WETLANDS, Vol. 17, No. 3, September 1997, pp. 416–423

REWETTING OF A CUTOVER PEATLAND: HYDROLOGIC ASSESSMENT

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Abstract: Exploitation of peatlands results in the degradation of hydrophysical conditions suitable for the re-establishment of peat-forming vegetation, notably *Sphagnum* mosses. Regeneration of peat-forming mosses necessitates a high and stable water table. The objective of this study was to evaluate the performance of open water reservoirs constructed to improve the hydrologic conditions required for growth of *Sphagnum.* A section of abandoned peatland, where former drainage ditches have been blocked, was treated by excavating reservoir ditches at 3-, 5-, and 8-m intervals to increase the local water storage. The colonization of *Sphagnum fuscum* and *S. angustifolium* diaspores scattered on the experimental baulks between the reservoir ditches was measured. Results indicate that water storage increased at the experimental site. The water table was higher and more stable, with an average maximum depth of 0.46 m at the rewetted site compared to 0.55 m at the control site. The volumetric moisture content of the surface peat was improved by rewetting, showing an average of 62% compared to 55% at the control site. Negative soil water tension at the −0.1 m depth was ameliorated at the experimental sites and nearly eliminated where 5-m experimental ditch-reservoir spacing was employed. *Sphagnum* establishment was successful on all experimental baulks, showing a higher percentage cover where soil moisture was more readily available.

Key Words: peatlands, restoration, rewetting, cutover peatland, open water, *Sphagnum* re-establishment, water table, soil moisture

INTRODUCTION

In Canada, peatlands cover about 12% of the land surface. Most of these peatlands occur within the boreal zone and remain relatively intact because of their remoteness. In the temperate zone, peatlands are under pressure from urban development, forestry, agricultural drainage, and to a lesser extent, from the peat-harvesting industry (Rubec 1996). In eastern Canada, we are not aware of any assessment of vegetation recovery in peatlands that have been under urban, forestry, or agricultural usage. However, we know that past harvesting operations leave behind abandoned peatlands that most often do not return to a natural peat-forming cycle (Lavoie and Rochefort 1996). Can restoration improve this problem? This study will focus on a hydrologic approach to restoration.

Mining operations alter many peatland functions that normally enable growth of peat-forming vegetation (Wheeler and Shaw 1995). Thus, cutover peatlands usually evolve into harsh environments, often devoid of vegetation and with insufficient moisture in the uppermost layers to permit recolonization by typical peatland species like *Sphagnum* (Schouwenaars 1993, Price 1996).

PROBLEMS AND AIMS

Exploitation of peatlands usually involves prior drainage operations with open ditches. Once the water is drained, surface vegetation is removed and the peat deposit is harvested mechanically. These operations result in major transformations of the hydrophysical properties of the exposed peat layers, which constitute a limiting factor when peatland restoration is attempted.

The hydrologic conditions necessary for peatland regeneration include a high moisture content of the peat (Okruszko 1995). Verry (1984) and Schouwenaars (1995) suggest that the water table during the summer should remain within 0.4 m of the surface and should have a narrow range of fluctuations to permit *Sphagnum* growth. In a natural peatland, these conditions are ensured by the presence of the acrotelm, which is the uppermost peat layer (<0.5 m) formed of living and poorly decomposed *Sphagnum* vegetation (Ingram 1978). The acrotelm's porous structure confers a high water storage capacity, which helps to regulate water-level fluctuations (Wheeler and Shaw 1995, Price 1996). However, in cutover peatlands, the acrotelm either has been completely removed or has suffered important structural changes (Schothorst 1977), and the remaining peat is more decomposed and has a lower water-storage capacity. This results in larger water-table fluctuations (Schouwenaars 1993, Mawby 1995, Price 1996). Ultimately, this reduces the potential for re-establishment of peat-forming vegetation since young *Sphagnum* plants are vulnerable to drought and desiccation (Schouwenaars 1992, Sagot and Rochefort 1996).

The creation of suitable hydrologic conditions is required for the re-establishment of peatland vegetation. Most attempts to rewet cutover peatlands consist of blocking existing drainage ditches (Eggelsmann 1988, Blankenburg and Schafer 1992, Inoue *et al.* 1992, Meade 1992, Schouwenaars 1992, Vasander *et al.* 1992, Mawby 1995). Results from these experiments showed an increase in the water-table elevation. Eggelsmann and Schwaar (1979), Nick (1984), Meade (1992) and Schouwenaars (1992) attempted ditch-blocking with the specific aim of increasing the ratio of open water. They obtained encouraging results and concluded that the creation of open water reservoirs is an option that needs further investigation. Hydrologic guidelines for this water-management option are discussed further in studies by Eggelsmann (1988), Beets (1992), Blankenburg and Schafer (1992) and Schouwenaars (1995). The present experimental design is based on a model described by Schouwenaars (1988) and Beets (1992). The objectives of this study were i) to evaluate the effect of creating open water reservoirs on the hydrologic regime of adjacent peat, ii) to determine the optimum peat/water surface area ratio, and iii) to assess whether such management practices have a direct impact on *Sphagnum* recolonization.

