Big Meadow Bog Hydrology Restoration: As Built Report

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FINAL

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Executive Summary

On June 17, 2015, the Fern Hill Institute for Plant Conservation, acting on behalf of the Eastern Mountain Avens Recovery Team, issued a Request for Proposals (RFP) for the a "Design to allow an adaptive hydrological restoration of Big Meadow Bog, Brier Island, Nova Scotia". The review committee selected the East Coast Aquatics' Inc. (ECA) submission to the RFP process. The shared vision of the project partners is that "*.... **the Big Meadow Bog wetland ecosystem is restored, leading to the recovery of sustainable populations of Geum peckii and associated historic and rare plant communities...."*** (Hill *et al.* 2015).

The design document (ECA 2015) was completed late in 2015. ECA recommended that six prescriptions be utilized for the full restoration of hydrology at Big Meadow Bog. The two primary activities (ditchblocks, ditch re-profiling), along with one optional activity (removal of woody vegetation) were completed. The optional activities were not expected to affect whether recovery occurs but were likely to contribute to the rate of hydrologic recovery. Additionally, a pond and naturalized control structure at the northern extent of the bog was also restored.

With securement of a Nova Scotia Wetland Alteration approval (no: 2016-095960) to complete the project, the initial ground works in the southwest portion of the bog on lands owned by the Nature Conservancy of Canada during the spring of 2016. Following the securement of additional land access, the remaining restoration works took place during the spring of 2017 through the remaining southern half of the bog, and early fall of 2017 for the entire northern half of the bog. In total 123 ditchblocks were constructed to restore the natural hydrological regime of Big Meadow Bog, and to initiate reactivation of the former channels within the bog. This was completed along with 3700 m of ditch re-profiling, that returned some of the micro-topography across the site to its historic conditions, eliminating elevated spoils piles and deep ditch segments that had been constructed in 1958-59. In the north, a pre-1920's man made feature referred to as both the "ice pond" and Jimmy's Pond was excavated to depths that approximated the pre-ditching habitat, and a naturalized outlet was constructed to restore the historic upslope hydrologic influence of the pond on the northern extent of Big Meadow Bog. More than 1400m^2 of pond habitat was re-stablished at the Jimmy's Pond site, and an additional 5000+m^2 of natural "Lily" ponds within Big Meadow Bog were set on a path to re-establishment with the restoration of site hydrology. Finally, trees and large shrubs were cut from some 34 ha of the bog surface. These plants had encroached on the bog since the 1959 ditching, encouraged by the drying surface and nutrient enrichment by colonizing herring gulls on the altered site. Their removal is intended to reduce evapotranspiration, thus facilitating the hydrologic recovery of the bog, and to limit competition to *Geum peckii* growth in lagg zones of the bog. The removal of the sparse tree growth across the main bog is anticipated to have an additional effect of deterring gull roosting within the bog.

The restoration work was completed primarily with the use of two compact excavators along with the use of compact tractor and trailer, various hand tools and hand labour. Work was completed in a phased manner within the constraints of land access, gull nesting activities, and seasonal conditions. Overall, the south half of the bog was restored first, followed by the north half, with cutting of large woody cover being the final activity completed.

During the design phase ECA concluded that while Big Meadow Bog has been significantly altered, the restoration of hydrologic conditions that approximate those observed pre-1958 is both feasible and achievable (ECA 2015). The restoration design for Big Meadow Bog has recognized that a

number of complex and interrelated uncertainties exist with respect to the rewetting of the site, including the response of nutrients, Herring gull nesting behavior, and the response of the vegetation community and in particular *Geum*. Despite these uncertainties, various indicators observed in the short time period following restoration would suggest a trajectory toward a much wetter BMB has been initiated. These indicators include the presence of surface water along depressions across the main bog during the dry season, the re-establishment of a large (4500m^{2+}) and deep (>0.7m) standing water area at the former "Big Lily Pond" location, re-activation of natural shallow channels within the bog landscape, discoloration and dieback of various plant species that appears associated with re-wetting stress, rapid colonization of disturbed area with herbaceous wetland species including graminoids and mosses.

ECA predicts that the implementation of the restoration prescriptions across the BMB site will lead to the raising of the water table within the bog such that it emulates the levels experienced at the site pre-1958. ECA anticipates that the various components of the Big Meadow Bog ecosystem will respond at different time scales to the rewetting, including: water level (1 to 5 yr.), Herring gull nesting (1 to 3 yr.), nutrients (1 to 3 yr.), *Geum*/plants (2 to 5 yr.), hydrological function and peat structure (10 to 20 yr.), although uncertainty exists on these timelines (ECA 2015). Return to near pre-alteration ecological conditions and relationships is likely on the scale of decades.

Thanks

The staff at East Coast Aquatics would like to thank the Avens Recovery Team (Samara Eaton, Nick Hill, Craig Smith, John Brazner, Sherman Boates) for engaging us in this fascinating project. We are pleased to have had such a hands on role in restoring the landscape of Big Meadow Bog.

ECA would also like to thank the local community of Westport who were keenly interested in the restoration and in various ways facilitated our work on Brier Island. Particular recognition goes out to Wally and Joyce DeVries, Danny Kenny, Vicky Graham and Stephen Lombard.

Table of Contents

1.0 ECA's Mandate

On June 17, 2015, the Fern Hill Institute for Plant Conservation, acting on behalf of the Eastern Mountain Avens Recovery Team, issued a Request for Proposals (RFP) for the a "Design to allow an adaptive hydrological restoration of Big Meadow Bog, Brier Island, Nova Scotia". The review committee selected East Coast Aquatics' Inc. (ECA) submission to the RFP process.

Although ECA was tasked with the hydrological restoration of Big Meadow Bog (BMB), this work was to be completed within the context of the planned recovery of the globally endangered Eastern Mountain Avens *Geum peckii*. The recovery plan for this small herbaceous plant had the following vision and goals (Hill *et al* 2015).

> ***Project Vision***
> The shared vision of the project partners is that *....* ***the Big Meadow Bog wetland ecosystem is restored, leading to the recovery of sustainable populations of Geum peckii and associated historic and rare plant communities....***
>
> ***Project Goals***
> - By 2050, the peatland vegetation community[1] is restored to a minimum of 75% of the pre-ditching extent of the Big Meadow Bog.
> - By 2050, increase the Avens' population numbers and total individuals within the Big Meadow from 2014 levels[2].

The hydrologic restoration design of Big Meadow Bog targeted the restoration of major ecosystem processes in support of these vision and goals through restoring ombrotrophy in the central raised bog and lagg zone between the central bog and the perimeter swamp. The lagg is the primary habitat for Eastern Mountain Avens, and a key to its long-term survival. It is intended that the hydrologic restoration reduce the nutrient load of the raised bog, allowing it to return to an ombrotrophic state, and generally raise the shallow water table in the bog and lagg through increased retention.

Based on the *Geum peckii* context for hydrological restoration several specific restoration objectives were identified to ECA that, based on scientific study of the project site prior to the design phase, were believed to mitigate identified threats to *G. peckii* recovery (Environment Canada 2011).

> ***Restoration Objectives***
> - Restore summer low flow period shallow groundwater elevation to within 0-20cm of the ground surface in lagg areas.
> - Re-create natural ground saturation conditions that are likely unsuitable/undesirable for ongoing nesting of Herring Gulls.
> - Re-create a natural rate of discharge for the project site.
> - Re-establish bog/fen hydrology using measures that require little or no future maintenance, do not create liability situations for the project partners or

[1] *Low biomass, sphagnum based community supporting dwarf ericads and fine sedges*
[2] *In 2014, the Big Meadow Bog supported 6 populations and 2550 individual Geum peckii*

landowners, can be adaptively managed if necessary, and that blend with the natural landscape of the site.

To design the hydrologic restoration of BMB within the context and constraints of the Eastern Mountain Avens recovery plan, ECA carried out three distinct steps in the restoration design process.

1. Completion of both remote and onsite evaluation of past direct and indirect impacts to wetland hydrology.

2. Completion of a hydrology restoration trial and monitoring activities.

3. Development of a hydrologic restoration design for Big Meadow Bog.

2.0 Restoration Design Summary

ECA completed an extensive restoration design document that is only briefly summarized here. Further details on design and construction requirements can be found in the design document (ECA 2015).

ECA identified several guiding principles for the hydrology restoration design of Big Meadow Bog including:

- Low cost of implementation,
- Techniques shown to have been successful in previous peatland restoration projects,
- Limited future liability for project team and property owners,
- Limited future maintenance obligation for project team and property owners,
- Based on empirical data from Big Meadow Bog hydrology restoration pilot (Autumn 2015),
- Adaptability, as additional data becomes available and in response to a phased implementation of restoration.

The resulting three primary components of the restoration design that were completed are briefly summarized in Table 1.

