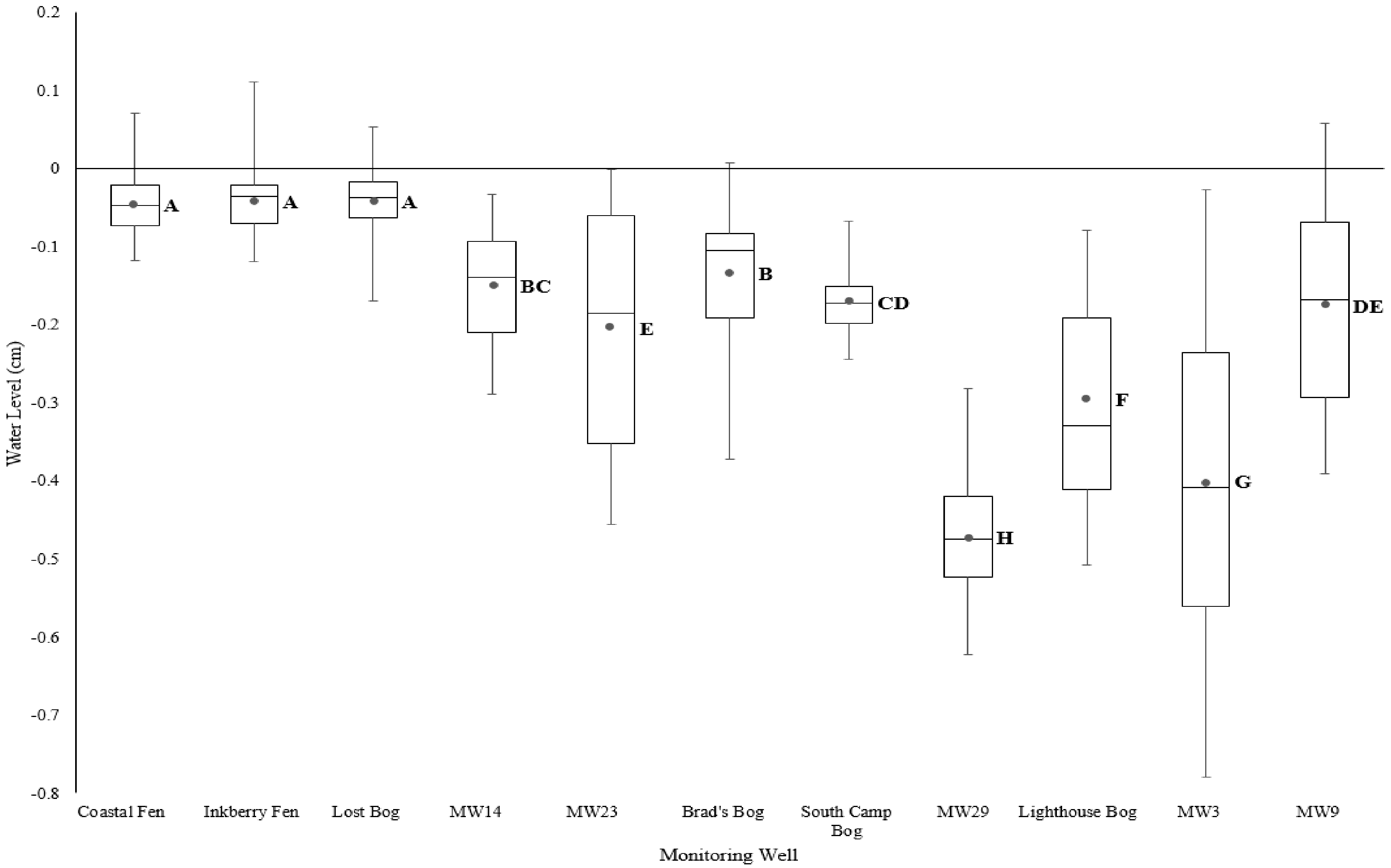

Figure 10. Boxplot of daily median water level (m) relative to ground surface (0 m) of all monitoring wells for the period of analysis. MW23 has less than half the values than the remaining sites. Mean value for the corresponding wells was represented as a grey circle. Boxes for monitoring wells that do not share a letter are significantly different ($p \leq 0.05$).

6.1.2 Daily Median Water Level analysis for Summer of 2015

Apart from the comparatively stable SB, every well's water level decreased during the growing season of 2015. However, the rate and magnitude of decrease was greater in the disturbed sites (Figure 9). Although SB had the most stable water levels throughout summer 2015, the water table was lower. The Undisturbed Fens water table was significantly closer to ground level than any other wetland disturbance group (Figure 10, $p \leq 0.05$).

The Disturbed Fen, MW14, kept the highest water levels throughout summer in the BMB complex. Additionally, apart from the Undisturbed Fens, MW14, SB and MW9 water table depth in summer 2015 was significantly higher than the remaining wells (Figure 10, $p \leq 0.05$). However, MW9 water levels still had a large drawdown in response to the growing season. LiB and MW9 had the second greatest drawdown compared to the significant drop observed in MW3 (Figure 9). All three Disturbed Bogs dropped below 30 cm in depth.

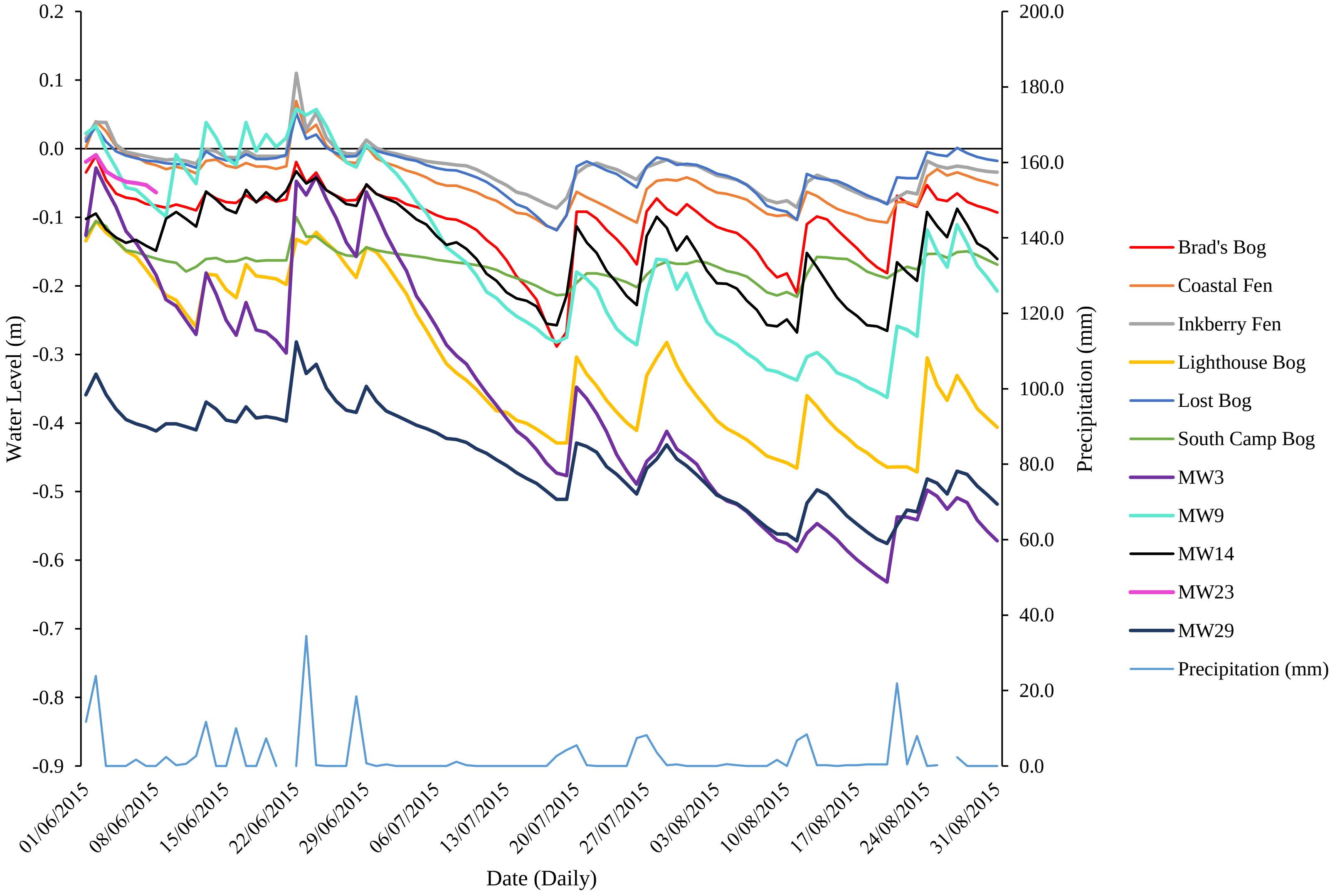

Figure 11. Daily water level medians (m) with precipitation (mm; light blue lines) for summer of 2015 hydroperiod. Water level is relative to ground surface (0.0 m).