STUDY AREA

The study area, located in the Lac-St-Jean region of Québec, is part of the Ste-Marguerite-Marie peatland

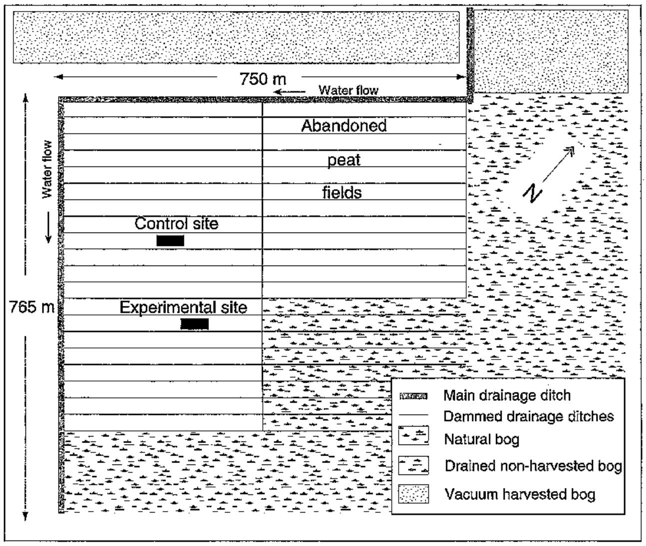

Figure 1. Location of the experimental site (70 × 20 m) and the control site within a section of the cutover peatland. The sites are immediately adjacent to a natural section and a currently harvested section of the bog.

(48°47'N, 72°10'W), which is a 4,312-ha ombrotrophic peatland. The study was conducted during the 1994 field season on a part of the bog that was exploited and abandoned in 1991. The area is underlain by sedimentary rock, primarily Ordovician limestone, covered by a thick layer of marine clay originating from the glacial Laflamme Sea episode. Deposits of deltaic sand form complex structures above the sedimentary bedrock (LaSalle 1968). The mineral sediments have a well-developed iron pan (Price 1996), which forms a low permeability layer and isolates the peatland from the regional aquifer. Above this lies moderately decomposed peat. The ground surface is almost devoid of vegetation, except for isolated stands of herbaceous species, typically *Eriophorum spissum* Fern. The climate can be described as humid continental, with mean January and July temperatures of −17.1°C and 17.5°C, respectively. Mean annual precipitation is 820 mm, 25% of which falls as snow (Environment Canada 1993).

The study site (70 × 20 m) (Figure 1) is located in the middle of a harvested peat field in a section of the peatland that has been exploited using the Haku technique (Monenco Ontario Ltd 1981) from 1990 to 1991. In Canada, a peat field, sometimes referred to as a bay, is the peat substrate located between two drainage ditches, which are usually 30 m apart. The experimental site is representative of the majority of the abandoned peat fields at this bog. After harvesting was abandoned, the drainage ditches were dammed with residual peat in the spring of 1993. On this site, the first 0.45 to 0.60 m of peat was cut over, leaving an

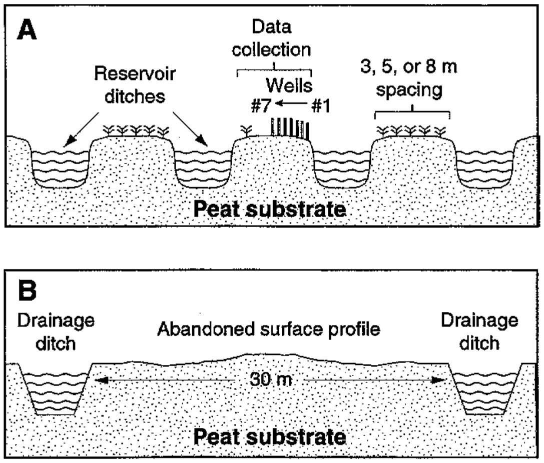

Figure 2. A) Experimental design showing the experimental baulks delimited by reservoir ditches. The design shown above was reproduced for each of the 3-, 5-, and 8-m experiments. The hydrologic measurement equipment was installed on the middle baulk. B) Typical surface profile of a harvested and abandoned peat field, as at the control site.

average residual peat thickness of 1.85 m (personal communication, R. Roy 1995).