The methods prescribed for Big Meadow Bog were adapted from Yorkshire Peat Partnership 2015 as appropriate for the local project site characteristics. Details on construction approach for each of these structures is presented in the restoration plan (ECA 2015). However, generally, numerous blocks were to be established in all the ditches that had been excavated in the late 1950's such that the ditches no longer convey surface waters, but instead divert water away from the ditchline to the former natural lagg channels. As shown in Figure 1, the tops of the ditch blocks were constructed to typically extend ~0.8m above the adjacent ground surface at construction time, ensuring that the blocks will not be overtopped and resulting in all surface water being redirected into adjacent vegetation as sheet flow. The constructed ditchblock elevation will diminish with time as the structures fully settles into the landscape. Ditch blocks were constructed of locally available catotelmic peat, dug from adjacent borrow pits. This deeper peat (~>0.4 m) was used whenever available, and pits of >2m were typically excavated to source the material, although on the south extremes of the BMB project area mineral soils were the predominant soil present. In such cases, a clean mineral ditchblock was constructed and topped with native vegetation sod mats. Ditchblocks were never more than 50 m apart and were as close as 6 m apart at the higher gradient north and south ends of the project area.

Table 1: Summary of prescribed hydrology restoration approaches that were implemented at BMB.

Prescription	Brief Description	Brief Rationale
1. Ditch Blocks	Construction of frequently spaced ditch blocks composed of peat (or peat and stone where applicable) along all excavated ditches, completely blocking the flow of water within the ditch.	All surface water flows are re-directed into adjacent vegetation and natural channels, leading to a re-activation of the site's historic drainage network and raising of the water table.
2. Re-profiling of Ditch Edges	Steep, erodible ditch edges are re-profiled to a gradual slope and covered with native vegetation.	Reduction of deep-water safety hazards, increased ditch stability, and provision of a diversity of micro-habitats to allow for native vegetation re-colonization.
3. Woody Vegetation Reduction	Cutting of deciduous and coniferous tree species and shrubs within the central raised bog.	Reduction in evapotranspiration and low ground shading, promoting the faster recovery of water levels and former vegetation communities.

Following >50 years of draining, the surficial peat (acrotelm) at BMB was degraded because of oxidation due to increased aeration, desiccation, and compaction. Such changes to peat pore structure can lead to an impairment of its natural water regulation functions, such as water storage, which may not automatically re-establish with rewetting (Price *et al*, 2003). For this reason, surficial peat was not used in the construction of ditchblocks. However, this material was worked into the ditch between blocks as part of the ditch re-profiling process. Following the construction of ditch blocks, water depths in some ditches could exceed 1.5 m, and would represent a safety hazard for researchers, visitors and residents of Brier Island. Furthermore, the Yorkshire Peat Partnership has found that re-profiling, when completed in conjunction with ditch blocking, allows for the rapid establishment of native ombrotrophic bog floral species (Matt Cross, personal communication, October 23, 2015).

Re-profiling took place in virtually all ditched areas of BMB by excavating under the live sod layer and stretching material into the ditch as shown in Figure 2. As feasible based on-site characteristics, live material would be left on the surface of the re-profiled ditch. Short segments were sometimes left unrestored as significant large tree root systems adjacent to the ditch would have required extensive and deep excavation before re-profiling could take place, and such extensive disturbance was not deemed warranted. In such areas there was typically an abundance of tree waste and slash from the felled tree, and this material was pushed into the ditch to effectively eliminate the depth hazard. The shallowing of the ditch to near adjacent ground elevation created an undulating surface topography which provides a range of microhabitats that can aid in the re-establishment of a healthy and diverse sphagnum community (Shepard *et al*, 2013, Price *et al*, 2003). The diversity of micro-habitats associated with re-profiling, will facilitate a native floral and faunal re-colonization.

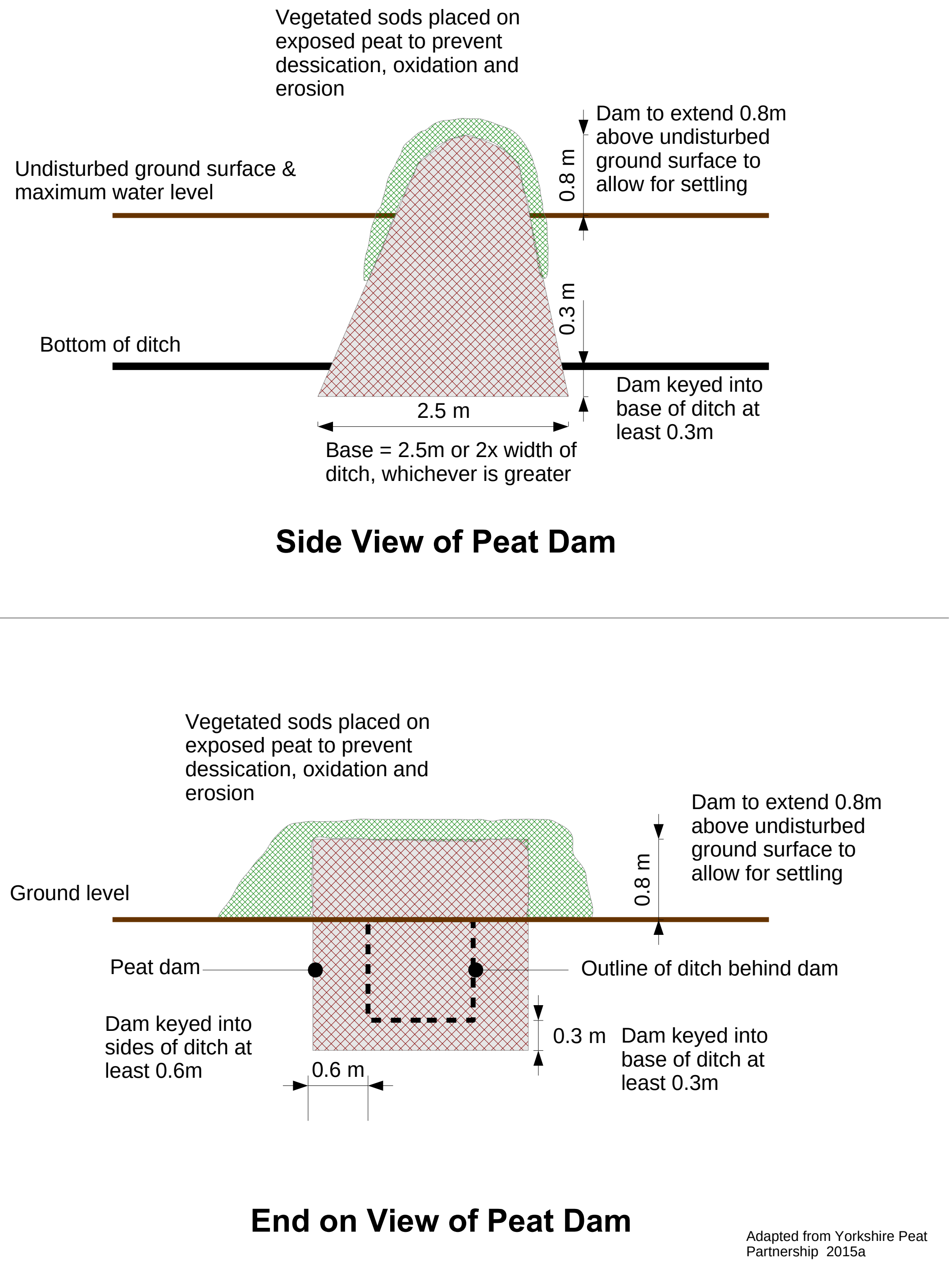

Figure 1: Side and end views of peat ditch block.

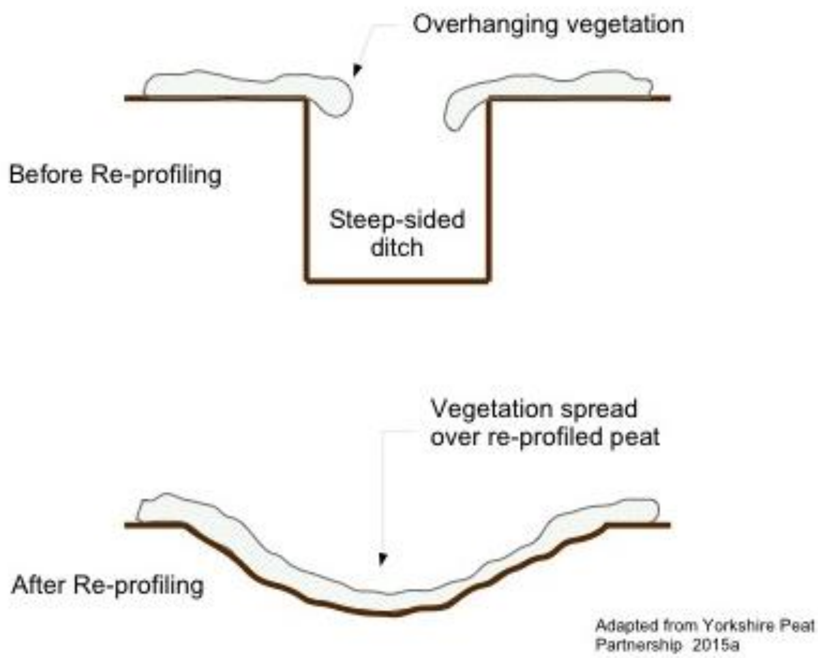

Figure 2: Schematic for re-profiling of ditch edges.