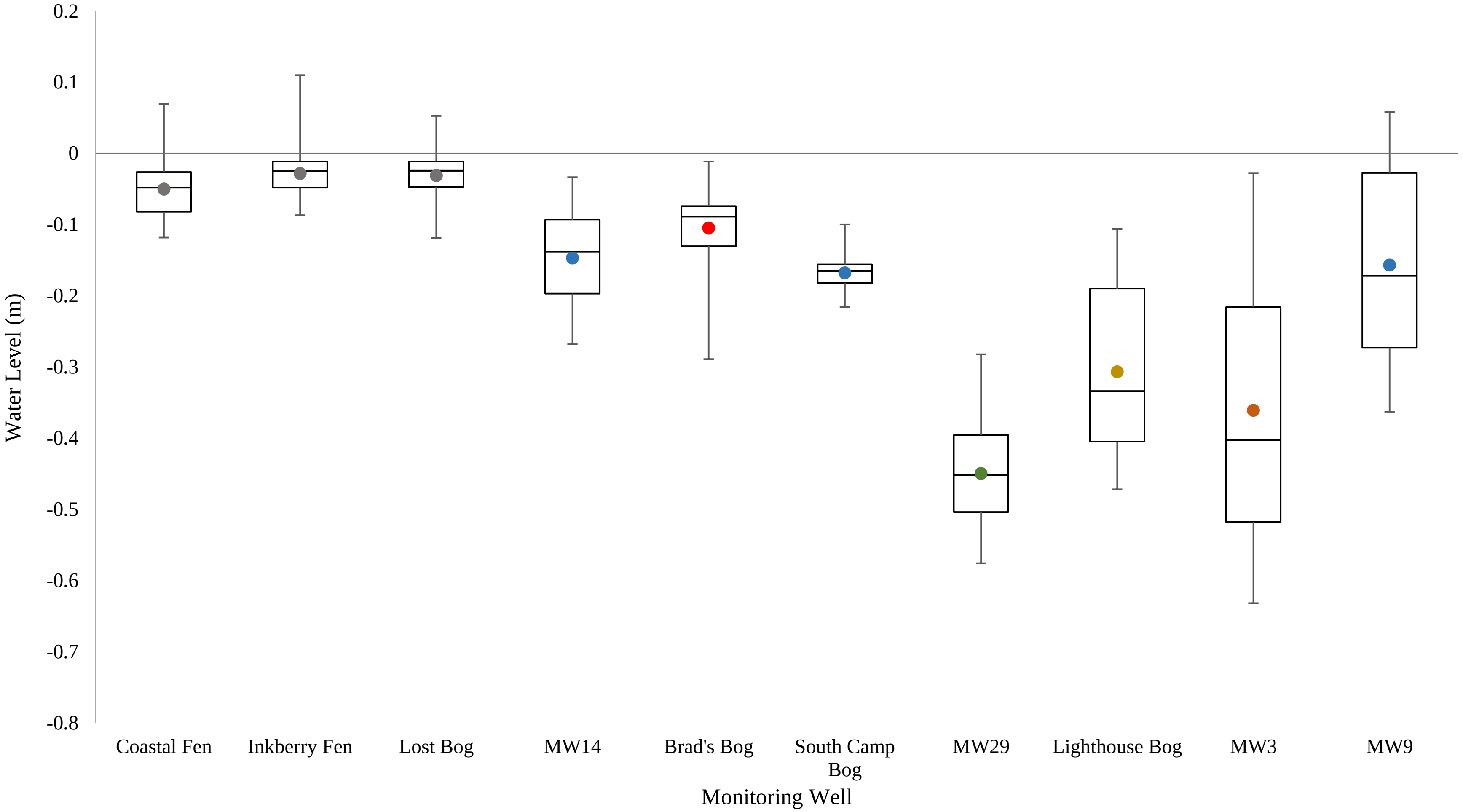

Figure 12. Boxplot of daily median water levels (m) relative to ground surface (0 m) for all monitoring wells during summer of 2015. MW23 was omitted because it was not recording during this time. Mean values are represented as circles. Means that are different in colour are significantly different ($p \leq 0.05$).

6.1.3 Monthly Water Table Fluctuations

When evaluated across Undisturbed and Disturbed wetland types for every month, disturbed sites were significantly different from their undisturbed counterparts (Table 3, $p \leq 0.05$). Additionally, with the exception of MW14, Undisturbed Fens and SB mean monthly fluctuations were significantly smaller than the BMB wells ($p \leq 0.05$).

The smallest mean monthly fluctuations were observed in SB, which never exceeding 13.6 cm in any particular month (Table 3). The Undisturbed Fens mean amplitude of fluctuation was the smallest after SB. In addition, there was little to no difference between the overall, summer and fall means for the Undisturbed Fens. The largest monthly range was ~20 cm in June and September 2015.

Fluctuations in both Disturbed Fens were generally greater than the Undisturbed Fens (Figure 7). Although it was not found to be significantly different, MW14's mean monthly fluctuation was nearly double the Undisturbed Fens (Table 3). For the period that MW23 was recording, the mean monthly fluctuation was nearly triple the fluctuation in the Undisturbed Fens. Similarly to the Undisturbed Fens, the difference between summer and fall means was small (~1 cm) for the Disturbed Fens. However, both means were approximately 10 cm greater than the means for the Undisturbed Fens.

Mean monthly fluctuations at BB, MW14 and RB were only significantly smaller than MW3 (Table 3, $p \leq 0.05$). The mean monthly fluctuations were similar between BB and RB, however RB was slightly smaller (Table 3). RB typically had less summer fluctuation than BB, however in the fall, both Undisturbed Bogs had a similar increase to the amplitude of fluctuation. The largest fluctuation occurred in September of 2015 for both BB and RB.

Table 3. Monthly water level fluctuation for individual monitoring wells, mean monthly fluctuations for summer and fall, and overall mean by undisturbed and disturbed wetland group. Fluctuation was calculated as the difference between the highest and lowest monthly value in cm. Values are for months where all loggers were recording, except MW23 which was only recording from August to November 2014. The group mean for Disturbed Fens includes MW23 values, but summer and fall group means do not. June, July and August are designated as summer months. September and October are designated as fall months. Means, within the same contextual comparison, that do not share a letter are significantly different ($p \leq 0.05$). *Geum peckii* count refers to the number of plants on each site.

	Undisturbed Fens			**Disturbed Fens**		**Undisturbed Bogs**			**Disturbed Bogs**		
Date (mm/yy)	CF	IF	LoB	MW14	MW23	BB	SB	RB	LiB	MW3	MW9
Aug-14	7.0	6.3	12.5	21.6	33.1	20.0	5.8	21.4	25.4	27.9	31.0
Sep-14	8.9	6.4	13.9	24.4	33.9	21.8	7.1	18.5	36.0	17.5	39.3
Oct-14	14.1	11.6	10.1	23.1	39.8	21.7	8.9	16.8	45.1	60.3	44.2
Nov-14	11.7	11.7	9.6	11.9	12.1	14.7	12.4	16.2	18.1	39.7	19.4
-	-	-	-	-	-	-	-	-	-	-	-
Jun-15	20.3	16.8	17.1	16.3	-	24.5	12.0	21.9	21.3	37.5	20.3
Jul-15	10.7	9.0	12.3	20.4	-	23.2	7.1	14.0	27.4	38.2	27.4
Aug-15	9.5	7.6	12.5	22.6	-	19.9	7.6	12.0	35.2	19.2	29.0
Sep-15	18.9	17.1	16.9	25.8	-	26.7	13.6	34.7	41.3	67.8	36.2
Oct-15	10.9	6.3	8.1	14.4	-	13.4	4.9	13.7	21.6	39.6	23.3
Mean	$12.4^{\mathbf{C}}$	$10.3^{\mathbf{C}}$	$12.6^{\mathbf{C}}$	$20.0^{\mathbf{BC}}$	$29.7^{\mathbf{AB}}$	$20.7^{\mathbf{BC}}$	$8.8^{\mathbf{C}}$	$18.8^{\mathbf{BC}}$	$30.2^{\mathbf{AB}}$	$38.6^{\mathbf{A}}$	$30.0^{\mathbf{AB}}$
Geum peckii count	156	-	-	100	747	1336	805	-	1	-	-
Group Mean	$11.8^{\mathbf{A}}$			$23.0^{\mathbf{B}}$		$16.1^{\mathbf{AB}}$			$32.9^{\mathbf{C}}$		
Summer Group Mean	$11.8^{\mathbf{B}}$			$20.2^{\mathbf{AB}}$		$15.8^{\mathbf{B}}$			$28.3^{\mathbf{A}}$		
Fall Group Mean	$11.9^{\mathbf{B}}$			$21.9^{\mathbf{B}}$		$16.8^{\mathbf{B}}$			$39.3^{\mathbf{A}}$		

The amplitude of monthly fluctuations and the seasonal fluctuations were greatest in the Disturbed Bogs. Fluctuations were significantly larger than those in Undisturbed Fens and Undisturbed Bogs during summer and all of the wetland disturbance groups in fall ($p \leq 0.05$).

Among the Disturbed Bog group, both LiB and MW9 had similar monthly ranges. Mean monthly fluctuations in LiB and MW9 were approximately 10 cm greater than BB and RB (Table 3). MW3 had the largest mean monthly fluctuation (Table 3). The well had the greatest monthly fluctuation in most months, with peaks in September 2015 (67.8 cm) and October 2014 (60.3 cm). LiB and MW9 had the closest amplitude of fluctuation to MW3, but were still over 15 cm smaller.