METHODS

Experimental Design

The study was conducted between May 6 and August 31, 1994. A section of the abandoned peatland was rewetted by excavating 3 series of reservoir ditches, with 4 parallel ditches per series, and each series having a ditch spacing of 3, 5, and 8 m, respectively (Figure 2A). This overall design was not replicated. The ditches were all located on the same peat field. The zone between the ditches are referred to as baulks. The experimental ditches were 1 m wide, 1 m deep, and 20 m long, and were oriented perpendicular to the harvesting drainage system. The function of these ditches was to increase the local water storage following precipitation and snow melt. Fresh *Sphagnum* diaspores (*S. angustifolium* (Schimp.) Klinggr. and *S. fuscum* (C. Jens. *ex* Russ.) C. Jens. *in* Tolf in 1:1 ratio), originating from the upper 10 cm of an unspoiled part of the adjacent peatland, were scattered by hand on the experimental baulks between the reservoir ditches in autumn of 1993 immediately after the ditches had been dug. The initial plant cover of introduced *Sphagnum* was at a ratio of 1:20 (i.e., 1 m^2 of material was spread over 20 m^2), as described by Rochefort *et al.* (1995). Part of the same plant material was reintroduced on a abandoned peat field in three different areas for comparison. The experimental site as well as a control site (Figures 1 and 2) were monitored daily for different water-balance variables. At the experimental site, all measurements were made on the middle baulks between two reservoir ditches in order to minimize boundary effects from the periphery of the experiment (Figure 2A). Both the control and experimental sites were drained, harvested, abandoned, and had ditches blocked at approximately the same time. Both the control and the experimental sites were at least 200 m from the natural bog.

Hydrologic Data

During the measurement period, rain was collected with a tipping bucket gauge. Evaporation was estimated with the Bowen ratio-energy balance method in a set-up identical to that used by Price (1996) with the theory and method described in detail by Price (1991). Net radiation was measured with a (REBS) net radiometer. Ground heat flux was obtained with two (REBS) soil heat flux plates embedded 1 cm below the surface. A 4-level aspirated psychrometer system was used to measure dry bulb and wet bulb temperatures.

For water-table monitoring, transects were established perpendicular to the ditches on the experimental baulks to the middle point between the reservoir ditches. A total of 7 wells were placed along the transects of each experimental baulk to a depth of 0.75 m below the surface. Two wells were placed at 0.2 and 0.4 m from the edge of the reservoir ditch. Five additional wells were installed at a distance of 0.5 m from the ditch's edge and then every 0.25, 0.50, or 0.85 m interval, respectively, for the 3 m, 5 m, and 8 m experimental baulks. Wells were made of PVC (25-mm i.d.) with 0.75 m slotted intakes and were covered with a 250-μm geotextile screen. These were lowered into boreholes so that their intakes were above the peat-mineral interface. On the control site, a transect was established from a blocked drainage ditch to the middle of the 30-m-wide peat field, and wells were placed at 1, 2, 5, 10, and 15 m from the edge of the ditch. Wells were of slotted 50-mm (i.d.) PVC and were referenced to a common datum using standard surveying techniques. Water-level measurements in the ditches began June 24.

Soil moisture content was calculated using surface (0–50 mm layer) samples (196 ml) collected daily on the experimental baulks (1 per experimental baulk) and on the control site (2 samples), for a total of 5 samples per day. On the control site, samples were collected both on the flat harvested section and on the central ridge to account for variations due to the typical profile of abandoned harvesting peat fields (Figure 2B). Wet samples were weighed (M_{wet}), placed in an oven at 105°C for 24 h, then weighed again (M_{dry}). Volumetric soil moisture (θ_v) was calculated as

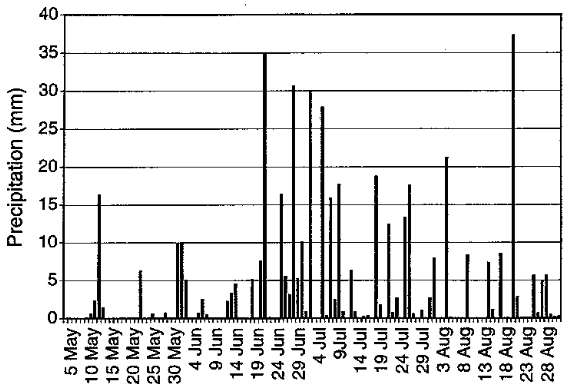

Figure 3. Total daily precipitation (mm) at the experimental site in 1994.

$$\theta_v = \frac{(M_{wet} - M_{dry})/r_w}{\text{volume}} \quad (1)$$

where r_w is the density of water (1000 kg m^{-3}).

Matric tension was determined by using multi-level tensiometers (Soil Moisture Corp.), which were installed on each experimental baulk and on the control site. Daily readings are expressed as total head (cm) relative to the ground surface, at depths of 0.1, 0.2, 0.3, 0.4, and 0.5 m. Note that 1 cm of head is approximately equivalent to 1 mb of pressure.

Sphagnum Establishment Performance

After one year of growth, the *Sphagnum* cover on the experimental surfaces was estimated. Thus, at the end of September 1994, the percentage cover was recorded using 6 quadrats (0.25 m × 0.25 m) per experimental baulk or control surface, giving a total of 18 quadrats for a given experimental spacing.