Constraints for Design
During the design phase a few constraints to implementation of the prescribed restoration activities were identified, and ultimately these had an influence on the final construction sequence and approach. These constraints and the resolutions employed included:

- There exist only a limited number of heavy equipment access points to site. Each of the available access points in turn has unique constraints, such as requiring prior consent from landowner, development of the access, and distance to restoration work areas.
  Resolution: All machinery work was completed by accessing Big Meadow Bog from a single location in the northwest. This required "walking" of excavators as much as 2.2 km in one direction to complete work on the southern extent of the bog. Hand tools, personnel access, and other supplies were carried in to work areas in backpacks over distances ranging from 900m to 1.4km depending on which smaller access trails were used.

- Given its protected status, heavy equipment movements at the site had to avoid areas with high *Geum* concentrations.
  Resolution: Mapping of all *Geum* plants and other monitoring structures were carried onboard excavation machinery in a hand held to avoid individual plants and monitoring arrays. If areas within a few meters of plants had to be accessed, pathways were first walked to ensure *Geum* was avoided.

- Given the above two constraints, as well as the unconsolidated ground surface of the wetland, there are signification limitations on the ability to transport restoration materials out onto bog. The movement of conventional construction materials such as stone, wood, soil for use in restoration is thus severely curtailed.
  Resolution: Only on-site materials were used in the construction of ditchblocks and re-profiling activities. Constructing ditchblocks was given priority over reprofiling of ditches if appropriate site material was scarce.

- As a result of the autumn 2015 hydrology restoration trial, ECA has established that at present, it is possible for heavy equipment to traverse the bog with care. Following the commencement of restoration and raised water levels, it was anticipated that the bog surface would become increasingly unstable for heavy equipment making it difficult for heavy equipment to access every structure to make significant alterations once the surrounding areas have been flooded. Similarly, given the limited number of access points, it may be difficult for equipment to traverse a previously restored area to access an un-restored area.
  Resolution: Many areas were naturally or seasonally soft depending on saturation levels. Log mats were made, held together with steel rope, and used as a working surface in soft areas. Soft ground would in some cases not permit machinery to work extensively in an area without risk of entrapment within the peat substrate, creating a time constraint of how long a machine could remain at a given location. In such scenarios construction of ditchblocks was given priority over re-profiling of ditches if. Finally, an overall sequencing priority saw all work in the south completed first, so that restored ground would not have to be traversed a second time with heavy equipment.

- As a bird species protected under the Migratory Birds Convention Act, the herring gulls that nest at Big Meadow Bog must be considered. Work and timing of work must leave the birds nesting undisturbed. Subject to subsection 5(9) of the act, "no person shall disturb, destroy or take a nest, egg, nest shelter, eider duck shelter or duck box of a migratory bird". The first Herring Gull *Larus agentatus* eggs are laid on Brier island about the third week of May with fledging occurring by July 01 annually (Mills and Laviolette 2011). This provides a timing constraint for construction work.
  Resolution: Work was completed from late March to late April, and from late August until early September to avoid disturbance to nesting gulls and new fledged birds.

Construction Sequence Phasing

Within the restoration design document (ECA 2015), ECA recommended a sequence and phasing for construction. From a practical perspective, the North/South divide in BMB drainage allowed the two ends to be addressed separately. Initial landownership constraints dictated that 2016 construction could only take place in the southwest on lands owned by the Nature Conservancy of Canada. This allowed restoration of all western ditching to be completed during April 2016. By the spring of 2017 access had been secured for the remaining restoration areas on the central and eastern ditches. However, given that the most feasible machinery access point was in the north, and the desire to not have to travel over restored areas to access unrestored areas, work was initiated in the south half of BMB in April of 2017. A period of shutdown was then followed to allow for nesting of Herring gulls on the site, an activity that was occurring more predominantly in the north at the time. Following fledging, crews returned in late August 2017 to complete the restoration of Jimmy's Pond in the most northerly extent of the project area, followed immediately by completion of all ditch restoration in the northern half of BMB during September 2017. Following completion of all heavy machinery restoration activities, tall shrubs (>2 m) and trees that had encroached the bog surface were cut across the entire site during several visits over the period of September 2017 to February 2018.

This overall sequencing is graphically shown in Figure 3. Further details on final construction and observations are presented in the following sections of this report, which are organized based on this sequencing. In summary, over 3.7 km of ditches were re-profiled following the installation of 123 ditchblocks. This is approximately 40 % more than proposed (87), and a result of additional structures being installed at key confluences of spur and main ditches, and along steeper areas at the north and south extremes of the project area. As proposed, such additional structures would need to be added once tree cover was removed and each individual site could be carefully assessed during construction. ECA always erred on the side of redundancy during construction to ensure the long-term stability and minimal risk of failure of the restoration.

Table 2: Number of constructed ditchblocks across BMB during the restoration activities.

Drainage	**Ditch**	**Slope of Ground Surface**	**Ditched Length** (m)	**Vertical Elevation Change** (m)	**Average Spacing Between Blocks** (m)	**Constructed Number of Ditchblocks**
North	East	0.37	991	3.68	50	27
	Central	0.48	1011	4.86	40	32
	West	n/a	0	5.98	n/a	None
South	East	0.61	530	3.23	30	34
	Central	0.49	690	3.38	20	18
	West	1.2	176	2.18	15	12
					Total	**123**

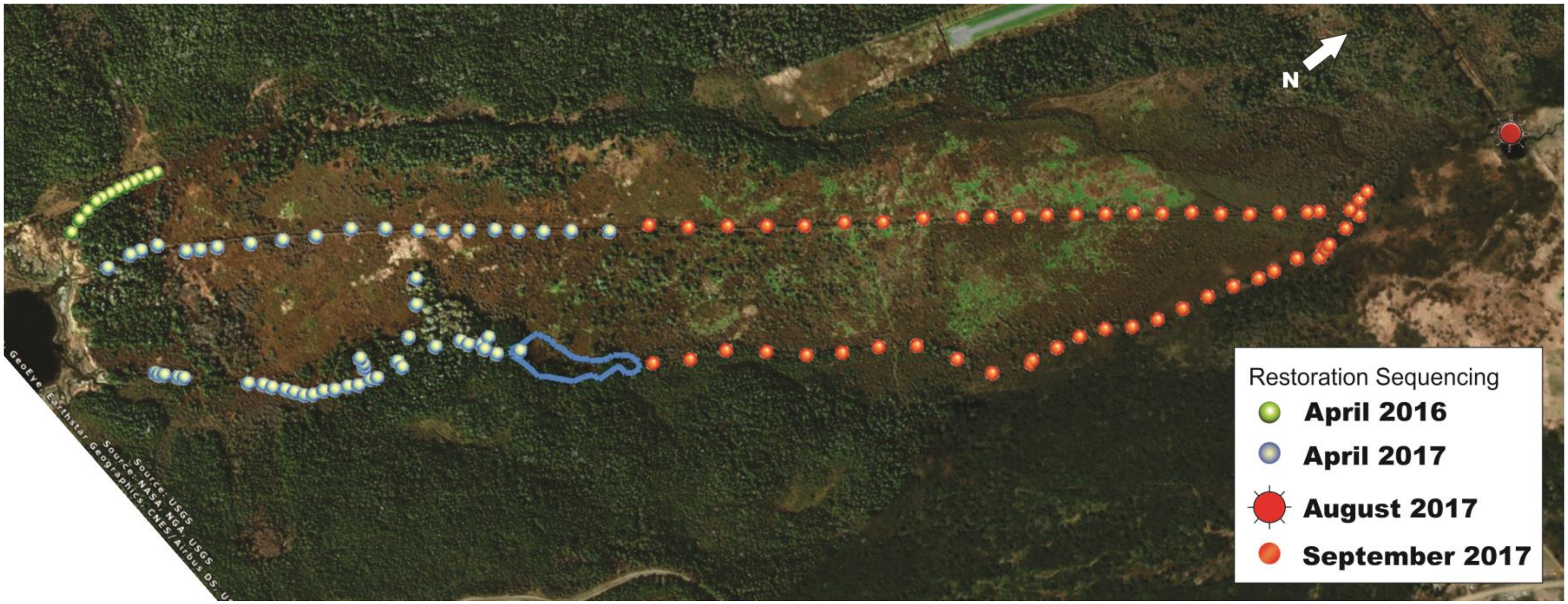

Figure 3: A pictorial representation of ditchblock construction and re-profiling sequencing at Big Meadow Bog. Each dot represents the specific location of a constructed ditchblock. Also shown is the location of Jimmy's Pond restoration site in the extreme north, and the post restoration boundary of the Big Lily Pond (blue line).