6.1.4 Water Table Depth Duration

Undisturbed Fens had a significantly higher proportion of inundated and saturated water levels. Inundation occurred 7 to 10 % of the time, while the remaining observations were saturated (> 90 %) (Table 4). Since none of the recorded water levels were dry, they had significantly lower proportion of water levels in this stratum relative to all other wetland disturbance classes (Table 4, $p \leq 0.05$).

Together, the Disturbed Fens were inundated ~8% less frequently than the Undisturbed Fens. Separately, MW14 was saturated for nearly three quarters of the observations, however the water table fell to the dry depth stratum for the remaining record of water levels (Table 4). Compared to MW14, MW23 had a greater frequency of dry water levels. The water table in MW23 was dry 15.4% more than MW14, and below -40 cm for 7.9% of the observations.

Three quarters of the Undisturbed Bogs observations were saturated (Table 4) and, apart from a small percentage (< 1%) of inundated water levels in BB, the remaining observations were dry. The distribution of water levels among depth strata were similar between the Undisturbed Bogs and MW14.

Table 4. Water table depth duration from hourly water levels during the period of analysis. Depth duration is expressed as a percentage (%) of overall values. Because the logger at MW23 was removed earlier it has less than half the hourly values of the remaining sites. Data from RB was not included in this comparison (see Methods for explanation). Due to the confounding effect of the runway ditch to MW9, it was left out of the Disturbed Bogs group mean. Group means were examined for significant differences based on wetland disturbance class. Means, within the same contextual comparison, that do not share a letter are significantly different ($p \leq 0.05$). No significant differences among all disturbance classes were observed below 40 cm in depth. Geum peckii count refers to the number of plants on each site.

	Undisturbed Fens			**Disturbed Fens**		**Undisturbed Bogs**		**Disturbed Bogs**		
Water level from ground level (cm)	CF	IF	LoB	MW14	MW23	BB	SB	LiB	MW3	MW9
Geum peckii count	156	-	-	100	747	1336	805	1	-	-
Inundated (> 0cm)	9.66	8.22	7.82	0.03	1.05	0.76	0.00	0.00	0.34	6.83
Group Mean	8.57^{A}			0.54^{B}		0.38^{B}		0.17^{B}		-
Saturated (-20 cm ≥ x < 0 cm)	90.35	91.78	93.64	72.47	48.18	75.67	78.56	27.38	19.28	49.43
Group Mean	91.92^{A}			60.30^{B}		77.12^{AB}		23.33^{C}		-
Dry (-40cm ≥ x < -20 cm)	0.00	0.00	0.00	27.50	42.86	23.57	21.44	43.41	29.77	43.73
Group Mean	0.00^{A}			35.18^{B}		22.51^{B}		36.59^{B}		-
x > -40 cm	0.00	0.00	0.00	0.00	7.90	0.00	0.00	28.93	50.61	0.02
Group Mean	0.00^{A}			3.95^{A}		0.00^{A}		39.8^{B}		-

Water table depth durations in MW9 were different from the other Disturbed Bogs due to the confounding affected of the runway ditch, which resulted in a greater percentage of water levels in the saturated depth stratum than LiB and MW3 (Table 4). Apart from the Undisturbed Fens, MW9 had the greatest amount of inundation and MW9 had over 20% greater saturated observations than the other Disturbed Bogs. Thus, when MW9 was excluded from some of the statistical comparisons among groups, LiB and MW3 had significantly greater frequency of water table depth in the dry stratum. LiB had over 70% of its hydroperiod below -20 cm. However, the percentage of low values was greatest in MW3 (Figure 7), with over half of its observations below 40 cm in depth (Table 3).

6.2 DAILY MEDIAN WATER LEVEL HYDROGRAPH

It was apparent that the greatest amplitude of water level fluctuations occurred during the period of analysis (Table 2, Table 3, and Figure 7). However, the hydrograph, which incorporated winter of 2015 and 2016 when Monitoring Wells were not simultaneously recording, captured typical hydrological characteristics that were excluded from the statistical analysis (Figure 11).

The hydrograph captured the only seasonal period in which the BMB wells had water levels with less variable characteristics and greater proximity to ground level, with greater similarity to the behaviour observed in the Undisturbed Bogs and Fens. As was alluded to by the smaller amplitude of fluctuations for the Disturbed Fens in November, MW14 and MW23 progressed to more stable water levels closer to the ground surface from the previously variable fall and summer months (Figure 11). However, in late fall 2014, MW23's water level rose over 30 cm closer to ground level, surpassing water levels at MW14. Water levels in the well were closer to -5 cm, as opposed to the lower mean water table observed during the period of analysis of -20.81 cm (Table 2).

Similar to the Disturbed Fens, by November 2014 the amplitude of monthly fluctuation in MW9 was smaller (Table 3) and decreased as winter progressed (Figure 11). However, water levels still had greater variability than the Disturbed Fens.

In comparison to the other BMB Monitoring Wells, MW3 was the only well which remained variable during winter 2015 (Figure 11). In absence of precipitation, water levels would drop over 10 cm, and have similar magnitude of water level rise when precipitation returned. In winter 2016, LiB had similar decreasing water level behaviour in absence of rainfall to MW3 in the winter 2015 (Figure 11).

The Undisturbed Fens and Undisturbed Bogs were able to maintain higher water tables in the winter 2016 and winter 2015 for RB, even through absence of precipitation.

In addition, following a significant drop to SB’s water table in mid fall 2015, in combination with the recharge to BB’s water table in mid fall 2014, the water table was approximately 10 cm greater in BB than SB (Figure 11). The different water table depths were unalike the similar mean water table depths observed during the period of analysis (Table 2).

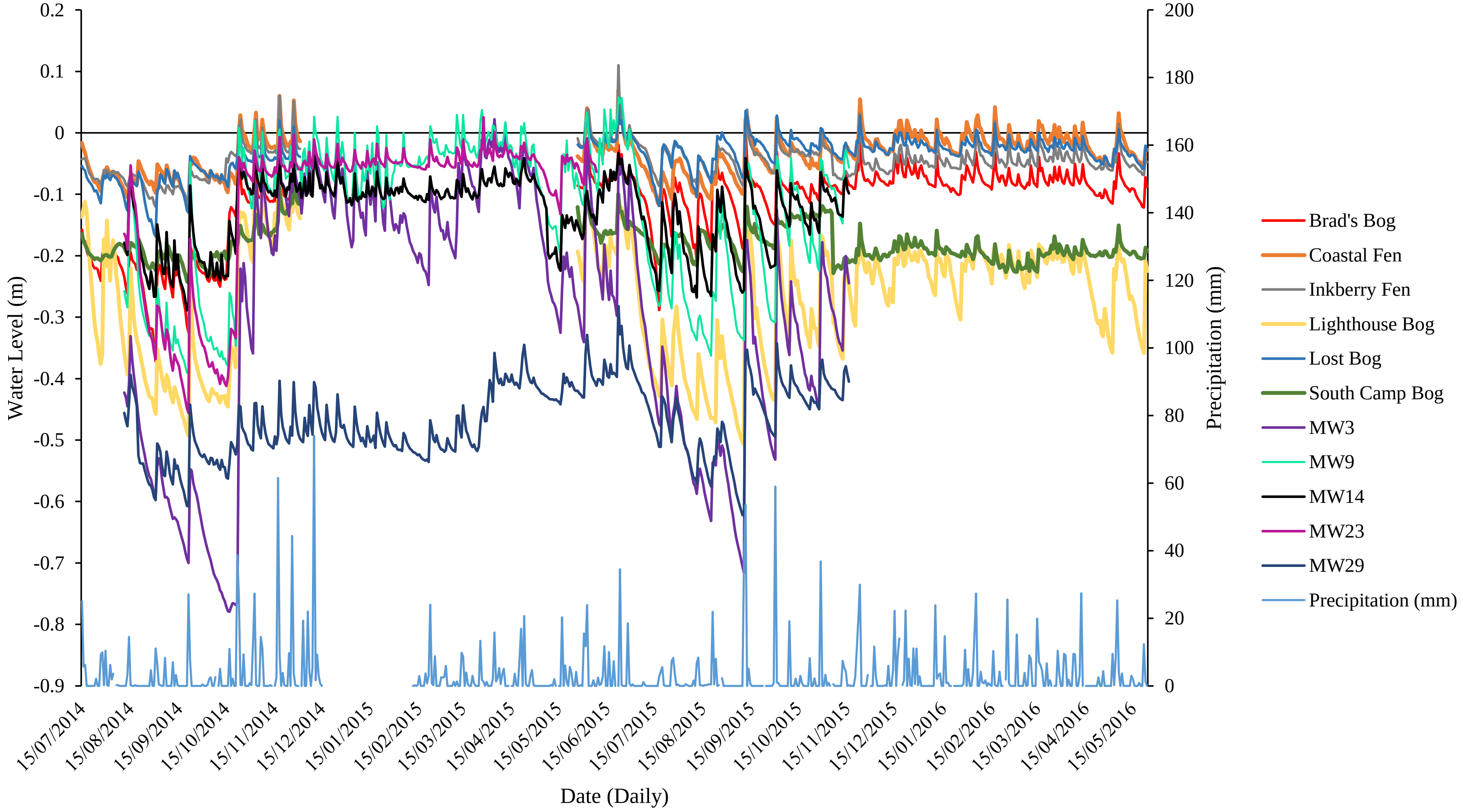

Figure 13. Hydrograph of all wells based on daily water level medians (m) with precipitation (mm; light blue lines) from July 15 2014 to May 24 2016. Includes data from December 1 2014 to May 27 2015 for the BMB wells and RB. Also includes data from July 15 to August 11 2014 and November 16 to May 24 2016 for the remaining reference wetlands. All monitoring wells were not simultaneously recording for these segments of time, thus were not included in statistical analysis. Water level is relative to ground surface (0 m).