RESULTS

Hydrologic Data

For the period May to August 1994, rainfall measured at the study area was 453 mm, compared with a 30-year mean value of 396 mm (Environment Canada 1993). Rain was not evenly distributed over the study period (Figure 3). The month of May was relatively dry, with total precipitation of only 38 mm, compared to the published normals of 80 mm. June and July produced most of the rain events, with total precipitation of 147 mm and 174 mm, respectively, compared to 30-year normals of 85 and 121 mm. August was closer to the long-term normals, with 112 mm total precipitation, compared to 109 mm (Figure 3). Evaporation ranged from 0.4 to 6.7 mm day^{-1}, and the overall daily average was 3.8 (± 1.6 mm day^{-1}), for a total of 368 mm for the study period.

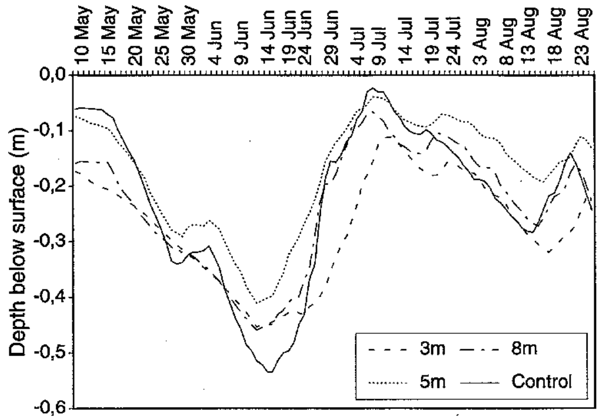

Figure 4. Average water-table depths below the soil surface at all experimental baulks and at the control site (7-day moving averages).

In early May, the water table was very close to the peat surface (Figure 4), having been fully recharged by snow melt. From May to mid-June, there were few rain events, and there was a general lowering of the water table at all measurement locations. Starting June 12, the water table began rising in response to more frequent rainfall, which replenished the water supply, reaching its highest level in mid-July, but sustaining a relatively high water table for the duration of the summer. The water table at the control site experienced the greatest range and most rapid fluctuations, from +0.03 to −0.56 m, compared to the experimental site. The median water-table depth for the control, 3, 5, and 8 m sites were −0.19 m, −0.25 m, −0.13 m, and −0.21 m, respectively. At the experimental site, the water table responded differently depending on the distance separating the reservoir ditches. The water table at the 5 m experimental baulk was continuously higher than the 3 m and 8 m experimental baulks (Figure 4). Duration curves (Figure 5) indicate that the water table at the 5 m experimental baulk was also more stable (i.e., flatter curve) than at the 3 and 8 m baulks, and the control site was the least stable (i.e., steepest curve).

Evidence that water was moving laterally from the ditches towards the peat baulks is shown by the sloping water-table profiles (Figure 6). Water-table profiles for mid-June (Figure 6A) represent the driest period during the study. Water-flow direction at the 3- and 8-m experimental baulks is generally toward the center of the baulk. At the 5 m baulk and control site, flow is primarily toward the ditch/reservoir. During the wetter period in mid-July, the water movement is generally toward the ditch at the 3-, 5-, and 8-m experimental baulks, and away from the ditch and the center at the control site (Figure 6B).

The volumetric moisture content of the 0–50 mm

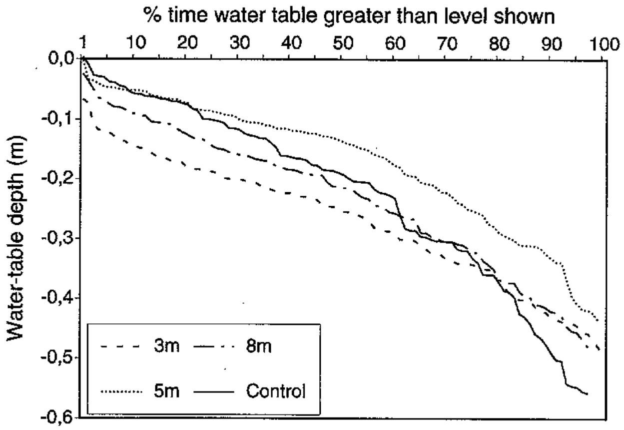

Figure 5. Water-table-duration curves for experimental and control sites showing % time water table was greater than the level shown (m).

layer was measured at all locations to give an indication of the water storage within the surface peat. The seasonal trend was similar to that of the water table. The 5-m experimental baulk seemed to have a higher average volumetric soil moisture content and lower standard deviation (67 ± 10%) compared to the 3- and 8-m baulks (58 ± 13% and 63 ± 10%, respectively). The control-site soil moisture was 62 ± 11% on the flat harvested portion and 50 ± 14% on the raised central ridge.

Matric tension (Figure 7) follows the same seasonal and spatial trend as soil moisture. Water tension at the plane of measurement (−0.1 m) is expressed relative to the surface. Thus, a value of zero cm represents a condition in which the water table is at the surface (and 10 cm (~10 mb) of water pressure exists at the plane of measurement). If the total head falls to −20 cm (about −20 mb), then the water table is 20 cm below the surface, and there is −10 cm (about −10 mb) of matric tension at the 0.1 m depth. Negative total head persisted at all sites during the measurement period (Figure 7) (i.e., the water table remained below the surface). At the 5-m experimental baulk, the total head dropped below −10 cm (about −10 mb) for a very brief period (August 12–20, 25). During this period only, therefore, the soil at the −0.1 m depth was under matric tension. Minimum values of approximately −30 cm (−30 mb) were observed at the 3- and 8-m baulks and at the control site.