3.0 Restoring NCC Lands

The first restoration works took place on lands owned by the Nature Conservancy of Canada (NCC) on the south western portion of BMB (see Figure 4). In comparison to the eastern ditches, which profoundly affected the lagg areas, there was relatively little ditching on the western side of Big Meadow Bog. Only about 170 m of ditch, all in the south west on NCC lands, were excavated. Restoration activities took place in this area during the spring of 2016. Work began with the removal of tree cover that had encroached since 1958 when the ditch was dug, into the project area. Approximately 0.7ha of dense forest cover was cut (see Figure 5 and 7). Trees were felled, and partially limbed and bucked to allow them to settle close to the ground. However, no cut material was removed from the site, piled, or burned. The one exception was in a corridor along the southwest ditch line. Here cut material was moved to allow access of the compact excavator to construct ditchblocks and re-profiling.

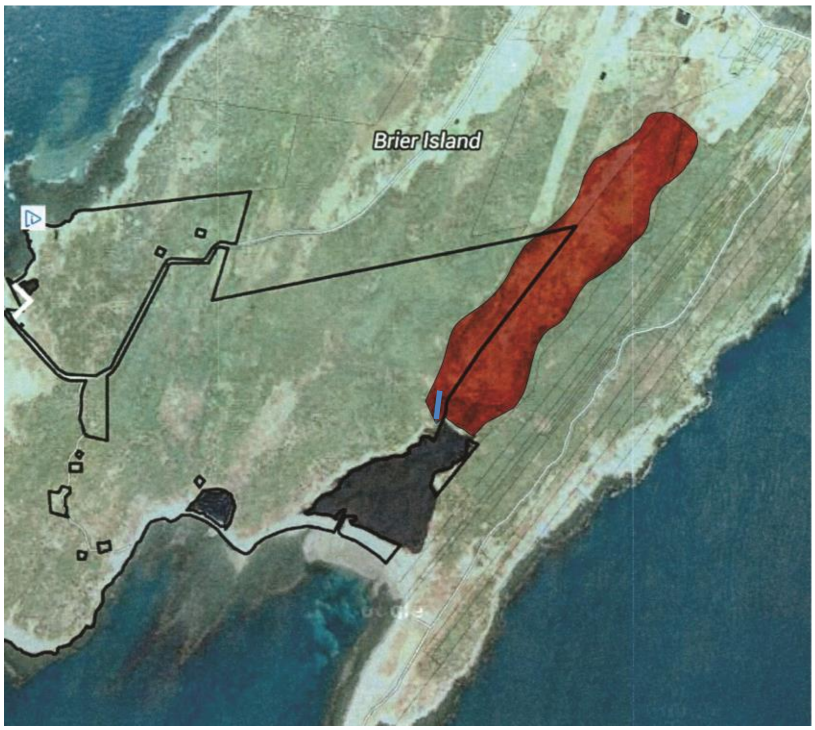

Figure 4: NCC lands on Brier Island are shown bounded by the heavy black line. An approximate boundary of Big Meadow Bog is shaded red. A thin blue line within the bog depicts general location of the south west ditch.

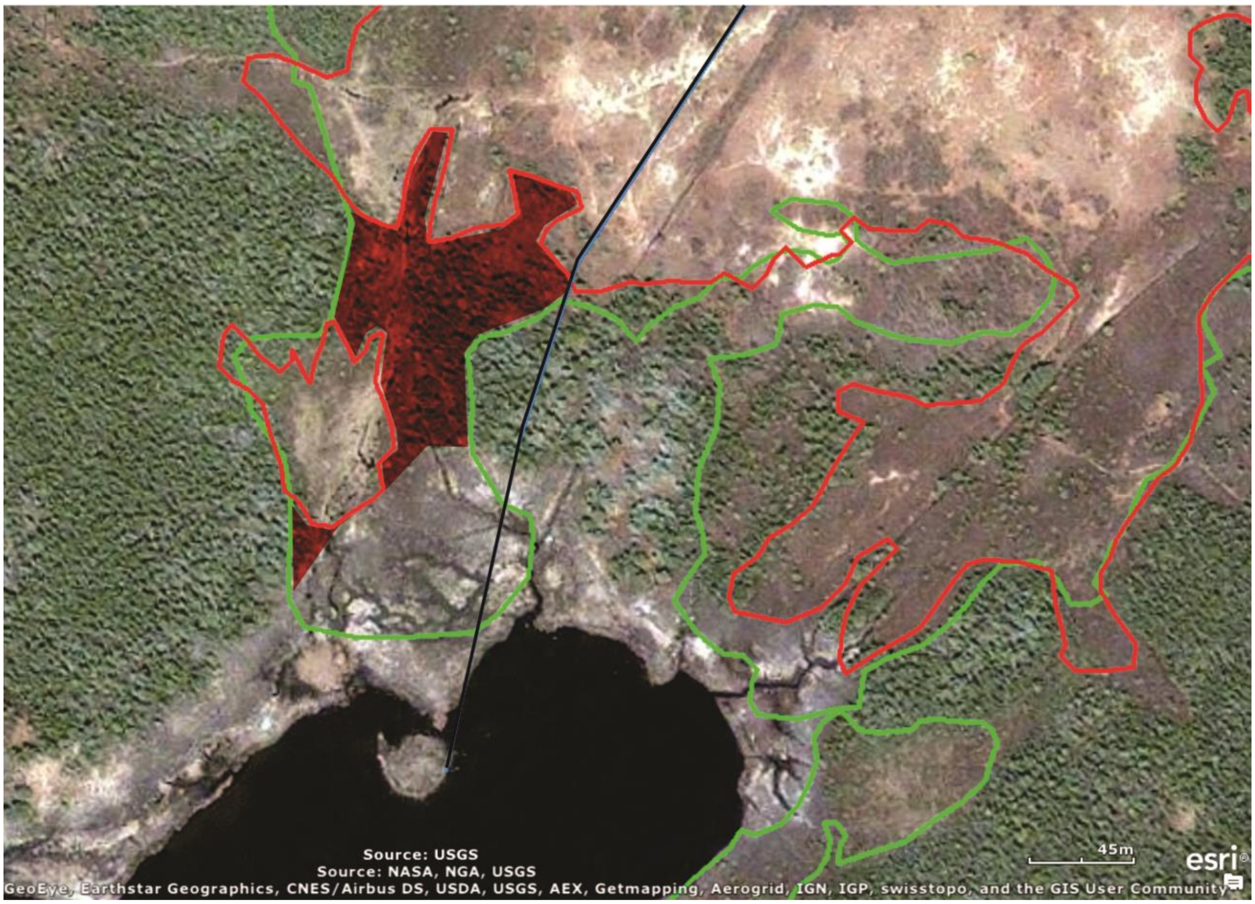

Figure 5: An area adjacent to the southwest ditch totaling approximately 0.72 ha had been encroached by trees in BMB on NCC lands (shaded red) since 1955. This area had all trees felled for the hydrological recovery of the bog and associated lagg.

The southwestern ditch was generally excavated in close proximity and parallel to the natural stream channel within the marginal lagg zone. Therefore, to initiate construction "in the dry" ECA installed a diversion at the most upstream confluence of the ditch and natural channel and began pumping ditch flow around the construction area. Installation of ditchblocks and re-profiling began at upslope end of the ditch and proceeded to the head of tide at the edge of Big Pond in the south. As shown in Table 3, 12 ditchblocks were installed, and 176 m of ditch recontoured in the southwest. Spacing of ditchblocks varied based on ground slope, which became steeper southward near Big Pond. This higher gradient area required approximately twice as many ditchblocks per unit length as the flatter portions (see Figure 6). It was also noted that at approximately the gradient break, soils changed from being predominantly organic peat to mineral and stone overlain by a gradually thinner organic layer as Big Pond was approached (Figure 8).

Table 3: Constructed number of blocks and horizontal spacing for the southwest ditch on NCC lands.

Drainage	**Ditch**	**Slope of Ground Surface**	**Ditched Length** (m)	**Vertical Elevation Change** (m)	**Average Spacing Between Blocks** (m)	**Anticipated Number of Ditchblocks**
South	West	1.2	176	2.18	9-20	12