6.3 RESPONSE TO LARGE RAINFALL EVENTS

Precipitation response can be characterized seasonally (Figure 7, Figure 9 and Figure 11). Based on the monthly fluctuations, the fall months had some of the largest water level changes in all wells (Table 3). Fluctuations during September and October can be more accurately analyzed at an hourly resolution in response to individual rainfall events.

The magnitude of water level rise in response to rainfall was significantly higher in the Disturbed Bogs compared to the Undisturbed Fens and Bogs (Table 5, $p \leq 0.05$). In addition, the percentage of water level recession within twelve hours of the peak water table height in the Disturbed Bogs was significantly lower than both Undisturbed Bogs and Fens ($p \leq 0.05$). Compared to the Disturbed Fen, water level recession was not significantly different ($p > 0.05$).

6.3.1 Water Level Rise in response to Rainfall

SB's water level rise was the lowest among all wells (Figure 12). Thus, with the exception of SB, the Undisturbed Bogs had a greater magnitude of water level rise than the Undisturbed Fens (Table 5). Additionally, the Disturbed Bogs and Fens had greater water level rise than either of their undisturbed counterparts. The magnitude of water level rise in Disturbed Fens was 14% greater than the Undisturbed Fens. The Disturbed Bogs had 37.7% greater water level rise than Undisturbed Bogs.

Among the Undisturbed Bogs, the water table increase in BB following rain events was 6.7% smaller than the Domed Bog. Water level rise in LiB and MW9 were upwards of 20% greater than the two Undisturbed Bogs. However, the greatest water level rise was in MW3, which was upwards of 50% greater than the Undisturbed Bogs (Figure 12).

6.3.2 Water Level Recession Post-Rainfall

The magnitude of water level recession between disturbance and wetland type was inversed to the water level rise. The Disturbed Fen and Bogs had the largest initial water level rise, however the quantity of water that receded from the water table was smaller than the Undisturbed counterparts (Table 5). Thus, the higher quantity of water gained from rainfall in Disturbed Bogs and the Disturbed Fen was retained for longer. The Disturbed Fen had 4.8% less water table recession than the Undisturbed Fens, and the Disturbed Bogs had 9% less than the Undisturbed Bogs.

Between the Undisturbed Fen and Undisturbed Bog group, water level recession was similar. However, among the Undisturbed Bogs, BB was different from SB and RB. BB's water level recession was more than 10% greater than Both SB and RB.

Table 5. Characteristics of each monitoring well's water table in response to three storm events in fall of 2015. MW23 was no longer recording. Water level rise is the percentage of water level increase between the initial water level to the peak water level relative to the storm size (%). Absolute water level rise in cm is in parentheses below the percent rise. The 12 hr recession is the percentage (%) of the water level rise that was lost within 12 hours of the water level peak. Raw data sample resolution is 1 hr. Mean water level rise that do not share a letter are significantly different ($p \leq 0.05$). Mean 12-hour Recession that do not share a letter are significantly different ($p \leq 0.05$).

	Undisturbed Fens			**Disturbed Fen**	**Undisturbed Bogs**			**Disturbed Bogs**		
	CF	IF	LoB	MW14	BB	SB	RB	LiB	MW3	MW9
Precipitation Event (mm)	**Water Level Rise (%)**									
Event 1 (83.75)	21.5 (18.1)	19.6 (16.4)	19.0 (15.9)	27.6 (23.08)	31.8 (26.6)	19.0 (15.9)	40.4 (33.8)	48.4 (40.5)	80.6 (67.5)	32.8 (27.5)
Event 2 (56.25)	18.7 (10.5)	14.4 (8.1)	17.2 (9.7)	33.2 (18.7)	30.4 (17.1)	10.5 (5.9)	32.4 (18.2)	53.2 (29.9)	85.3 (48.0)	57.1 (32.1)
Event 3 (38.25)	19.9 (7.6)	12.3 (4.7)	15.2 (5.8)	33.7 (12.9)	23.8 (9.1)	7.3 (2.8)	33.5 (12.8)	55.7 (21.3)	96.2 (36.8)	58.6 (22.4)
Mean Water Level Rise (%)	20.0^{DEF}	15.4^{EF}	17.1^{EF}	31.5^{CDE}	28.7^{DEF}	12.3^{F}	35.4^{BCD}	52.4^{B}	87.4^{A}	49.5^{BC}
Group Mean (%)	17.5^{A}			31.5^{A}	25.4^{A}			63.1^{B}		
Precipitation Event	**12-hour Recession (%)**									
Event 1	21.5 (3.9)	25.6 (4.2)	27.0 (4.3)	16.9 (3.9)	35.7 (9.5)	27.0 (4.3)	16.6 (5.6)	18.0 (7.29)	14.8 (10.0)	4.8 (1.3)
Event 2	22.9 (2.4)	18.5 (1.5)	15.5 (1.5)	17.1 (3.2)	31.6 (5.4)	10.2 (0.6)	18.7 (3.4)	11.7 (3.5)	15.6 (7.5)	15.2 (4.9)
Event 3	18.4 (1.4)	21.3 (1.0)	29.3 (1.7)	17.1 (2.2)	24.2 (2.2)	21.4 (0.6)	25.0 (3.2)	13.1 (2.8)	18.8 (6.9)	17.4 (3.9)
Mean 12-hr Recession (%)	20.9^{AB}	21.8^{AB}	23.9^{AB}	17.0^{AB}	30.5^{B}	19.5^{AB}	20.1^{AB}	14.3^{B}	16.4^{AB}	12.5^{B}
Group Mean (%)	22.2^{A}			17.0^{AB}	23.4^{A}			14.4^{B}		

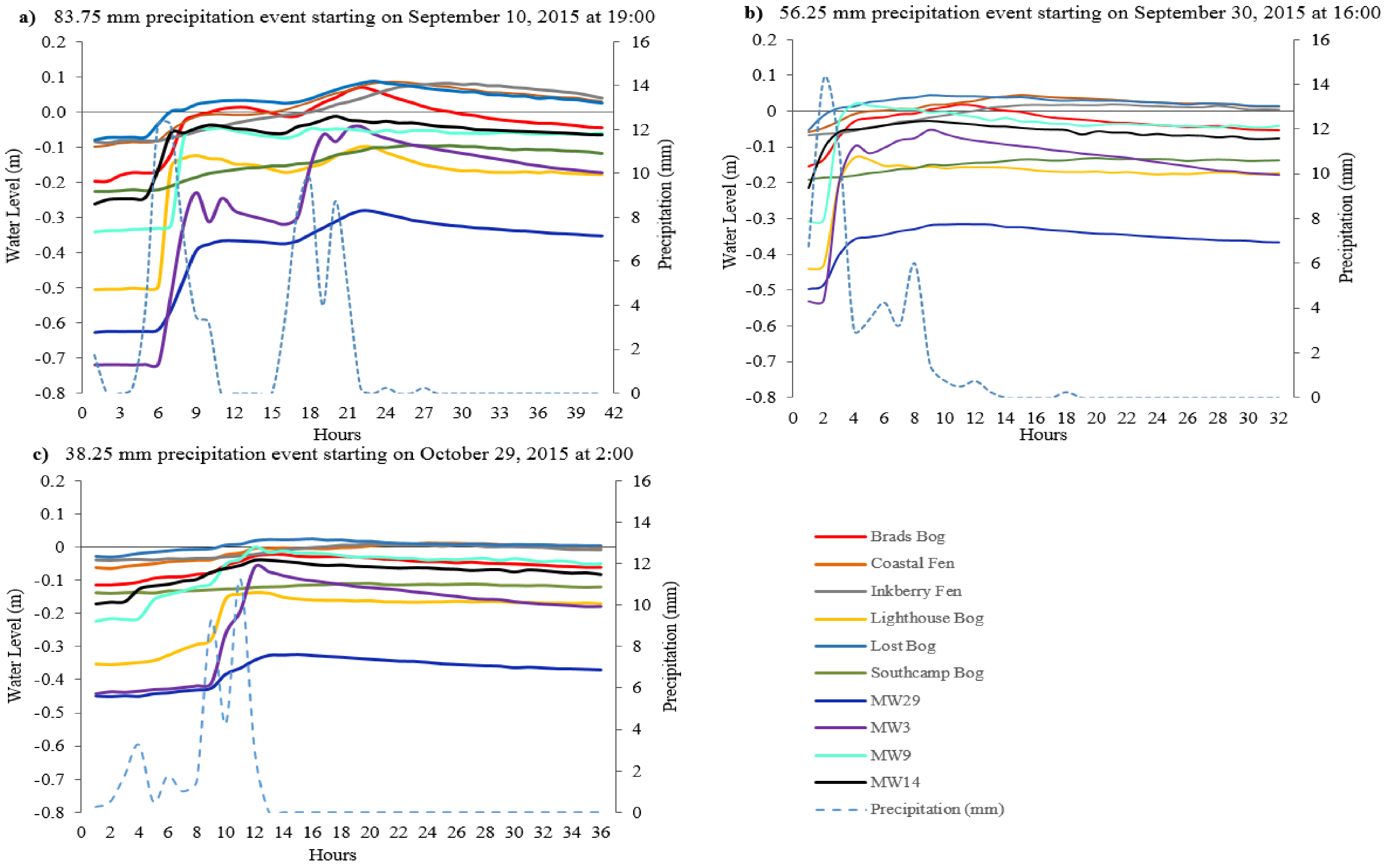

Figure 14. Water level (m) dynamics following three large (> 38 mm) rain events in 2015, including precipitation (mm; dotted light blue lines). Each plot spans from the first hour of rain until twelve hours past the last monitoring well has reached its peak water level.