Sphagnum Establishment Performance

Only the mean and standard error are presented in Figure 8, as the experimental design had been developed to test a model for rewetting peat and not to specifically test *Sphagnum* recovery. There does not seem to be much difference in terms of *Sphagnum*

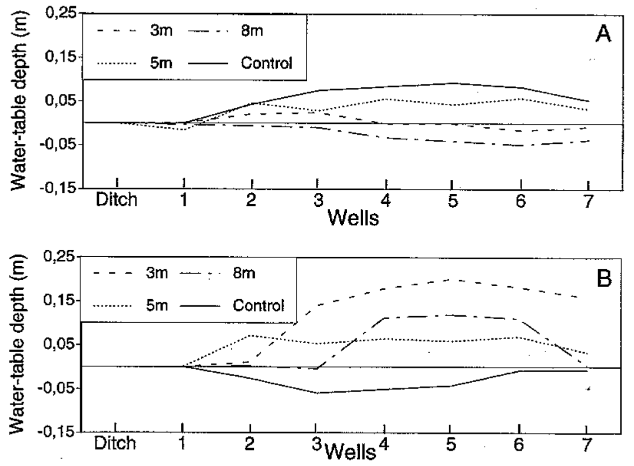

Figure 6. Water-table profiles during A) a dry period (9 June) and B) a wet period (16 July). Depths (in m) are relative to ditch water levels at each experimental baulk and at the control site.

cover between the experimental baulks, but a mulch cover over the reintroduced *Sphagnum* (unpublished experiment) did improve the recolonization process relative to *Sphagnum* reintroduced on rewetted peat only.

DISCUSSION

Improvement of Peatland Hydrologic Conditions for Restoration

A high and stable water table has been shown to be an important factor in the establishment and survival of *Sphagnum* mosses (Beets 1992). Schouwenaars (1988) suggests that the water table should remain within 0.40 m of the surface during the growing season to ensure the presence of typical peatland vege-

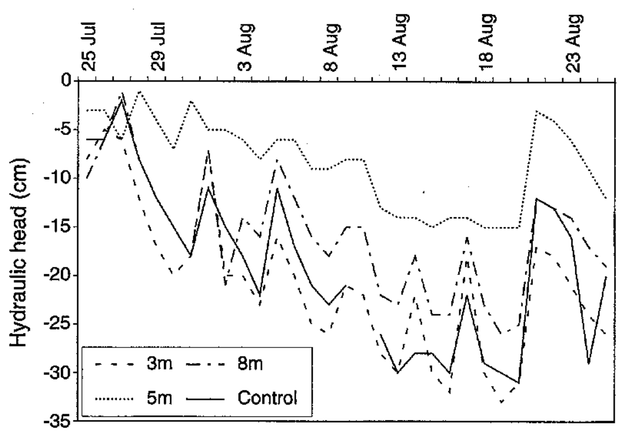

Figure 7. Soil water tension (total hydraulic head relative to the surface) at a depth of 0.1 m below the surface, at the experimental baulks, and at the control site.

tation. This was achieved at the 5-m experimental baulk, where the water table was above the 0.40-m level for 95% of the time (Figure 5). The 3-m and 8-m experimental baulks also had high average water-table levels (88% and 86% of the time above 0.40 m, respectively), compared to the control site (84% of the time). The relatively wet summer conditions of 1994 (Figure 3) resulted in higher water-table levels than would otherwise occur. In a dry year, the role of water reservoirs would be more evident and more important. Consequently, there were only slight variations between the seasonal average water-table positions at each site.

A greater distinction between the rewetted and the control site lies in the amplitude of water-table fluctuations, which were greater at the control site than at the experimental baulks (Figure 4), where open water reservoirs stabilized the water table. This is reflected in the steeper water-table-duration curve for the control site (Figure 5) and also by the standard deviation of water level, which was 50% greater than at the experimental baulks. Furthermore, the degree of water tension developed at the 5- and 8-m experimental baulks was notably less than at the control site. There was little improvement at the 3-m site. Thus, with regard to the first objective of this study, it can be concluded that the creation of open water reservoirs enhanced the rewetting of the cutover peatland.

In a natural peatland, the high specific yield of the upper peat layers minimizes the water-table fluctuations in response to water fluxes (Price 1996). Specific yield is the parameter that relates the change in water storage in a soil to the change in water level. This property is destroyed when the acrotelm is removed by harvesting and by subsequent decomposition and subsidence (Schothorst 1977). The specific yield of the peat in this area reported by Price (1996) declined from 0.55 at a natural peatland to 0.05 at the cutover peatland. The presence of reservoir ditches at the experimental site had the effect of increasing the mesoscale ("bulk") specific yield of the baulks. This is because the specific yield of the open water in the ditches is unity. The bulk specific yield for the experimental baulks can be calculated based on the proportion of peat and open water and their respective intrinsic specific yield (i.e., 0.05 and unity). For the 3-, 5-, and 8-m baulks, the bulk specific yield was calculated as 0.38, 0.25, and 0.17, respectively.