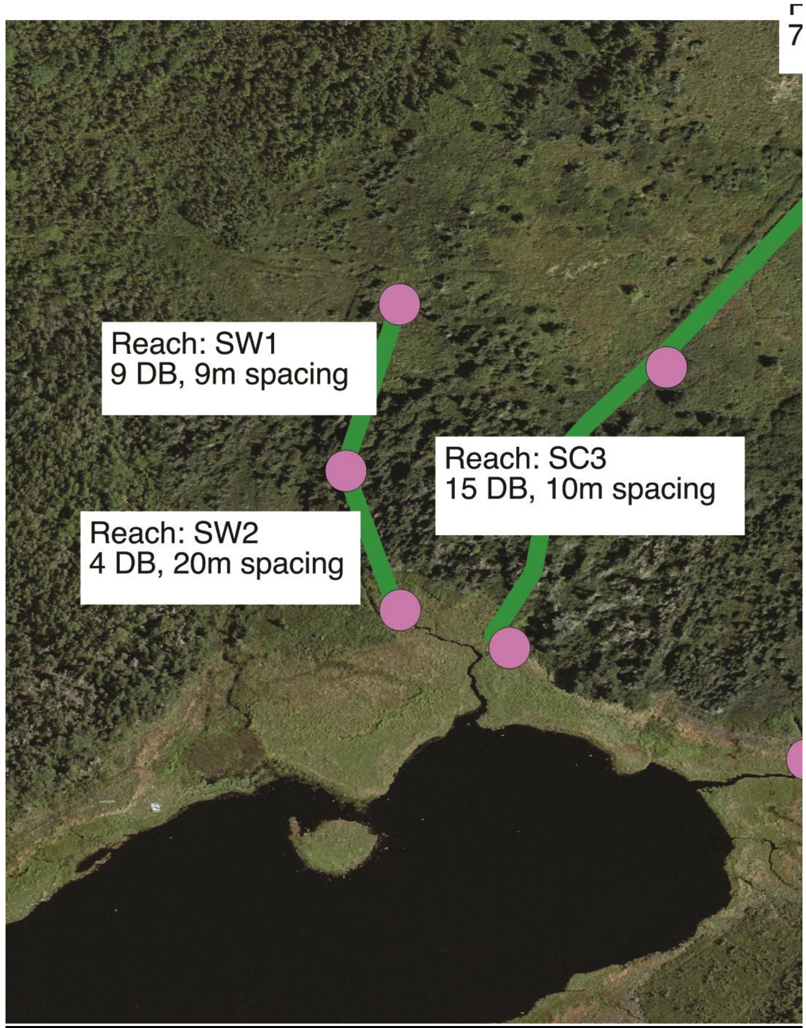

Figure 6: Two defined slope reaches with appropriate ditch block spacing have been identified for the south west ditch (left portion of image). Thirteen ditch blocks were prescribed.

Following installation of the third ditchblock, all lagg channel discharge remained out of the ditch, instead flowing south along the reactivated natural lagg channel, that remained within the landscape, until it reached Big Pond (Figure 9 and 10). Mature tree growth that had been cut from the historic ditch spoil piles and adjacent to the ditch had extensive root systems that hindered efforts to build ditchblocks and recontour the ditch (Figure 11). Although the construction was successfully completed, surface disturbance was greater in this project area than other locations of BMB given the presence of roots, mineral nature of some soils, and lack of sod to be placed on top of restored areas. This may provide opportunities for weedy pioneering species to initially dominate colonization along the restored ditchline. Similarly, the high volume of cut slash on the ground in this project area may influence the plant colonization trajectory.

Figure 7: View landward from Big Pond along the southwest ditch prior to restoration, demonstrating the mature tree encroachment that existed pre-restoration.

Figure 8: The mineral, rather than peat, nature of soils near big Pond are visible in this image, as is the relative depth of the Southwest ditch prior to remediation.

Figure 9: The natural lagg channel (photo right) was reactivated with stream flow following the initial upslope ditchblock installation, allowing the remaining ditch work (photo left) to be carried out "in the dry".

Figure 10: Following significant rain during initial construction, ditchblocks immediately impounded water and redirected sheet flows to the reactivated lagg channel rather than along the ditch.

Figure 11: A view south along the southwest ditch toward Big Pond following tree cutting, and during clearing of the construction corridor along the brook (L) and following initial re-profiling activities (R).

As the southwest ditch was completed (April 2016) a year before any other restoration work was initiated (May 2017), some initial observations of hydrological restoration implications were observed. This included the relatively rapid colonization of the site with herbaceous wetland species growth (see Figure 12), indicators of plant stress (discoloration of foliage, dieback) within the non-typical community that had colonized the site over the past number of decades, visual presence of surface water at ditchblock sites and along the re-activated lagg channel, and initial moss colonization of the bare peat areas that had resulted from construction.

Figure 12: Approximately 16 months post restoration, the southwest ditch that is located on NCC lands was well vegetated with a diversity of herbaceous plants and mosses.

4.0 Central Ditch

The central ditch completely transected Big Meadow Bog from Big Pond in the south to near Westport in the north. Webster et al. (2015) noted that following rain events, discharge quickly leaves the central ditch in both the north and south directions. However, actual volume of discharge from the central ditch had been observed to be quite low (typically 0.01-0.1 m^3/sec) (Webster et al 2015, ECA 2015). No natural central channel would have existed in the central portion of the bog prior to the 1958 ditching, unlike the natural lagg channels in the east and west. Historically the domed shape of the bog would have shed water toward the lagg and away from the central portion of the bog. Therefore, the excavation of the ditch would have captured very little surface sheet flow, but it would have carried predominantly a base discharge from shallow groundwater deeper within the bog, and effectively lowered the water table across a large area of the bog surface. As shown in Figure 13, the central ditch, and adjacent landscape of the bog were significantly different in 1958 than that which existed at the time the 2017 restoration activities along this section were initiated.

Figure 13: A northward view of Big Meadow Bog central ditch when it was freshly "ditched" in 1958 or 1959 (Source: LaRue and Toms 2013). Note the high water table within the central ditch, a state never observed during the design and restoration period (2015-2017) within the central ditch.

Prior to restoration, ECA recorded observations of the excavated ditch dimensions. Overall, the central and east ditches were wider and deeper than the south west ditch. Everett Powell, the equipment operator who excavated the ditches (1958), recalled that the ditches were each 6' (1.83m) wide and 6' (1.83m) deep upon construction (LaRue and Toms, 2013). At the time of restoration, most of the central ditch was a steep "V" profile, most likely a result of the slumping of unstable soft peat on the sides and, and to a limited degree, downcutting (erosion).

As shown in Table 4, 50 ditchblocks were constructed along the central ditch, and over 1.7 km of ditch was re-profiled. Work began on the southern half of the central ditch in the spring of 2017, while the north half was completed following fledging of gulls from nests on the bog, in September 2017. Concurrently, work was being completed by a second excavator working along the east ditch.

Generally large woody vegetation was sparse across the main bog, and access for restoration along the central ditch was unencumbered with a few exceptions. The most significant woody growth was cleared with a chainsaw prior to construction of ditchblocks and re-profiling. Clearing of large spruce for a linear distance of approximately 60 m was completed in the southern end through to Big Pond, and along 45 linear m of dense alder growth at the north end of the central ditch around the confluence with the outlet ditch and the east ditch (see Figure 14) to allow excavator access for restoration activities.

Table 4: A summary of constructed ditch blocks and re-profiling along the central ditch at Big Meadow Bog.

Drainage	Ditch	Slope of Ground Surface	Ditched Length (m)	Vertical Elevation Change (m)	Average Spacing Between Blocks (m)	Constructed Number of Ditchblocks
North	Central	0.48	1011	4.86	40	32
South	Central	0.49	690	3.38	20	18
					Total	**50**

Figure 14: Dense tree/tall shrub growth along historic ditch lines had to be cut prior to restoration to gain machine access. Here, an alder stand in the north confluence is cleared.

Re-profiling ditch walls has the advantage of addressing the hazard of deep-water while providing a range of aquatic micro habitats (~0.5 m to 0 m water depths) and ditch wall stability. Immediately following restoration activities these small bodies of surface water were visible along the south central ditch (Figure 15), but generally were absent from the north central ditch (Figure 16). Overall the north central appeared drier throughout construction, despite low ditch water discharge occurring. However, this could have been, at least in part, due to the late seasonal timing of construction in the north. The south water table remained visible in surface depressions even during the September work period, having been charged by earlier season precipitation and moisture levels.

Figure 15: This August 2017 view of the central ditch, recently restored with ditchblocks and re-profiling, depicts the shallow water microhabitats post restoration. The image is take from near the middle of Big Meadow Bog looking south to Big Pond (Photo credit: Mike Dembeck photography mikedembeck.com).

Figure 16: A northward view of Big Meadow Bog central ditch when it was freshly restored in September 2017, having been recontoured and ditchblocks installed. This view approximates the 1958 post ditching view of Figure 13.

Kennedy and Drage (2015) reported the results of a peat depth survey conducted in 2014 along transects (1, 2, and 3) east to west across Big Meadow Bog. Maximum peat depths of 4.5-5.0 m occurred near the center of BMB, tapering to <1.0 m in depth at the north and south ends. Through the central portion of BMB, borrow pit areas used to obtain catotelmic peat for ditch block construction would be excavated to 2.5 – 3.5m depth into the peat. During restoration of the south central ditch, mineral soils were encountered shortly after entering the south spruce tree line through to the edge of Big Pond. Many large rocks (0.2 to 0.8m) were within the soil matrix of the south. In the north at the confluence of the central and east ditches, and along the north outlet ditch, a peat layer of approximately 1.5 m was underlain by fine mineral soils.

It was also observed during construction along the central ditch that wood pieces, recognizable as tree pieces, were found in much of the north half of BMB at a depth typically deeper than 0.8m. This is a likely indicator that the bog was at one time forested before large scale regional climate changes led to the more open bog system that was the known state prior to the 1958 alterations.