7. DISCUSSION

A number of hydrological characteristics were examined throughout this study, including: (i) mean water table depth, which, when examined among wetland classes, help observe if there are conditions of relative hydrologic consistency; (ii) monthly water table fluctuations, which provide a measure of environmental stress; (iii) percentage of time the water table remained in different depth strata, which is useful to classify wetland types; and (iv) response to individual rainfall events, which provide a measure of water storage, retention and runoff (Richter *et al.* 1996; Schaffer *et al.* 2000; Holden *et al.* 2011). The following discussion deals with each of these characteristics, organized according to disturbance and wetland group. First as a description of typical hydrologic behavior in Basin Bogs, Domed Bogs and Horizontal Fens in NS. Second, as an assessment of the degree of hydrological impairment in the Disturbed peripheral lagg-fen in BMB and the Disturbed Bogs. And finally, to provide an estimate of the potential hydrological influence required for EMA to thrive. The discussion will draw on general site description measurements to further support interpretation of the water level data.

7.1 PROPOSED TYPICAL HYDROLOGIC CONDITIONS

7.1.1 Hydrodynamics of Undisturbed Fens

Undisturbed Fens were hypothesized to have greater seasonal stability than the remaining wetland types, which was supported by the hydrologic characteristics observed in CF and IF. Mean water table depth and hydrologic characteristics such as maximum, minimum and range of values were quite stable and consistent in both Horizontal Fens. Hydrology in CF and IF suggests that the mean water table in relatively unaltered Horizontal Fens should typically be within 5 cm of ground level.

Monthly fluctuations for the Undisturbed Fens were the smallest among all disturbance and wetland types, and were generally unchanged by seasons, further supporting the original hypothesis. This hydrologic stability in Undisturbed Fens is in part due to the inherent water holding capacity of the deep peat layer that is typical of certain fen forms (NWWG 1997), but is likely also due to the more consistent supply of water inputs that fens receive from groundwater and runoff from the adjacent terrain (Keddy 2000; NWWG 1997; Mitsch and Gosselink 2007; Tiner 1999).

Observations related to water table depth duration further supported the hydrologic stability hypothesis for Undisturbed Fens. The vast majority of recorded water levels occurred in the shallow root zone for both CF and IF which is likely sustained by groundwater inflows (Johansen *et al.* 2017). The minimum recorded water level, a metric which Cole and Brooks (2000) state refers to a single event that may be rare or in response to extreme climate events, such as a drought rather than the general hydrologic characteristic, was -12.3 cm. Johansen *et al.* (2017) study on groundwater dependant terrestrial ecosystems (fens) found that the ecological significance of higher water table and water level stability is a greater success of bryophytes species.

The fact that Horizontal Fens had the smallest water level rise and relatively rapid recession following large rainfall events, is most likely related to the small available storage capacity resulting from their typically high water table levels. Holden and Burt (2003) hydrological study on blanket peat define saturation-excess runoff as overland flow that occurs when the soil profile is completely saturated, which can occur even in instances of low rainfall intensity. When peat is saturated previous to rainfall, runoff will occur at a faster rate (Holden and Burt 2003).

The hydrodynamics observed in CF and IF, suggest that LoB was originally misclassified as a Basin Bog and should have been classified as a fen. Virtually all hydrodynamic characters (e.g., mean level, fluctuations, water table depth durations and storm responses) were consistently similar to those observed in CF and IF. In addition, LoB had considerably larger shrubs and greater shrub cover than either of these fens, which would lead to greater evaporative outputs, but the mean water table was higher than CF and IF. This, along with the other water level characteristics that were observed, provides further evidence that LoB should have been classified as a Horizontal Fen.

Although, the recorded groundwater pH is more acidic than the pH observed in CF and IF, neither had groundwater pH above 5.5, which is considered to be the standard for moderately rich fens (Zoltai and Vitt 1995). Nonetheless, poor fens, associated with a pH below 5.5, still have similar hydrology to rich Fens (Zoltai and Vitt 1995).

7.1.2 Hydrodynamics of Undisturbed Bogs

The Undisturbed Domed Bog and Basin Bogs were expected to have inherently different hydrodynamics. The geomorphology of Domed Bogs was expected to result in lower water levels in RB than the Basin Bogs, which was supported by the data collected for this study. However, unexpectedly, there were also significant differences in hydrologic stability observed between the Undisturbed Basin Bogs.

7.1.3 Basin Bogs

Mean water table and water table depth durations were generally similar between SB and BB and suggest that the majority of water levels in relatively unaltered Basin Bogs should be in the shallow root zone. However, in contrast to the Horizontal Fens, the water table in Basin Bogs should be expected to fall into the dry stratum (> 40 cm below ground) for 20-25% of the fall and growing season. Price *et al.* (2003) study of hydrologic processed to abandoned and restored peatlands, state that development of peat properties and landscape position of bogs lead to the ecosystems deriving water inputs solely from direct precipitation. Thus, the lower water table is likely attributed to water inputs being limited to precipitation.

Unlike the Horizontal Fens, a hydrological baseline was more difficult to characterize for Basin Bogs due to the differences in hydrologic stability. Fluctuations in BB suggest that a Basin Bog will typically have twice the amplitude of fluctuation of fens. Since true bogs are deprived of a regular inflow of groundwater or adjacent runoff (Price *et al.* 2003), their dependence on precipitation may result in larger fluctuations than more minerotrophic systems.

However, fluctuations in SB were the smallest of all the sites (bogs or fens) that were classified as Undisturbed. Although the mean water table depth and durations were similar between Basin Bogs, the minimal amplitude of fluctuation in SB is more suggestive of the hydrologic characteristic identified for Horizontal Fens. In addition, SB had a groundwater pH value similar to CF and more basic than both LoB and IF suggesting some surface or groundwater inputs and that SB is not a “true” bog, fed by precipitation only. Given the right local conditions, peatlands may have a successional trajectory from fen to bog over time (Tiner 1999; Howie and Tromp-van Meerveld 2011), so SB may be in transition between wetland classes.

7.1.4 Domed Bog

Given the undisturbed character of the surrounding landscape, hydrodynamic assessment of RB suggests that a relatively unaltered Domed Bog, in this part of the province, typically has a water level range 50 cm below the surface in the centre of the bog for most of the fall and growing season. Since the water table has a tendency to drain outwards from this type of bog (Bragg 2002), water levels on the periphery of the dome structure would be closer to ground level. Howie and van Meerveld (2013) study on bog and lagg characteristics in British Columbia observed significantly higher water tables laggs which were in well defined on the perimeter of a domed bog.

The amplitude of monthly fluctuations and the range of hydrologic values suggest that Domed Bogs have smaller fluctuations than those in Basin Bogs. More wells instrumented with data loggers would be needed to fully confirm these conclusions.

The hydrologic behaviour in response to rainfall in RB suggests that a Domed Bog does not have significantly greater water level rise than Basin Bogs. The greater hydrological isolated nature of Basin and Domed Bogs increases storage holding time relative to fens (Tiner 1999) slowing recession rates following rain events. However, water level recessions in the Domed Bog were smaller than the Basin Bog, suggesting a Domed Bog will have greater water retention than Basin Bogs. Bragg's (2002) study of hydrology in peatlands explains that the lasting saturation in a dome structure is attributed to an equilibrium between precipitation inputs and impeded, but consistent, lateral drainage.

7.2 DEGREE OF HYDROLOGICAL IMPAIRMENT

The overall effect of the drainage ditch on hydrological behaviour was similar in all of the wells in BMB. However, the degree to which each water table characteristic was either amplified or lowered was dependent on the landscape position, either in the raised bog portion of BMB or the peripheral lagg-fen, and the proximity of the central drainage ditch to the well. In Boelter's (1972) study of water table drawdown around an open ditch, they observed little effect beyond 5 m of the drainage ditch with highly decomposed peat and in instances where peat was less decomposed, the water table could be affected upwards of 50 m from the ditch. Rothwell *et al.* (1996) report that the distance affected by the ditch is dependant on peat properties and the depth of the ditch, with the age of the ditch positively correlated to more highly decomposed peat.

Kennedy *et al.* (2015) have previously identified different influences that are affecting the different Transects on which the monitoring wells are placed. Each transect exhibited different degrees of deviation from the typical hydrologic characteristics for both bog and fen.

