CONCLUSION

Even under extremely dry meteorological conditions, part of the fenland can be re-wetted by inundation, even though the parameters used in the model can not be determined very accurately. Conservative estimations of these parameters, however, do not change this conclusion..

ACKNOWLEDGMENTS

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REFERENCES

AG Boden (1994) *Arbeitsgruppe Boden der Bundesanstalt f. Geowissenschaften u. Rohstoffe u. den Geol. Landesämtern in der BRD (Hrsg.)* Bodenkundliche Kartieranleitung. 4. Aufl., Hannover, in Kommiss. bei Schweizerbart'sche Verl.buchhandl., Stuttgart.

DVWK (1996) Ermittlung der Verdunstung von Land- und Wasserflächen. *DVWK- Merkblätter zur Wasserwirtschaft*, Nr **238**, Bonn, 135 S.

Mundel, G. (1982a) Untersuchungen über die Evapotranspiration von Grasland auf Grundwasserstandorten. 1. Mitteilung: Beziehungen zwischen meteorologischen Faktoren und Evapotranspiration. *Arch. Acker- u. Pflanzenbau u. Bodenkd.* **26** (8), Berlin, 507-513

Schmidt, W., (1995) Einfluß der Wiedervernässung auf physikalische Eigenschaften des Morkörpers der Freidländer Großen Wiese. Z.f. *Kulturtechnik u. Landentwicklung* **36**, 107-112

Succow M. (1988) *Landschaftsökologische Moorkunde.* Jena

Wojahn, E. and Schmidt, W. (1987) *International Symposium zum Thema „Bodenentwicklung auf Niedermoor und Konsequenzen für die landwirtschaftliche Nutzung"*, Band 1, Eberswalde

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METHODS FOR RESTORATION OF A CUTOVER PEATLAND, QUEBEC, CANADA

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SUMMARY

Drainage, then removal of the acrotelm of a bog peatland abruptly altered the hydrological regime of the cutover section of an expansive plateau bog peatland near Lac St. Jean, Quebec. Drainage in 1990 lowered the water table by about 0.5 m, causing an increase in the peat bulk density in the catotelm (residual) peat. This varied seasonally, and was 40% less in a site that was cut and drained three years later. The cutting and increase in bulk density was accompanied by a decrease in the specific yield of surface peat from greater that 0.5 to less than 0.05. Consequently, the seasonal and event based water table variations were more extreme. Blocking drainage ditches was an important first step in restoration, which resulted in a water table rise of 0.2 - 0.4 m over the drained condition. This was further improved by about 0.1 m by using passive recharge (seepage) reservoirs to re-supply the adjacent peat baulk with water following water table drawdown by evaporation. A pumped recharge (seepage) system kept the water table up to 20 cm higher than in a nearby undisturbed (natural) site. However, these and other results indicate that surface wetness is better evaluated on the basis of soil moisture and soil water tension, than with the water table. Soil moisture changes occurred without changes in the water table, when the water table was below 50 cm. Therefore retention of soil moisture was an important consideration. This was best achieved by using straw mulch, which provided greater amelioration of surface conditions than the mechanical methods noted above.

Keywords: peatland restoration, bog, hydrology, peat, restoration

INTRODUCTION

Sphagnum peat harvesting operations are an important economic activity in smaller rural locations; many of these are focused in southern and central Quebec, and eastern and northeastern New Brunswick. There are about 12,000 ha of currently harvested, or cutover and abandoned bogs in Canada (Keys, 1992). Peat cutting is a destructive process, and exhausted sites are simply abandoned. Few of these have regenerated to functional bog ecosystems (Famous *et al.,* 1991) because the disturbed hydrological and microclimatic conditions are unsuitable for *Sphagnum* regeneration. In Quebec, this has resulted in less than 10% of the area of abandoned bogs showing any *Sphagnum* regeneration (Lavoie and Rochefort, 1996). Since *Sphagnum* is the dominant peat forming vegetation, its reestablishment is a benchmark for successful restoration.