Unlike the one-dimensional water-table adjustments normally associated with specific yield and the gain or loss of water, here there is a more complex response involving lateral water transfers between the peat baulks and the ditches. This interchange of water ameliorated water-table fluctuations and effectively increased the Sy to a higher "bulk" value. At the control site, the lower "bulk" specific yield caused water-table instability, which was manifest in the steeper rising and falling limbs of the water-level hydrograph (Figure 4).

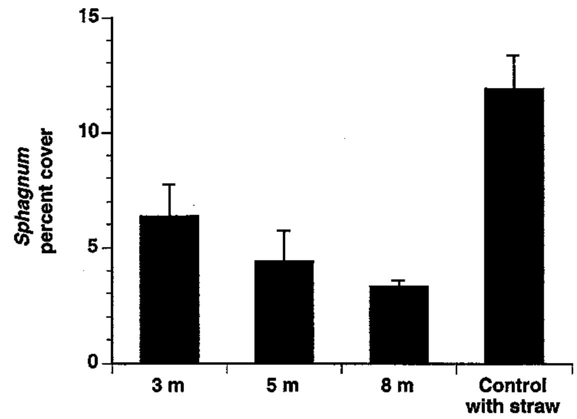

Figure 8. *Sphagnum* cover on bare peat surfaces (mean ± SE). Average percentage covers of 18 quadrats used at each experimental spacing for estimation. Data on *Sphagnum* cover under a mulch cover were from an unpublished experiment for comparison.

The water-table profiles presented in Figure 6 show an asymmetric pattern of water flow between reservoir ditches. This was apparent at the 5-m experimental baulk, where the water table perpetually sloped toward the ditch, suggesting water input from the adjacent ditch (from the right in Figure 6). This was confirmed by follow-up measurement of the water levels in all experimental ditches in 1995. This showed that the ditch adjacent to the 5-m measurement baulk had an absolute water-level elevation above that in all other ditches, with water level declining away from it in both directions (i.e., toward the 3-m and 8-m baulks), including toward the adjacent 5-m ditch where measurements were made. The lack of symmetry about the center-line between ditches makes it difficult to adequately characterize the flow patterns with the experimental set-up employed.

Since the survival and growth of artificially reintroduced *Sphagnum* (Quinty and Rochefort 1997) rely upon an adequate moisture supply at the surface (Sagot and Rochefort 1996), water-table position is only important in that it is related to the volumetric soil moisture at the surface. The results indicate that a higher water table and generally wetter conditions contributed to a greater and more constant volumetric moisture content of the surface peat. This was further demonstrated at the control site, where distinct differences occurred in the volumetric moisture content in response to the typical harvested surface profile (Figure 2B). Where the distance of the water table to the surface is greater, the moisture deficit caused by evaporation was less apt to be re-supplied by capillary water flow upward from the water table.

An indication of the potential for capillary flow is more directly apparent in the soil water tension data (Figure 7). Matric tension was consistently least at the 5-m experimental baulk and greater at the 3- and 8-m baulk and control sites, where the water table and soil moisture were lower. At the wetter sites, water demand by surface evaporation was being more effectively met by water moving upward from the zone of saturation, which was closer to the surface. The driest surface (3-m experimental baulk) had the greatest tension gradient between the −0.2 and −0.1 m depth, suggesting that the evaporative demand was not being matched.

Sphagnum Moss Establishment Performance in Relation to the Creation of Water Reservoirs

The general objective of this project is to facilitate the establishment of *Sphagnum* diaspores by increasing the amount of water available for moss use. The results indicate that lateral water exchange between the open water reservoirs and the peat substrate did ameliorate the hydrologic conditions associated with a low water table, thereby making them more suitable for *Sphagnum* growth. *Sphagnum* establishment, with 4.5% to 6.4% cover on the 3-m and 5-m experimental baulks, was greater than the 0.5% cover usually achieved when a similar density of *Sphagnum* mosses are reintroduced on abandoned peat fields with no cover or rewetting design besides the damming of the former ditches (Rochefort *et al.* in press). When the percent covers of the experimental baulks are compared to *Sphagnum* simultaneously reintroduced with a straw mulch (Figure 8), it seems that the microclimatic variables at the peat-air interface were more important for *Sphagnum* establishment than the small differences in hydrologic conditions associated with the different experimental spacings. Thus, good rewetting of the peat improved *Sphagnum* colonization even though the study was conducted in a relatively wet year. The presence of a mulch, however, seems even more advantageous for *Sphagnum* growth. The effect of a mulch cover on microclimate variables at the peat-air interface is currently under investigation.