7.2.1 Hydrodynamics of the Disturbed Fens

Relative to MW3 and LiB, water table characteristics in both MW14 and MW23 were not as low or amplified. However, in comparison to the relatively unaltered Horizontal Fens, the hydrodynamic difference resulting from drainage was obvious and significant.

Both MW14 and MW23 are outside the 50 m radius which Kennedy *et al.* (2015) suggest experiences the greatest impact from the central drainage ditch. However, it is believed that previous to the ditch excavation, when BMB complex was originally a Domed Bog (Hill *et al.* 2016), surface sheet flows and baseflows would radiate outwards towards the peripheral lagg-fen. Thus, an important source of water from the historically Domed Bog has diminished and has been redirected into the central drainage ditch (Kennedy *et al.* 2015).

The apparent diminished supply of baseflow groundwater from the previously domed structure of the central bog has likely lead to the lower mean water table depth compared to the reference fens. Mean water table depth and amplitudes of fluctuations in MW14 resembled those in the Basin Bog, BB, rather than the Horizontal Fens. The mean water table depth was threefold the depth of the water table typical of Horizontal Fens and the amplitude of monthly fluctuations was nearly twice those characteristic of fens. MW14 water table was mostly saturated, but unlike the Undisturbed Fens, over a quarter of its water table was in the dry stratum (> 40 cm below ground), similar to the Basin Bogs. According to Bradford (2016) synthesis of wetland alteration in southern Ontario, water level changes on the order of 10 to 30 cm can result in changes to the vegetation community. The average shrub height and cover was greater in MW14 than both Undisturbed Fens.

The changes to the hydrologic characteristic such as fluctuations and water table depth compared to the reference Horizontal Fens suggest that MW14 has become increasingly dependent on precipitation for water inputs, as does the more acidic pH. The response to individual rainfall events further supports this suggestion. Since the mean water table was approximately 10 cm lower than the fens, MW14 had larger initial water storage capacity. The water level rise in response to rainfall was similar to those observed in the Undisturbed Bogs, BB and RB.

However, MW14 typically also had greater water retention than both the Undisturbed Bogs and Fens. The greater water retention in MW14 may be attributed to the peripheral lagg-fen having retained, what Howie and Tromp-van Meervel (2011) describe as an essential role, of allowing excess water to leave the bog during times of higher precipitation. When addressing misconceptions related to the role of groundwater, Bradford (2016) states that although the groundwater inflow can become a small percentage of the annual proportion of inflow, it may remain important to sustain the rates of evapotranspiration during the growing season. Thus, even though MW14's water table may currently be primarily driven by precipitation, it does not mean it is no longer dependent on groundwater.

MW23 was hypothesized to have the least variable hydrodynamics in the BMB complex because of its position near a lightly disturbed portion of the lagg. However, the hydrologic characteristics are more irregular than those in MW14, even though it is approximately twice as far from the central drainage ditch. This suggests ditching affects along the northwestern portion of BMB may have had greater influence than was previously thought (Hill et. al. 2016). In addition, Kennedy et al (2105) suggest that surface water from upslope pathways on the northwestern end of BMB that was diverted by the runway ditch to Transect 2, was originally an important source of water to MW23. Therefore, this portion of the lagg-fen has been deprived of important sources of water from both the adjacent northwestern upland and the eastern groundwater baseflows from the central bog. As was observed at MW14, the hydrodynamics suggest MW23 is increasingly dependent on precipitation.

MW23's water table depth duration and mean water table depth were lower than MW14. MW23's mean water table depth was below the shallow root zone, which, in comparison to the water table depth duration in Horizontal Fens, is quite low. The amplitude of the mean monthly fluctuation was nearly 10 cm greater than the other disturbed lagg-fen. Additionally, the water table depth durations were skewed toward dryer depth strata and lower than both MW14 and the Basin Bogs.

In Johansen *et al.* (2017) study on the relationship between vegetation and groundwater dependant terrestrial ecosystem (fens) in Denmark, they observed that the diversity in plant species sharply decreased when seasonal water fluctuations exceeded 25 cm. This supports the idea that water level fluctuations may be driving the shift in vegetation from typical peatland species to a simplified community dominated by old-field species now observed throughout much of BMB (Hill et al. 2016).

Howie and Tromp-van Meerveld (2011), state that to successfully restore hydrology in a raised bog, the lagg must sustain the water levels in the bog by maintaining high water levels itself and allow for excess water to leave the bog in the form of runoff. The atypical hydrological characterization of MW14 and MW23 suggests that neither site is able to sustain the high water levels required for a healthy raised bog. In addition, since the runoff from the central bog in BMB complex is mostly redirected into the central drainage ditch or other peripheral ditches, the high water needed in the lagg-fen to maintain levels in the adjacent bog is no longer available. To support restoration targets on the central bog of BMB, the lagg must be restored to perform either function.

7.2.2 Hydrodynamics of the Disturbed Bogs

MW3 and MW9 were expected to have the greatest hydrological variability, but the variability in MW3 was more significant than MW9. This well is closest to the central drainage ditch and deprived of the northwestern upslope surface water redirected by the runway ditch (Kennedy *et al.* 2015). MW3 was significantly more variable and generally had water levels that were lower than the remaining wells.

Both the range in the hydrologic characteristics and the amplitude of monthly fluctuations in MW3 are unusual hydrodynamics compared to the Basin Bogs and the Domed Bog. The mean water table depth in MW3 was generally over twice as low as the depth in the Basin Bogs and the well had nearly twice the amplitude of fluctuation. In the Strack *et al.* (2008) study on the effect of water table drawdown to a peatlands dissolved organic carbon content, they observed a directly proportional relationship between increased magnitude of water level fluctuations and the increase in age to a drainage ditch. Considering the central drainage ditch in BMB was excavated over 50 years ago (Hill *et al.* 2016), the maturity of the ditch is likely contributing to the high amplitude of fluctuations in MW3.

In MW3, water table depth was below 40 cm for over half of the observation period. In contrast, water levels were concentrated in the shallow root zone about 75% of the time in relatively unaltered Basin Bogs. Landry and Rochefort (2012) assessment of peatland’s response to drainage and rewetting, state that since drainage ditches inherently lowers the water table, the peat profile will not be saturated for most of the time. However, contrary to MW3, the water table depth in MW9 had a greater distribution of values in the shallow root zone.

MW9 was expected to have mean water table depth, amplitude of monthly fluctuations, and water table depth duration comparable to those in MW3, however the hydrologic characteristics were instead similar to those observed in MW23. Although the patterns in water level dynamics observed at MW9 were different than originally anticipated, they still appeared to be atypical from what would be expected in a relatively unaltered Domed or Basin Bog. However, as Kennedy *et al*. (2015) have suggested in their baseline hydrological assessment of BMB, MW9 is receiving water diverted by ditches in the sloping swamp along the runway of BMB. The water input from the ditch seems to be compensating for water lost to drainage from the central ditch. Thus, the well has higher water table and smaller amplitude of fluctuation than those observed in MW3

It seems likely that dryer conditions are leading to increased shrub cover at both MW3 and MW9 (Hill et al. 2016), which in turn may be further lowering water levels. A low water table favors higher shrub colonization and growth, resulting in a higher rate of evapotranspiration (Morgan-Jones *et al.* 2005) and leading to further lowering of the water table. In Van Seters and Price's (2002) conceptual model of hydrologic change to a disturbed bog in Quebec, they observed increased water loss due to evapotranspiration and greater summer water deficit when there was higher abundance of vascular plants. Anderson *et al.* (2000) study on the impacts of afforestation to bog hydrology also observed significantly lower mean water table depths when taller vegetation had been established on drained peat. The shrub cover in MW3 and MW9 is most likely also contributing to the greater amount of drawdown observed in the growing season and to the old-field species vegetation community on BMB.

Since the central part of BMB had a more classically domed geomorphology, the lower mean water levels observed in MW3 and MW9 might have been considered normal given their central location in the bog. However, due to the subsidence of the peat structure that has resulted from several decades of draining (Hill *et al.* 2016), initial targets for restoring hydrology in BMB should probably be based on the higher water levels that were observed in the Basin Bogs, BB and SB rather than in RB which still has a healthy domed character. This means that rewetting in BMB should be designed to increase the water table in the shallow root zone by about 50% in the area around MW3 and 20% in the area around MW9 to achieve levels observed in the relatively unaltered reference Basin Bogs. While acknowledging that natural succession following restoration can take decades or longer, healthy peat will eventually accumulate in the central bog and a more pronounced domed structure will likely return as well (Howie and Tomp-van Meervel 2011).

Outside of the BMB complex, LiB was expected to have similar hydrodynamics to those in the central bog of the BMB complex. The hydrodynamics in LiB have deviated away from the typical Basin Bog hydrology, almost certainly due to the effects of the road side drainage ditch. Although LiB was expected to have similar hydrodynamics to sites in the central part of the BMB complex, the hydrologic alteration at LiB was actually greater than in all of the BMB wells, except MW3. LiB’s mean water table was nearly twice the depth associated with the relatively unaltered Basin Bogs. The distribution of water levels was more frequently dry than MW9, but slightly less than MW3. The vegetation at LiB is similar in that low shrub cover is extremely dense, but unlike in MW3, taller shrubs have not yet colonized to any substantive degree. A greater number of wells instrumented with data loggers at various distances from the roadside ditch would help further quantify the degree of hydrological disturbance in this Basin Bog.