Drainage and extraction of surface peat alters the surface conditions and groundwater flow dynamics that govern the bog's relationship to the surrounding landscape (Bragg & Steiner, 1995). This alters the hydraulic and geochemical environment of the cutover peat on which *Sphagnum* re-establishment must occur (Heathwaite, 1994; Schouwenaars, 1993). Subsidence caused by shrinkage and compression (Schlotzhauer, 1998), and oxidation of the drained peat (Schothorst, 1977) alters the pore structure of the peat matrix, increasing water retention and decreasing hydraulic conductivity. Consequently, there is a decreased supply of plant-available water in the unsaturated zone (Okruszko, 1995). The problem results from the greater water tension in the surface layer of cutover peat, which can exceed –350 mb (cm) (Price, 1997). *Sphagnum* mosses, which are nonvascular plants, cannot draw moisture from the soil at these tensions. Hayward and Clymo (1982), note that pore water drains from the hyaline cells of *Sphagnum* at –100 mb (cm). The corollary of this is that water tension of the surface peat needs to be greater (less negative) than –100 mb. Otherwise the plants will desiccate, which they cannot tolerate for extended periods (Sagot and Rochefort, 1996).

The first step in restoring peatlands is to block the drainage ditches (Eggelsmann, 1988). This procedure essentially restores the water balance (Price, 1996), although not the water relations. For example, compared to natural bogs, the water table depth remains more variable, and the higher water retention decreases the soil moisture variability (Price, 1996). Soil moisture can be higher than hummock of a natural bog, but the associated water tension is also greater (Price, 1997). This is not remedied by rewetting. Therefore, additional steps are required to provide appropriate conditions for *Sphagnum* regeneration. This may include using open water reservoirs (LaRose *et al.,* 1997; Beets, 1990), reprofiling or contouring the surface (Bugnon *et al.,* 1997; Price *et al.,* 1998), or using mulch (Quinty & Rochefort, 1996; Price, 1997).

The above restoration methods have met with varying degrees of success. Therefore, the objective of this paper is to compare the success of the various restoration efforts made at a cutover peatland near Lac St. Jean, Quebec.

STUDY AREA

The study area is north of Lac Saint-Jean area of Quebec, Canada (48°47'N, 72°10'W). The average annual temperature is 1.7 °C, with average January and July temperature of -17.1 and 17.3 °C, respectively (Environment Canada 1982). Mean annual total precipitation is 906 mm (32% falling as snow). Mean annual runoff in the nearby Mistassini River is 623 mm (Environment Canada 1992). The peatland is situated on a terrace of deltaic sands in the Lac Saint-Jean lowland (Morin 1981), and is part of a 4315 ha bog-poor fen complex that can be classified as Plateau Bog (National Wetlands Working Group, 1987). The peat has accumulated over permeable sands, where a well-developed iron pan limits seepage losses (Price, 1996).

A portion of the peatland was drained, beginning in 1990. The upper 0.35 to 0.6 m (acrotelm) was block-cut in 1991 with heavy machinery. Ditches (30 m spacing) were blocked in spring 1993, but were not back-filled. On this section of bog were four experimental areas for which data were collected in 1995, along with data from an adjacent undisturbed site. The restoration sites include: 1) A control site which in which ditches were blocked in spring 1993 but with no other management (blocked site)(Price, 1996); 2) a site in which there were four unconnected 20 m long parallel ditch/reservoirs spaced 5 m apart, to increase the proportion of open water, with the intention of increasing passive lateral recharge (passive recharge site) (LaRose *et al.,* 1997); and 3) a seepage reservoir with pumped recharge to enhance lateral seepage to an adjacent peat field (Rochefort and Quinty, 1996)(pumped recharge site). A second area was also studied, which was drained in 1993, and cut in 1994. Ditches were not blocked (drained site). The cutover sites remain essentially devoid of vegetation. The section of natural bog is dominated by *Sphagnum fuscum, S. angustifolium, S. magellanicum, and S. capillifolium. Sphagnum* hummocks are typically 0.3 m above the *Sphagnum* lawn. There is a sparse cover of *Larix laricina* and *Picea mariana.*

METHODS

Results are reported for 1995. Details of the methods can be found in previous articles by (Price, 1996; Price, 1997; Price *et al.,* 1998; Rochefort & Quinty, 1996; LaRose *et al.,* 1997). In general, water tables were measured with transects of 25 mm dia. wells; rain with a tipping bucket; evaporation with the Priestley and Taylor (1972) method; soil moisture gravimetrically; and tension with tensiometers and a mobile pressure transducer.