5.0 East Ditches and Lily Ponds

In contrast to the central ditch, Webster et al. (2015) generally suggest that the northeast lagg ditch behaves more like a typical stream, and rainfall that arrives in the ditch during and following a rainfall event slowly drains through the network. ECA observed that in the marginal lagg zones where the east ditch had been excavated, the ditch intersected the former natural channel(s) in several locations. Unlike the central ditch, the east ditch from north to south was predominantly surrounded by forest cover at the time of restoration. This necessitated extensive cutting of a corridor along the entire length of the east ditch prior to restoration to facilitate machine access (see Figure 17). Like the heavily forested southwest ditch that had been restored on Nature Conservancy land a year earlier (Spring 2016), extensive large tree root systems along the east ditch hindered more typical re-profiling activities, as were successfully completed along the central ditch system. The root systems resulted in greater disturbance of the ditch margins during re-profiling, and as a result cohesive sod could not be used to top the re-profiling works in many areas. In the ditch sections with the heaviest and oldest growth trees, some short segments of ditch between the ditchblocks were filled with cut tree stems and slash and topped with a thinner layer of former spoil pile soil. There were 61 ditchblocks constructed and 1.4km of re-profiling completed along the east ditch in 2017.

Table 5: A summary of the constructed number of ditch blocks and horizontal spacing along the east ditch of Big Meadow Bog.

Drainage	**Ditch**	**Slope of Ground Surface**	**Ditched Length** (m)	**Vertical Elevation Change** (m)	**Average Spacing Between Blocks** (m)	**Constructed Number of Ditchblocks**
North	East	0.37	991	3.68	50	27
South	East	0.61	530	3.23	30	34
					Total	**61**

Figure 17: An excavator works in a recently cut corridor of trees along the north east ditch. The view is south westward across Big Meadow Bog and shows the scattered encroachment of larger trees across the main bog that would be felled as a final step in the restoration process. (Photo credit: Mike Dembeck photography mikedembeck.com)

Kennedy and Drage (2015) have concluded that the east stream/ditch system conveyed most of the water leaving the peatland as the groundwater gradient moves eastward across Big Meadow Bog, particularly in its southern half. This notion is supported by the fact that, at least visually, the southeast ditches have had the most significant impact on drying Big Meadow Bog. The three spur ditches, along with the main south east ditch, were excavated to drain at least four "Lily ponds" as shown in Figure 18. The Lily Ponds were shallow areas of standing water. In the spring of 2017, restoration on the east ditch began near the middle of BMB at the south outlet to the "Big Lily Pond" and preceded southward toward Big Pond. Concurrently, restoration on the south central ditch was taking place. The three spur ditches, were also restored during the spring phase. Although the southern portion of the eastern ditch is shorter than the northern portion, the complex nature of the former ponds and spur ditches in the east, along with the significant tree encroachment provided challenging conditions for construction.

The southeast ditch was found to have an armored substrate of cobble and rock along nearly its entire length, reflecting the thinner layer of peat along the lagg channel as compared to along the central ditch. The largest stones within the southeast ditch were ~2m in diameter, although most were 0.2 to 0.5m. These materials were excluded in construction of ditchblocks, and adequate peat could be found to construct all the ditchblocks on the east (see Figures 19 and 20). However, mineral and stone materials were used as available in the ditch between the ditchblocks as part of the re-profiling.

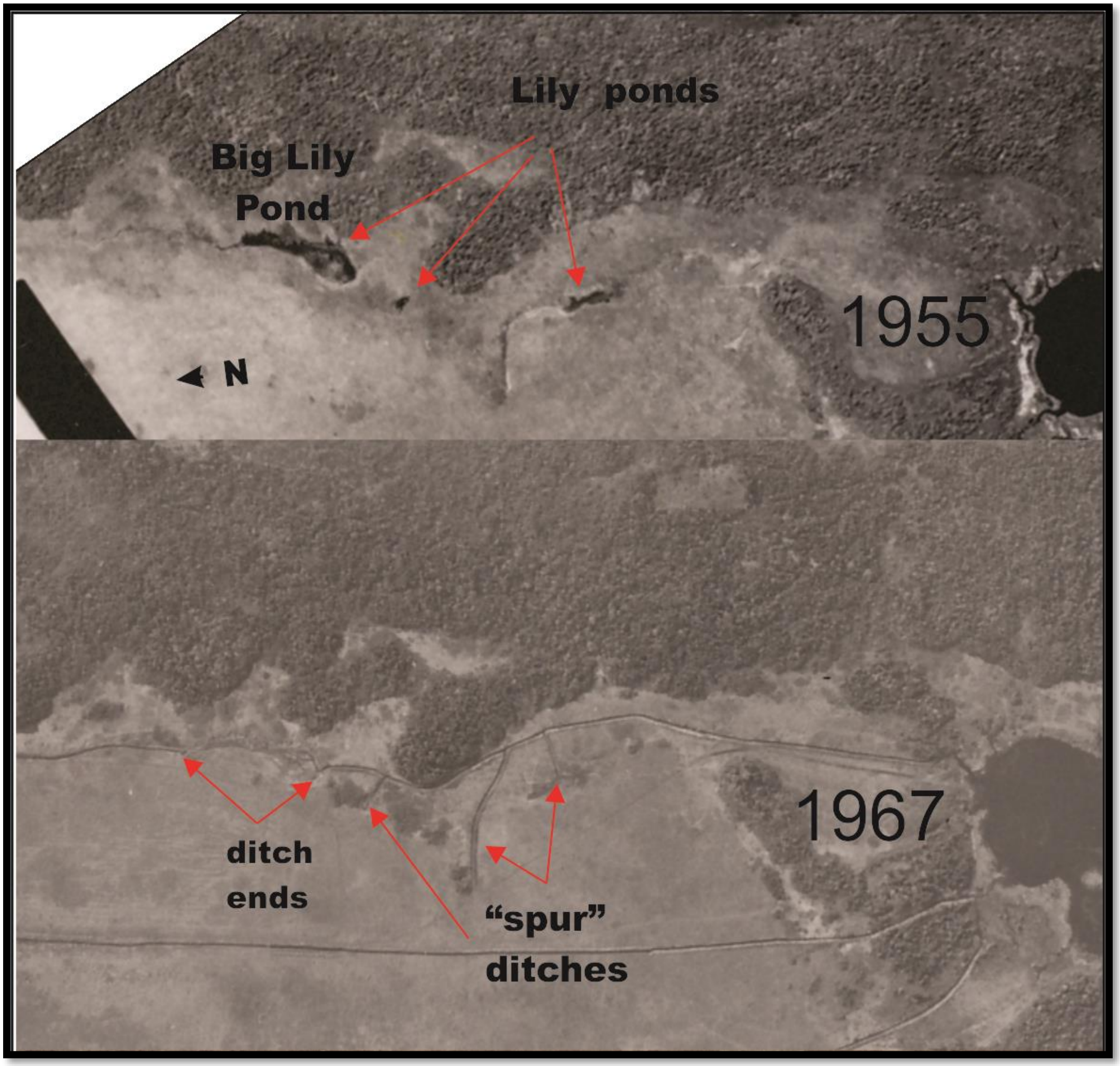

Figure 18: This time series of the "Lily Ponds" and the spur ditches in the south east of Big Meadow Bog clearly shows the transition from standing water prior to the ditching of BMB to the drained landscape of 1967.

Figure 19: A ditchblock nears completion on the southeast ditch. The compacted peat core is visible, waiting to be topped with available live "sod" that will promote quick growth and stability.

Figure 20: A before (L) and after (R) of ditchblock construction on the southeast ditch in a heavily forested stretch. Note that ditch has become dry from construction of upslope ditchblocks, allowing work to occur "in the dry". In the nearly completed photo (R), the ditchblock of wet catotelmic peat under the excavator buck is being compacted with an initial sod being placed on top of the far end of the ditchblock. Note the dry desiccated shallow peat piled in the image foreground that has been removed to allow access to deeper wet peat used in construction.

Following the initiation of restoration of the southeast ditch, the "Big Lily Pond" immediately began to capture surface water within the landscape depression of the former pond that had been dry for more than 50 years. The pond had been drained in two directions, north and south, by the east ditch. Within five months of the restoration construction being completed, the open water surface area of Big Lily Pond had grown to 4550m^2 (see Figure 15) and depths of >0.75m were measured at the southern end.

Figure 21: The Big Lily Pond on the southeast ditch had not held water in over 50 years prior to restoration at BMB. Following installation of ditchblocks (blue circles) the open water area recharged to 1950m^2 by May 2017 (green line) and over 4550m^2 by February 2018 (blue line).

It was noted that the draining of the Lily Ponds took as much as five years (LaRue and Toms 2013) despite the massive size of the excavated ditches. ECA (2015) suggested that this did not reflect how much water the ponds held, but rather the volume of water that was stored within the peat matrix of the bog surrounding the ponds. Based on 1955 imagery it appears the Big Lily Pond would have only flowed to the north. Restoration of the east ditch has re-established the natural height of land at the southern end of Big Lily Pond and promoted the rewetting of the surface landscape. The timeframe for re-establishment of the pond has been surprisingly quick, although further evaluation would need to be done to determine if the dimensions of the current pond appear similar to those of 1955, and whether the groundwater table has also been raised within that short time frame.