All of the Disturbed wetland types had greater water level rise following rain events than Undisturbed sites, which may be related to storage capacity differences. Studies by Holden *et al.* (2011) and Van Seters and Price (2002) suggest that the lowered water table in drained peatlands results in greater storage capacity previous to a rainfall event due to the lowered water table. MW3 water table rose by nearly 90% in response to rainfall events. This was only possible because water levels were significantly lower than what they would have been under pre-disturbance conditions. The much smaller rise observed in the Domed Bog, even though the baseline water table was similar to that observed in MW3, is likely due to water holding capacity differences in healthy and degraded peat. In Ketcheson and Price's (2011) study on the impacts of restoration to the hydrology of peatlands, state that when the water table is lowered it is typically found in the catotelmic peat, which has a largely reduced ability to regulate water storage and surface water runoff.

However, in contrast to Holden *et al.* (2011) observations that the rate of water table decline is greater in drained peatlands, the smallest 12-hour recession was observed in Disturbed Bogs in this study. Slower recession in disturbed sites was also reported by Conway and Millar (1960), who observed that increasing disturbance in bogs led to a decline in runoff response time. It seems likely that the central ditch is no longer effectively draining the central bog (Kennedy *et al.* 2015) at least on the 12-hour time scale associated with the rain events we examined. It is not completely clear why the Undisturbed Bogs have a more rapid rate of runoff than the Disturbed sites but it may be related to the differences in initial storage potential that was noted.

7.3 PROPOSED HYDROLOGIC CONDITIONS FOR EMA

Water level dynamics at MW14, MW23, BB and SB, where EMA populations were all relatively high, suggest that the EMA is best supported by water levels that are in the shallow root zone for much of the growing season (~75-80%) and only below the root zone for short periods (~20-25%). CF was the only one of the study sites that had an EMA population with water levels in the shallow root zone for more than 90% of the fall and growing season and an average water table within 5 cm of ground level. However, this population is smaller (156) than all of the other sites where EMA was found, with the exception of LiB, where water levels were extremely low and only 1 individual EMA plant was observed.

In You *et al.* (2015) study on the effect of inter-annual water level fluctuations to vegetation, they stated that frequency and amplitude of water level fluctuations are major driving forces affecting the distribution of wetland vegetation. It seems likely that these factors have played a role in influencing EMA abundance. The hydrodynamics at BB, which has the largest EMA metapopulation (1336) on Brier Island, suggests that the plant also requires regular fluctuation into the dry root zone (20 – 40 cm) as long as the duration is relatively short. However, this sort of fluctuation is apparently not a prerequisite for EMA success since there is a large population at SB, which has the least amount of water level fluctuation among all study sites. The data from SB suggests that EMA can be sustained in the absence of regular water level fluctuations if the water table is in the 20 to 40 cm depth range for at least 20% of the fall and growing season.

It seems important to note that the EMA population located near MW23 has experienced a 70% decline since 2012 (Hill *et al.* 2016) and it seems likely that this is at least in part due to the greater amplitude of water level fluctuations EMA plants have been experiencing in this part of BMB for many years. Water levels at MW23 were below the shallow root zone for greater than 40% of this study. Based on observations at our other study sites, these low water levels at MW23 suggest it may not be sustainable for the EMA populations, and instead may favor increasing encroachment by shrubs, and further reduce the suitability of BMB for EMA.

Therefore, successfully restoring higher water levels and smaller fluctuations to the periphery lagg-fen on BMB may not only sustain the water levels in the central bog, but could also lead to an increase in one of the larger EMA metapopulations. Although MW14 metapopulation is much smaller (100), restoring the lagg-fen may establish this perimeter of the lagg-fen as an important habitat for EMA.

8. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORK

Wetland functions are controlled by a number of environmental factors both within the wetland boundary and within the broader landscape (Bradford 2016). Although the hydrologic regime plays a principal role in wetland functions (Hunt *et al.* 1999) other controls include underlying geology, soil composition, wetland size, watershed size and adjacent water storage features, which were beyond the scope of this study. However, future work should focus on the other variables that may be influencing the water level dynamics in all of the wetland disturbance groups. Careful topographical and watershed analysis would help improve the understanding of water table dynamics.

Greater emphasis and consideration could be placed on correlating the pH and vegetation cover and height to the observed hydrodynamics. At present the pH and vegetation are based on a single site assessment. However, pH and vegetation play an important role in determining the class and form of a wetland (Mitsch and Gosselink 2007; NWWG 1997; Tiner 1999; Zoltai and Vitt 1995), thus, should be based on several measurements to increase confidence in results. The pH and vegetation observed could than be correlated with the individual bogs and fens to observe trends or similarities and further describe typical fen and bog characteristics in Nova Scotia. Moreover, pH and dominant vegetation composition are more than likely contributing to the population size and survival of EMA. Metapopulations are found in Basin Bogs and a Horizontal Fen which have different hydrodynamics, thus, there are more variable contributing to their ability to thrive in either habitat that were outside the scope of this study.

Since the response to rainfall events returned inconclusive results in respect to water table recession, a greater hourly rainfall dataset would be helpful. If a greater number of individual rainfall events were available, greater confidence could be attributed to the smaller recession rate in the Disturbed Bogs and Fens. Greater number of rainfall events may also disprove the current observed recession in this study. The current data is solely based on three individual rainfall events, and the likelihood of drained peatlands having a larger ability to store and retain water inputs seems unlikely.

A hydrodynamic comparison of monitoring wells in BMB along the same transect from the central bog to the peripheral lagg-fen would help improve the understanding of the distance of disturbance from the central drainage ditch. As previously mentioned, each transect has different degrees of drainage disturbance. Thus, hydrodynamics observed from various distances from the drainage ditch would help quantify the extent of disturbance based on the drainage influence observed along each transect.

Finally, since draining a peatland alters the peat soil properties that help regulate the water table and vegetation, the assessment of alteration to BMB should include a comparison of peat properties such as hydraulic conductivity, from the relatively unaltered peatlands to those on the central bog and lagg-fen of BMB. A comparison of soil properties would help determine restoration projections. If the degree of alteration to peat properties in BMB are small in comparison to the relatively unaltered peatlands, the wetland complex could have a faster rate of response to a rewetting restoration approach.

9. LITERATURE CITED

Aber, J.S., Firooza, P., and S. Ward. (2012). *Wetland environments: a global perspective.* Wiley, Hoboken, NJ. USA.

Anderson, A.R., D. Ray and D.G. Pyatt. (2000). *Physical and hydrological impacts of blanket bog afforestation at Bad a'Cheo, Caithness: the first 5 years.* Forestry vol. 73:5, pp.467-478

Boelter, D. H. (1972). *Water table drawdown around an open ditch in organic soils.* Journal of Hydrology (Amsterdam), vol. 15, pp. 329-340

Bradford, A. (2016). *Averting degradation of southern Ontario wetlands due to hydrologic alterations associated with development.* Canadian Water Resources Journal vol. 41:4, pp. 543-553

Bragg, O.M. (2002). *Hydrology of peat-forming wetlands in Scotland*. The Science of the Total Environment vol. 294, pp. 111-129

Brazner, J., Kennedy, G. and Drage, J. (2013). *Establishing baseline hydrologic conditions.* Pilot project proposal. NSDNR Internal Report.

Brazner, J., Kennedy, G. and Drage, J. (2015). *Understanding hydrology and water quality to increase restoration effectiveness – Phase I: Determining methodological best practices.* National Wetland Conservation Fund Final report. NCP-06-EC

Brown, R. (1988). *The influence of oceanic anomalies on the distribution of storm-petrels (Hydrobatidae) in NS.* Colonial Waterbirds vol.11, pp. 1-8

Butzer, K. (2002). *French wetland agriculture in Atlantic Canada and its European roots: Different avenues to historical diffusion.* Annals of the Association of American Geographers vol92:3, pp. 451-470

Charman, D. (2002). *Peatlands and environmental change.* Wiley, Wester Sussex, England.

Cole, C. A. and R. Brooks. (2000). *Patterns of wetland hydrology in the Ridge and Valley province, Pennsylvania, USA*. Wetlands vol. 20:3, pp. 438-447

Conway V, Millar A. *The hydrology of some small peat covered catchments in the northern Pennines*. J I Water Eng1960 vol. 14, pp. 415-424

Damman, A. and J. Dowhan. (1981). *Vegetation and habitat conditions in Western Head Bog, a southern Nova Scotian plateau bog.* Canadian Journal of Botany vol. 59:7, pp. 1343-1359

East Coast Aquatics. (2016). *Wetland hydrology reference study outstanding methodology questions.* Hydrology research plan outline.

Environment Canada. (2008). *Recovery strategy for the Eastern Mountain Avens (Geum peckii) in Canada.* Species at Risk Act. Recovery Strategy Series.

Elliott-Fisk, D. L. (1988). *The Boreal forest. In M.G. Barbour & W.D. Billings (Eds.).* North American Terrestrial Vegetation. Cambridge, England: Cambridge University Press pp. 33-62

Gilman, K. (1994). *Hydrology and wetland conservation.* Wiley, Chichester, NY, USA.