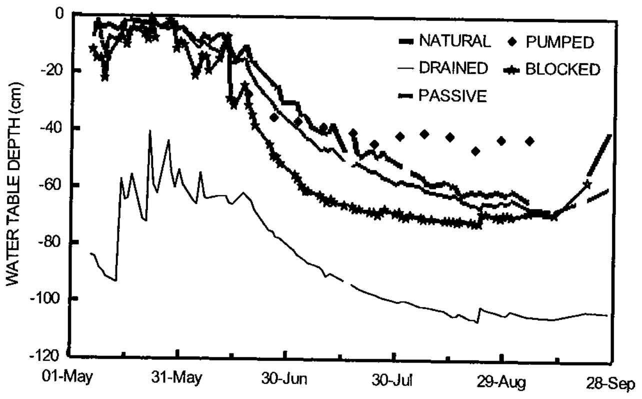

Fig. 1 Water table depth at the natural (undisturbed), drained, drained but with ditches blocked, passive seepage and pumped seepage sites, in 1995.

Fig. 2 Peat dam used to block drainage ditches

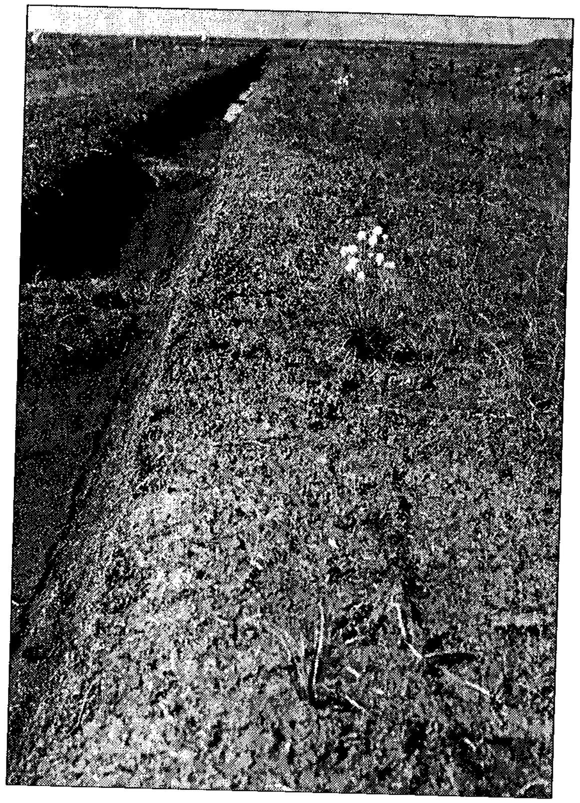

Fig. 3 Blocked drainage ditch later in the summer.

RESULTS AND DISCUSSION

Removal of the acrotelm, and collapse of the peat structure, caused the specific yield of the surface of the cutover bog to decrease from about 0.5 to 0.05. Consequently, the water table drop for an equivalent abstraction of water increased markedly. In the spring of 1995 the water table in the drained and blocked sites was particularly variable, and its elevation was lower than at the natural site Fig. 1. Daily seepage losses from the drained site were responsible for the significantly lower water table than occurred in the site with the drainage ditches blocked (Fig. 1). The efficacy of the peat dams is verified by the relatively high hydraulic gradients they can withstand (~1 m/m), as shown in Fig. 2.

Water table levels in the passive and pumped seepage experiments were raised considerably (Fig. 1). In the passive recharge system, the water table was generally within 10 cm of the natural site, but always lower. The ditch/reservoir at the passive recharge system were fully recharged following snowmelt. Since the specific yield of open water is unity, its water level changes are conservative. Therefore, in response to the large water deficit incurred over the 1995 summer, it dropped much more slowly than the water table in the adjacent peat fields. The result was a hydraulic gradient between ditch/reservoir and peat field that was dominantly toward the peat field. Consequently, the seepage that resulted raised the water table in the adjacent peat field. This is really no different than the hydrological setting of the blocked site, except in scale. The distance separating ditch/reservoirs in the passive recharge experiment was only 5 m, and the ditches were wider and deeper. At the blocked site, the ditches were also recharged in spring, but they have a much smaller volume (per metre of ditch length), and are spaced 30 m apart. The larger volume of water lost to evaporation from the blocked site (similar rate but larger surface area), quickly depleted water from the blocked ditches, and summer rainfall could not recharge them (Fig. 3).