Rewetting Strategy

The water table, soil moisture, and soil-water-tension data indicate that the experimental baulk with a 5-m spacing provided the most suitable condition for *Sphagnum* introduction. Beets (1992) suggested that the spacing of such reservoirs should not exceed 5 m for moderately decomposed peat. Although this seems to be corroborated by our results, we are unable to attribute this difference to the actual width of the experimental baulk. We believe, rather, that the 5-m experimental baulk benefitted from the advantage of its position between the other two experimental baulks, which provided a buffering effect. Water losses away from the 3- and 8-m baulks are suggested by the convex water-table profile over the experimental site. The locally elevated water level at the 5-m experimental baulk indicates that such water losses were minimized there. Furthermore, the magnitude of water loss at the 3-m baulk was greater, as suggested by its lower elevation. Substantially lower water levels in the peat field outside the experimental area caused drainage of the outermost parts of the experimental site (i.e., the 3- and 8-m baulks). The effect was most pronounced in the 3-m experimental baulk (i.e. lower water levels than the 8-m baulk), since drainage there was in the same direction as the regional water slope.

CONCLUSION

In the context of peatland restoration, the main objective of water management strategies is to create suitable conditions for *Sphagnum* growth and survival, as it is the key plant to re-establish peat-forming ecosystems. The creation of open water reservoirs was effective in improving the hydrologic conditions of the abandoned peatland, in that water levels were raised and water-table fluctuations were minimized. The water supply was successfully replenished since precipitation and snow melt water was captured in the reservoir ditches and redistributed throughout the adjacent peat profiles. Consequently, *Sphagnum* growth was enhanced. Although rewetting has not directly addressed the problems related to the poor physical structure of the unsaturated zone (i.e., the acrotelm has not been replaced), a higher and more stable water table was ensured by the presence of open water reservoirs. In time, the improved hydrologic conditions can contribute to produce a *Sphagnum* layer that will slowly restore the surface peat's self-regulating mechanisms.

Due to the nature of the experimental design, it was impossible to determine the optimum spacing of the reservoir ditches. This will need further investigation through field experiments and modelling in order to implement realistic restoration plans for cutover peatlands.

ACKNOWLEDGMENTS

This research was financially supported by the Natural Sciences and Engineering Research Council of Canada, grant OGP0138097 to LR and grant OGP0714626 to JP. As well, a research scholarship was awarded by La Fondation de l'Association des

Femmes Diplômées des Universités du Québec to SDL. Tourbières Fafard et Frères of Ste-Marguerite-Marie, Québec made our work possible by providing unlimited access to the experimental site and by providing technical support in the field. We gratefully acknowledge Sophie Pouliot for invaluable assistance in data collection. We also thank François Quinty and Suzanne Campeau for their advice and comments.

LITERATURE CITED

Beets, C. P. 1992. The relation between the area of open water in bog remnants and storage capacity with resulting guidelines for bog restoration. p. 133–140. *In* O. M. Bragg, P. D. Hulme, H. A. P. Ingram, and R. A. Robertson (eds.) Peatland Ecosystems and Man: An Impact Assessment. British Ecological Society and The International Peat Society (publishers), Dep. of Biological Sciences, University of Dundee, UK.

Blankenburg, J. and W. Schafer. 1992. Hydrologic reaction of raised bogs to peat cutting, p. 118–124. *In* O. M. Bragg, P. D. Hulme, H. A. P. Ingram, and R. A. Robertson (eds.) Peatland Ecosystems and Man: An Impact Assessment. British Ecological Society and The International Peat Society (publishers), Dep. of Biological Sciences, University of Dundee, UK.

Eggelsmann, R. 1988. Rewetting for protection and renaturation/regeneration of peatlands after or without peat winning. p. 251–260. *In* 8th International Peat Congress, Leningrad, Russia.

Eggelsmann, R. and J. Schwaar. 1979. Regeneration, recreation and renascence of peatlands in Northwestern Germany, p. 267–272. *In* Proceedings of the International Symposium on Classification of Peat and Peatlands. Hyytiala, Finland.

Environment Canada. 1993. Canadian climate normals 1961–90. Atmospheric Environment Service, Ottawa, ON, Canada.

Ingram, H. A. P. 1978. Soil layer in mires: function and terminology. Journal of Soil Science 29:224–227.

Inoue, T., Y. Umeda, and T. Nagasawa. 1992. Some experiments restoring hydrologic conditions of peatland in Hokkaido, Japan, p. 196–203. *In* T. Younos, P. Diplas, and S. Mostaghimi (eds.) Land Reclamation: Advances in Research and Technology. Proceedings of the International Symposium. Nashville, TN, USA.

Lasalle, P. 1968. Excursion géologique du Quaternaire Saguenay Lac Saint-Jean. p. 31. *In* Contribution au Congrès de l'ACFAS. 6–7 September 1968. Ministère des richesses naturelles du Québec, Canada.

Lavoie, C. and L. Rochefort. 1996. The natural revegetation of a harvested peatland in southern Québec: A spatial and dendroecological analysis. Écoscience 3:101–111.