Gorham, E. and L. Rochefort. (2003). *Peatland restoration: A brief assessment with special reference to Sphagnum bogs.* Wetland Ecology and Management vol. 11:1, pp. 109-119

Grayson, R., Holden, J. and R. Rose. (2010). *Long-term change in storm hydrographs in response to peatland vegetation change*. Journal of Hydrology vol. 389, pp. 336-343

Hill, N. (2016). *Report on benchmark conditions for Big Meadow Bog, Brier Island.* NWCF Grant proposal.

Hill, N., Kennedy, G., Smith, C. *et al.* (2016). *A restoration plan for Big Meadow Bog: Background, baseline studies and overall goals.* Application to Nova Scotia Environment Part I.

Hill, N., Kennedy, G., Smith, C. *et al.* (2016). *A restoration plan for Big Meadow Bog: Hydrologic modification, monitoring and performance measures.* Application to Nova Scotia Environment Part II.

Holden, J. and T.P. Burt. (2003). *Hydrological studies on blanket peat: the significance of the acrotelm-catotelm model.* Journal of Ecology vol. 91, pp. 86-102

Holden, J., M.G. Evans, T.P. Burt and M. Horton. (2006). *Impact of land drainage on peatland hydrology.* Journal of Environmental Quality vol. 35, pp.1764-1778

Holden, J., Z.E. Wallage, S.N. Lane and A.T. Mcdonald. (2011). *Water table dynamics in undisturbed, drained and restored blanket peat.* Journal of Hydrology vol. 402:1, pp. 103-114

Howie, S. and I. Tromp-van Meerveld. (2011). *The essential role of the Lagg in Raised Bog function and restoration: A review.* Wetlands vol. 31:3, pp. 613-622

Howie, S. and H.J. van Meerveld. (2013). *Regional and local patterns in depth to water table, hydrochemistry, and peat properties of bogs and their lags in coastal British Columbia.* Hydrology and Earth System Sciences vol.10:3, pp. 3143-3185

Hunt, R.J., J.F. Walker and D. P. Krabbenhoft. (1999). *Characterizing hydrology and the importance of ground-water discharge in natural and constructed wetlands.* Wetlands vol. 19:2, pp.458-472

International Joint Commision. (2012). *Wetlands need variable levels.* Retrieved from: http://www.ijc.org/loslr/en/background/w_wetlans.php

Johansen, O. M., D. K. Andersen, R. Ejrnaes and M.L. Pedersen. (2017). *Relations between vegetation and water level in groundwater dependent terrestrial ecosystems (GWDTEs).* Limnologica, http://dx.doi.org/10.1016/j.limno.2017.01.010

Keddy, P. (2000). *Wetland ecology: Principles and conservation.* Cambridge studies in ecology, Cambridge, UK.

Kennedy, G., Drage, J. and Nixon, C. (2015). *2014 Update on baseline hydrological monitoring at Big Meadow Bog, Brier Island, Nova Scotia.* Open file report, Nova Scotia Natural Resources. Geoscience and mines branch. Open File Report ME 2015-005.

Kessel-Taylor, I. (1984). *The application of the Canada land data system for quantitative analysis of land use dynamics on wetlands for twenty-three urban centered regions in Canada*. Environmental Canada lands Directorate Application Report R003200.

Ketcheson, S. and J. Price. (2011). *The impact of peatland restoration on the site hydrology of an abandoned block-cut bog*. Wetlands vol. 31, pp. 1263-1274

Landry, J. and L. Rochefort. (2012). *The drainage of peatlands: impacts and rewetting techniques.* Peatland Ecology Research Group. Department of phytology, Université Laval. 62 p.

Langlois, M. N., J. Price and L. Rochefort. (2015). *Landscape analysis of nutrient-enriched margins (lag) in ombrotrophic peatlands.* Science of the Total Environment vol. 505 pp. 573-586

Mackinnon, K. and D.B. Scott. (1984). *An evaluation of salt marshes in Atlantic Canada.* Technical Report No.1 for Environment Canada Lands and Integrated Programs Directorate – Atlantic Region.

McCartney, M. and M. Acreman. (2009). *Wetlands and water resources.* The wetland handbook, 1st edition, Blackwell publishing.

Middleton, B. (1999). *Wetland restoration, flood pulsing, and disturbance dynamics.* Wiley, NY, USA.

Mills, E. and L. Laviolette. (2011). *The birds of Brier Island, Nova Scotia.* Nova Scotia Institute of Science vol. 46, 111 p.

Minitab, Inc. (1998). *Minitab stastical software, version 17*. State College, PA USA.

Mitsch, W. and J. Gosselink. (2007). *Wetlands.* Wiley, Hoboken, N.J., USA.

Morgan-Jones W, Poole JS, Goodall R (2005) *Characterization of hydrological protection zones at the margins of designated lowland raised peat bog sites*. Joint Nature Conservation Committee, Peterborough. JNCC Report no. 365

National Research Council. (1995). *Wetlands. Characteristics and Boundaries.* National Academy Press, Washington, D.C. USA.

National Wetland Working Group. (1997). *The Canadian wetland classification system.* Wetlands Research Centre, University of Waterloo, Waterloo, ON, CA.

Nova Scotia Department of Natural Resources (NSDNR). (2011). *Nova Scotia Wetland Conservation Policy.* Nova Scotia Department of Natural Resources. Retrieved from: https://novascotia.ca/nse/wetland/docs/Nova.Scotia.Wetland.Conservation.Policy.pdf

Onset Corporation (1995). *HOBOware Pro, graphing and analysis software.* Bourne, MA, USA

Price, J. (1997). *Soil moisture, water tension, and water table relationships in a managed cutover bog*. Journal of Hydrology vol. 202 pp. 21-32

Price, J.S., A. L. Heatwaite and A.J. Baird. (2003). *Hydrological processes in abandoned and restored peatlands: An overview of management approaches.* Wetlands Ecology and Management vol.11, pp.65-83

Quinty, F. and L. Rochefort. (2003). *Peatland restoration guide, second edition.* Canadian Sphagnum Peat Moss Association and New Brunswick Department of Natural Resources and Energy. Quebec, Quebec.

Reid, M. (2012). *Better planning from better understanding: Incorporating historically derived data into modern coastal management planning on the Halifax Peninsula.* Graduate Project Report.

Richter, B., J. V. Baumgartner, J. Powell and D. P. Braun. (1996). *A method for assessing hydrologic alteration within ecosystems.* Conservation Biology vol. 10:4, pp.1163-1174

Rothwell, R. L., U. Silins and G.R. Hillman. (1996). *The effects of drainage on substrate water content at several forested Alberta peatlands.* Canadian Journal of Forest Research vol. 26:1, pp. 53-62

Shaffer, P, A. Cole, M.E. Kentula and R. Brooks. (2000). *Effects of measurement frequency on water-level summary statistics.* Wetlands vol. 20:1, pp. 148-161

Slack, N., D. Vitt and D. Horton. (1980). *Vegetation gradients of minerotrophically rich fens in western Alberta.* National Research Council of Canada vol. 58, pp. 330-350

Strack, M., J. M. Waddington, R. A. Bourbonniere, E. L. Buckton, K. Shaw, P. Whittington and J. S. Price. (2008). *Effect of water table drawdown on peatland dissolved organic carbon export and dynamics*. Hydrological Processes vol. 22, pp. 3373-3385

Species at Risk Act. (2016). *Action plan for the Eastern Mountain Avens (Geum peckii) in Canada.* Action Plan Series.

Sperduto, D and Nichols, W. (2004). *Natural communities of New Hampshire.* New Hampshire Natural Heritage Bureau and The Nature Conservancy.

Tiner, R. W. (1999). *Wetland indicators: a guide to wetland identification, delieneation, classification and mapping.* Lewis Publishers, Boca Raton, FL, USA.

Toms, R. and D. LaRue. (2015). *Counts of Geum peckii on Brier Island within permanent monitoring plots, 2014.* Morsey Tobeatic Research Institute, Kempt, NS.

Van Seters, T. and J. Price. (2002). *Towards a conceptual model of hydrological change on an abandoned cutover bog, Quebec.* Hydrological Processes vol. 16:10, pp. 1965-1981

Waddington, J., Quinton, W., Price, J., *et al.* (2009). *Advances in Canadian peatland hydrology, 2003-2007.* Canadian Water Resources Journal vol. 34:2, pp. 139-148

Wilson, S.J. (2000). *The GPI Water Quality Accounts: Nova Scotia's water resource values and the damage costs of declining resources and water quality*. Halifax: GPI Atlantic

Wilson, L., Wilson, J., Holden, J., *et al.* (2010). *Recovery of water tables in Welsh blanket bog after drain blocking: Discharge rates, time scales and the influence of local conditions*. Journal of Hydrology vol. 391, pp. 377-386

Whitefield, P., R. Hebda, J. Jeglum and S. Howie. (2006). *Restoring the natural hydrology of Burns Bog, Delta, British Columbia – the key to the bog's ecological recovery.* In A. Chantler (Ed.), Proceedings of the CWRA Conference, Vancouver pp. 58-70

Zoltai, S. and D. Vitt. (1995). *Canadian wetlands: Environmental gradients and classification.* Vegetatio vol. 118:1, pp. 131-137