To the north of Big Lily Pond the north east ditch generally paralleled the former lagg channel, lying 2 to 20 m west of the natural channel. The north eastern ditch is the longest portion of the east ditch, extending some 980m compared to the 535 m south eastern ditch. Restoration on the north east began concurrently with the north central in September 2017. Unlike the south east, water did not immediately impound upslope of constructed ditchblocks. Perhaps a reflection of the prediction that there is less groundwater gradient to the north. Woody material from a long ago forested landscape was encountered within the deeper peat layers (see Figure 22 and 23) of the east ditch, as it had been along the central ditch. Toward the north, the peat was typically underlain by a fine sandy grey soil but did not contain the larger cobble and boulder encountered in the south end of Big Meadow Bog.

Figure 22: This image of a ditch block borrow pit area in along the northeast ditch shows a peat layer of approximately 0.8m underlain by a light grey mineral soil, and pieces of wood within the peat matrix below approximately 0.5m.

Figure 23: Evidence of an old forest strata was found across much of the northern half of Big Meadow Bog. Along the northeast ditch this large root ball was excavated from some 0.7m below the bog surface.

6.0 Jimmy's Pond

Jimmy's Pond is located along the north outlet channel from Big Meadow Bog. It was formed by the pre-1929 construction and subsequent abandonment of a secondary road and culvert near the northern outlet of the wetland complex (Kennedy et al. 2015). The pond was also referred to as the "Ice Pond", a place where ice would be harvested for food preservation. The discovery of a hockey puck from the depth of the pond during restoration also speaks to the historic importance of the pond for recreational use. The failure of the outlet across the secondary road, sometime between 1978 and 88, was believed to have lowered the local water table and increased the effectiveness of the north outlet ditch in draining the northern end of Big Meadow Bog (ECA 2015). Aerial images show the progressive filling in of the pond from 1978 to 2011 (Hill 2017). Since 1988, the pond had decreased in surface area by roughly 50% (Brazner, 2016). This was in part the result of a lower invert across the outlet roadway, and in part the result of sediment infill from upslope peat erosion. The degradation of Jimmy's Pond is depicted in Figure 24. Restoration was intended to return the pond to a state similar to that of 1955 both in terms of surface area and depth. This was to be done by excavating infilled material and raising the invert of the outlet channel.

Figure 24: Jimmy's Pond shown in 1967 (L) with east, central, and north outlet ditching. Greater than 50% of the pond area is infilled as of 2011.

During restoration, the pond was effectively isolated from the watercourse running through it. A steel plate was installed at the inlet channel, and flow pumped around the pond to the stream channel below. A coffer dam of bags was installed at the outlet of the pond and a 2" pump used to draw down the water within the pond during construction (Figure 25). Silt fencing was erected between the pond and a spoil pile area where excavated material would be placed. Silt fencing was also placed along the southern edge of Jimmy's Pond where excavated material was to be broadcast for disposal.

Restoration began with the installation of an armoured inlet across the channel entering the pond. A small trench was excavated across the inlet below the pump around diversion, and 4-6" stone was placed across the inlet and up the sides of the channel bank to harden the inlet without changing its dimensions or invert elevation. This precautionary step is intended to prevent back cutting of the channel southward above the pond once excavation had taken place. The resulting long-term stability of the upstream channel should minimize erosion and deposition events that would necessitate future maintenance of the pond.

The second step in the pond restoration involved excavation of the infilled pond area on the western half of the pond (see Figure 26). Extensive use of timber cribbing was necessary to support the two compact excavators while the machines were working off the soft areas of infill. Material was excavated approximately 70 cm, or 50-60 cm below the pre-restoration water level, across the entire infill site. Nearly all the excavated spoils were moved to the spoil disposal area to the west of the pond, inside an area of silt fencing.


Figure 25: Coffer dam bags isolate the outflow from Jimmy's Pond, while a 2" pump was used to draw down the pond water level prior to restoration works.


Figure 26: Compact excavators sit on timber cribbing to excavate the pond infill.

Figure 27: Distant trees provide reference for this pre (Aug 2017) and post (Sept 2017) restoration eastward view of the pond.

Figure 28: Distant trees provide reference for this pre (Aug 2017) and post (Sept 2017) restoration southward view of the pond toward Big Meadow Bog. Stone in the foreground is part of the restored outlet channel, which further raised the water level within the pond.

As shown in Figure 29, the final step in the pond restoration was the placement of a load of stone (4-12”) to re-build the armoured outlet weir and raise the water level in the pond about 30-40 cm above the pre-restoration base flow level. The elevation of the outlet weir was established such as to not flood any of the marsh area south of the historic pond footprint, but to raise the pond water level to approximately that which occurred prior to partial failure of the outlet. The outlet invert was surveyed to remain lower than any area along the old secondary roadway that forms the northern boundary of the pond.

Figure 29: Pre and post restoration views of Jimmy's pond outlet channel. The outlet was raised .03-0.4 m and armoured for stability.

Raising the outlet of Jimmy's Pond increases the pond storage capacity and raises the local water table around the pond and southward to Big Meadow Bog. These restored hydrological features are anticipated to have an influence on discharge from the northern extent of Big Meadow Bog, regulating how quickly water will discharge flow from the bog. The confluence of the central and north east ditches lay a linear distance of some 190m from Jimmy's pond. The closest ditchblock constructed on the north outlet ditch from Big Meadow Bog is a linear distance of 175 from the south edge of Jimmy's Pond. In total, more than 1400m^2 of open water pond habitat was re-stablished (see Figures 27 and 28), adding to the diversity of habitats offered by the BMB site.

7.0 Woody Vegetation Removal

Between September 2017 and February 2018, the final step in the restoration of Big Meadow Bog was completed. This step was the removal of trees and tall shrubs (>2m) across much of the main bog. With progressive drying over the past 55 years, Big Meadow Bog has undergone numerous changes at a landscape scale, including colonization by coniferous and deciduous trees. The establishment of trees and woody shrubs has contributed to the drying of the site through increased evapotranspiration, as well as altering the herbaceous plant community through shading and competition. Existing literature supports the cutting of woody plants as part of the hydrological restoration of peatland communities (Shepard *et al* 2013; Anderson, 2010; Landry and Rochefort 2012), and therefore it was prescribed and undertaken as part of the Big Meadow Bog hydrological restoration.

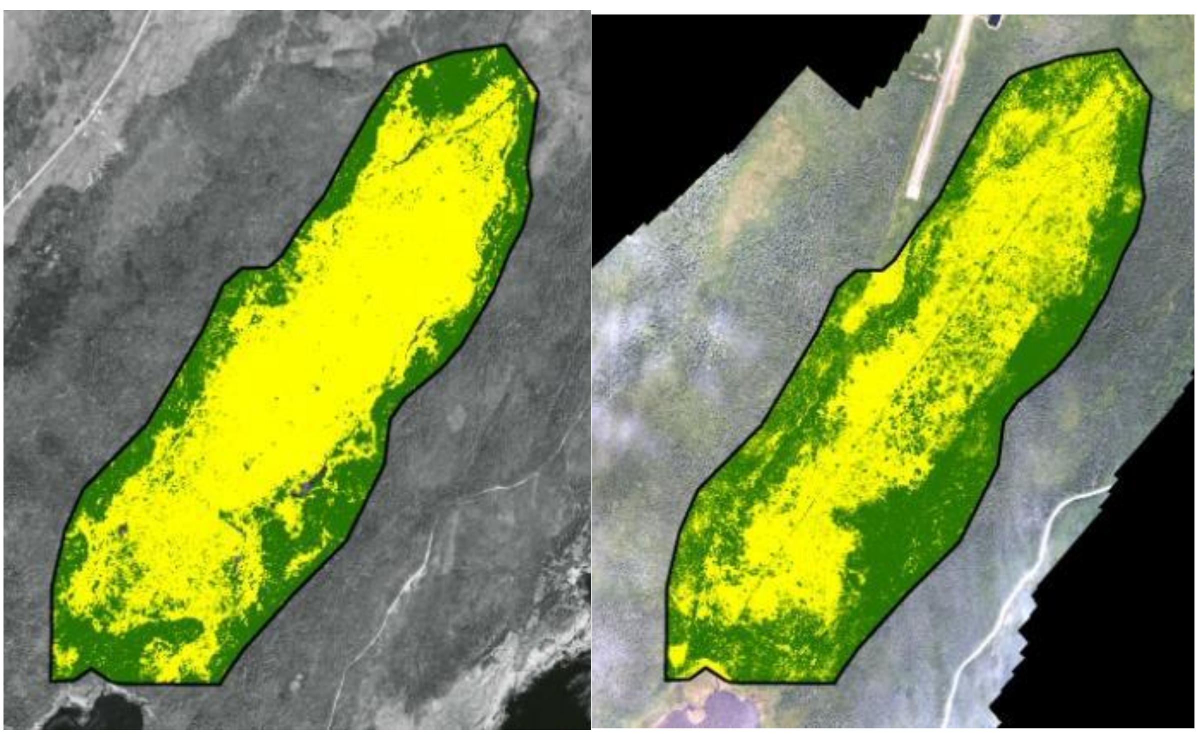

Figure 30: Supervised Maximum Likelihood habitat classification by polygons (Model 1) for 1955 (L) and 2015 (R) (Source. Toms 2015). Green indicates woody vegetation coverage on Big Meadow Bog, and the image demonstrates both a dense encroachment along the margins of the bog and a general sparse encroachment of trees across the open bog.