Mawby, F. J. 1995. Effects of damming peat cuttings on Glasson Moss Wedholme Flow, two lowland raised bogs in Northwest England, p. 349–357. *In* B. D. Wheeler, S. C. Shaw, W. Fojt, and R. A. Robertson (eds.) Restoration of Temperate Wetlands. John Wiley and Sons, Chichester, UK.

Meade, R. 1992. Some early changes following the rewetting of a vegetated cutover peatland surface at Danes Moss, Cheshire, UK, and their relevance to conservation management. Biological Conservation 61: 31–40.

Monenco Ontario Limited. 1981. Evaluation of the potential of peat in Ontario. Ontario Ministry of Natural Resources, Mineral Resources Branch, Occasional Paper No. 7. Toronto, ON, Canada.

Nick, K. J. 1984. Measures and chances of success for the regeneration of bogs after the complete industrial cutting of peat. p. 331–338. *In* Proceedings: 7th International Peat Congress. The Irish National Peat Committee and The International Peat Society, Dublin, Ireland.

Okruszko, H. 1995. Influence of hydrologic differentiation of fens on their transformation after dehydration and on possibilities for restoration. p. 113–119. *In* B. D. Wheeler, S. C. Shaw, W. Fojt, and R. A. Robertson (eds.) Restoration of Temperate Wetlands. John Wiley and Sons, Chichester, UK.

Price, J. S. 1991. Evaporation from a blanket bog in a foggy coastal environment. Boundary-Layer Meteorology 57:391–406.

Price, J. S. 1996. Hydrology and micro climate of a partly restored cutover bog, Québec. Hydrologic Processes 10:1263–1272.

Quinty, F. and L. Rochefort. 1997. Plant re-introduction on a harvested peat bog. p.133–145. *In* C. C. Trettin, M. F. Jurgensen, D.F. Grigal, M.R. Gale, and J.K. Jeglum (eds.) Northern Forested Wetlands: Ecology and Management. CRC/Lewis Publishers, Boca Raton, FL, USA.

Rochefort, L., R. Gauthier, and D. LeQuéré. 1995. Sphagnum regeneration—toward an optimisation of bog restoration. p. 423–434. *In* B. D. Wheeler, S. C. Shaw, W. Fojt, and R. A. Robertson (eds.) Restoration of Temperate Wetlands. John Wiley and Sons, Chichester, UK.

Rochefort, L., F. Quinty, and S. Campeau. 1997. Restoration of peatland vegetation: the case of damaged or completely removed acrotelm. International Peat Journal 7, in press.

Rubec, C. 1996. The status of peatland resources in Canada. p. 243–252. *In* E. Lappalainen (ed.) Global Peat Resources. International Peat Society, Jyskä, Finland.

Sagot, C. and L. Rochefort. 1996. Tolérance des sphaignes à la dessiccation. Cryptogamie, Bryologie et Lichénologie 17:171–183.

Schothorst, C. J. 1977. Subsidence of low moor peat soil in the western Netherlands. Geoderma 17:265–291.

Schouwenaars, J. M. 1988. The impact of water management upon groundwater fluctuations in a disturbed bog relict. Agricultural Water Management 14:439–449.

Schouwenaars, J. M. 1992. Hydrologic characteristics of bog relicts in the Engbertsdijksvenen after peat-cutting and rewetting, p. 125–132. *In* O. M. Bragg, P. D. Hulme, H. A. P. Ingram, and R. A. Robertson (eds.) Peatland Ecosystems and Man: An Impact Assessment. British Ecological Society and The International Peat Society, Department of Biological Sciences, University of Dundee, UK.

Schouwenaars, J. M. 1993. Hydrologic differences between bogs and bog-relicts and consequences for bog restoration. Hydrobiologia 265:217–224.

Schouwenaars, J. M. 1995. The selection of internal and external water management options for bog restoration. p. 331–346. *In* B. D. Wheeler, S. C. Shaw, W. Fojt, and R. A. Robertson (eds.) Restoration of Temperate Wetlands. John Wiley and Sons, Chichester, UK.

Vasander, H. A., A. Leivo, and T. Tanninen. 1992. Rehabilitation of a drained peatland area in the Seiseminen National Park in Southern Finland. p. 381–387. *In* O. M. Bragg, P. D. Hulme, H. A. P. Ingram, and R. A. Robertson (eds.) Peatland Ecosystems and Man: An Impact Assessment. British Ecological Society and The International Peat Society, Department of Biological Sciences, University of Dundee, UK.

Verry, E. S. 1984. Microtopography and water-table fluctuation in a *Sphagnum* mire. p. 11–31. *In* Proceedings: 7th International Peat Congress. The Irish National Peat Committee and The International Peat Society. Dublin, Ireland.

Wheeler, B. D. and S. C. Shaw. 1995. Restoration of Damaged Peatlands, HMSO, London, UK.

Manuscript received 30 September 1996; revisions received 18 April 1997 and 12 June 1997; accepted 17 June 1997.