The spatial extent of woody vegetation encroachment was assessed by Brad Toms, Mersey Tobeatic Research Institute (2015), and his findings were used to direct tree removal. Toms indicated approximately 9.6 ha of open area within BMB has been lost to tree encroachment since 1955 (see Figure 30), with a clear decrease in bog width as well as a decrease in the ratio of open habitat to forested habitat. Much of the most densely forested areas that have encroached the bog are on the west side of BMB, and ECA estimated 5.9 ha of the 9.6 ha lost open area occurs on NCC land and along the western lagg area. Another 1.6 ha of dense encroached forest lies around the Lily Ponds on the south eastern lagg, as shown in Figure 31. Smaller areas of dense woods have encroached in various other areas of the perimeter of BMB, and there had been a general sparse colonization of large trees and tall shrubs across much of the open bog, with a slight concentration in the central bog east of the central ditch.

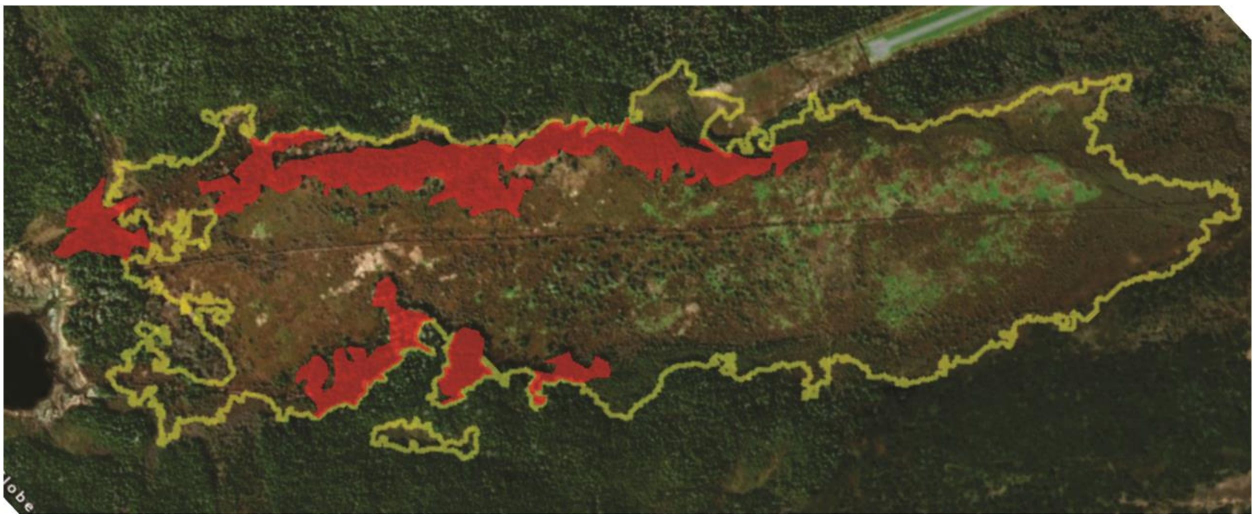

Figure 31: The 1955 treeline boundary around Big Meadow Bog is shown as a yellow line. As of 2011, the densest stands of forest that had encroached on the bog are shown in red and are concentrated in the southern half of BMB along the lagg areas (Source: modified from Toms 2015).

These encroachment observations are not unique to Big Meadow Bog, as drier conditions associated with drained peatlands has been observed in other locations to promote afforestation, which over time can further exacerbate peatland drying due to greater water losses from evapotranspiration and water interception (Van Seters and Price, 2001; Kopp et al., 2013 cited in Kennedy and Drage 2015).

The felling of woody vegetation as part of the restoration efforts occurred across approximately 33 ha of the main bog from the central bog outward toward the east and west ditches. As shown in Figure 32 and 33, all the sparse growth was felled, as well as dense areas around the south west and south east ditches, and a dense area along the west central lagg. Dense growth was also removed from corridors along the south central and west ditches to allow machine access for restoration. White spruce, Grey birch, Black spruce, alder and Wild Raisin were the predominant species cut. To a lesser extent Larch and other species were encountered.

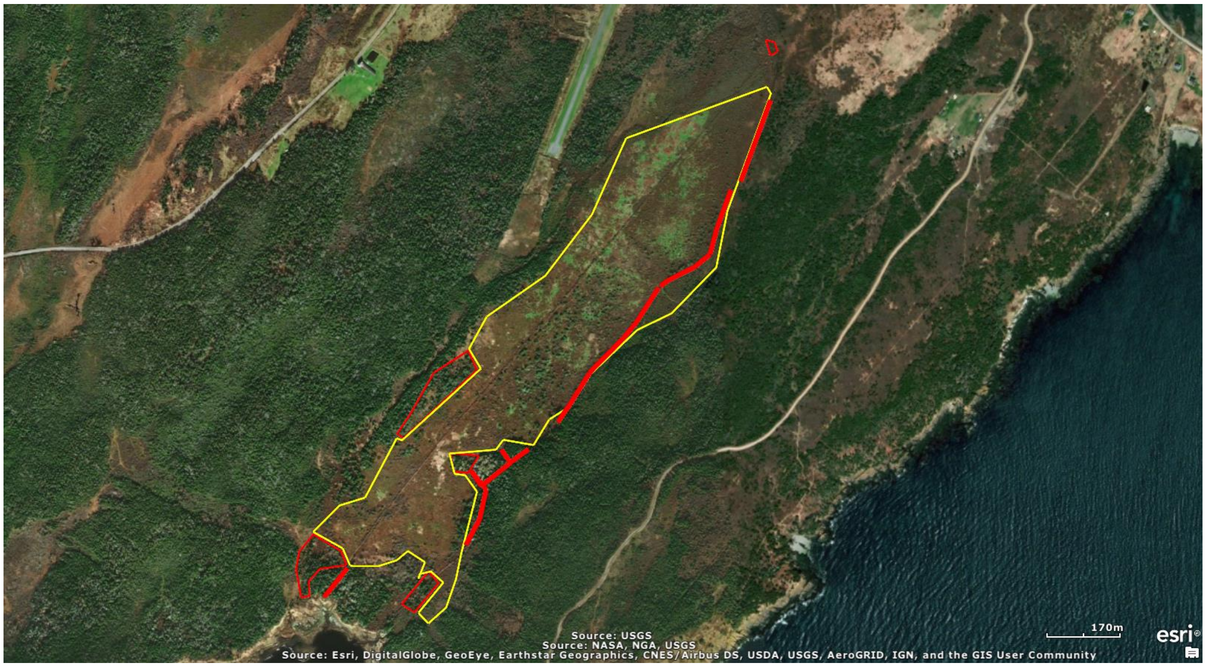

Figure 32: As part of the restoration efforts, removal of sparse tree cover occurred over some 31ha within the area defined by the yellow line. Dense tree removal occurred within red polygons (1.5ha) and along ditch corridors indicated with a red line.

Figure 33: A crew fells trees and tall shrubs on central Big Meadow Bog. All sparse tree cover on the main bog was felled whereas only select areas of dense forest encroachment along the bog margins was cleared.

All wood felling was completed manually with chainsaws. Trees were partially limbed and stems typically bucked in 8ft lengths to facilitate the slash settling to the bog surface. None of the vegetation was removed from the site, piled on site, or burned. Instead it was left as it fell to eventually be reclaimed into the bog. Some effort was made to ensure that slash was left to cover any bare ground that may have existed under the trees, as a means of discouraging gull nesting.

Although the density of trees across the open bog was sparse, removal was felt to be important in limiting evapotranspiration, reducing shade competition with preferred post restoration plant species, and as a gull deterrent (which add significant nutrient imbalance to BMB). Historically, one of the indirect impacts of ditching was improved gull nesting due to drying of Big Meadow Bog, and the gulls have been implicated in the changing ecology of Big Meadow Bog, effecting both physical impact and nutrient loading (LaRue and Toms 2013). The trees serve as roosts for adult birds (see Figure 34) and provide cover and bare ground for young birds. An evaluation of Eastern Mountain Avens revealed that about 4.8% of plants on Brier Island were affected directly by gulls damaging the plants (LaRue and Toms 2013), and this impact may be reduced if gull presence declines with restoration. A final observation of note following tree removal, it was possible to see the church steeple in Westpoint from the southern end of BMB, a 2km line of site that has likely not been possible for decades.

Figure 34: A roosting platform established by gulls deep inside a White spruce on Big Meadow Bog. Standing water surrounds the base of the tree following hydrological restoration.

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