In the pumped recharge experiment, water was pumped from a basin excavated into the peat, along

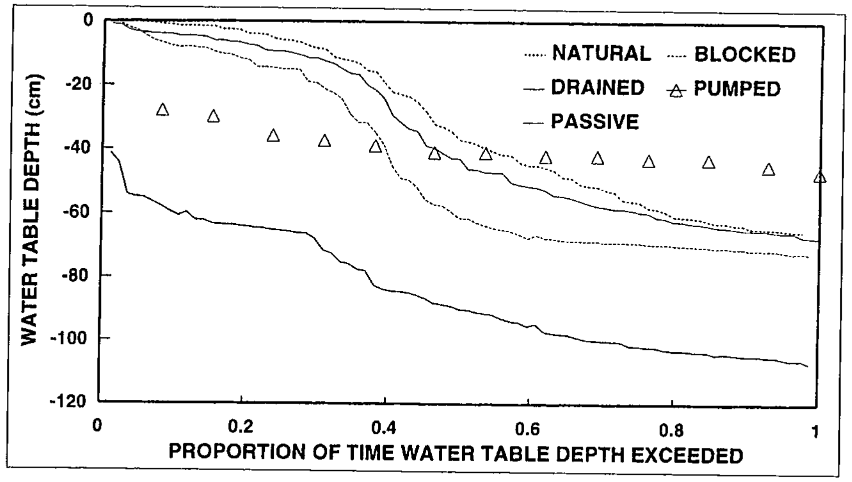

Fig. 4 Duration curves of water table depth for the natural (undisturbed), drained, drained but with ditches blocked, passive seepage and pumped seepage sites.

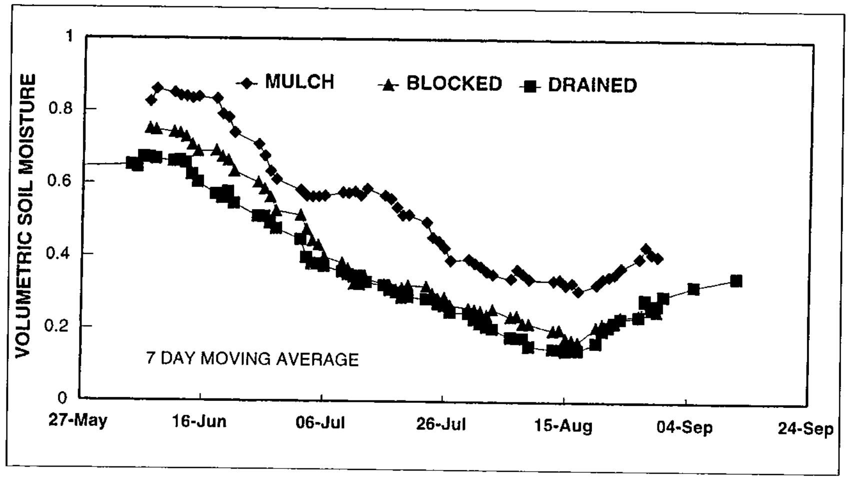

Fig. 5 Volumetric soil moisture (7 day moving average) at the drained and blocked sites, and at a blocked site with straw mulch.

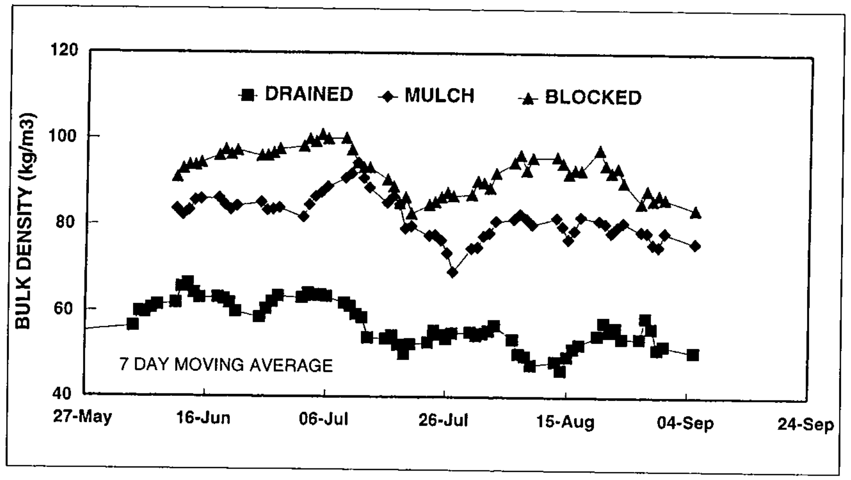

Fig. 6 Soil bulk density (7 day moving average)at the drained and blocked sites, and where a mulch was used. The drained site was more recently drained than the other sites, thus has not suffered the same degree of compaction.

the path of a main (active) drainage ditch, and was pumped over 300 m to the site. The pump was operated approximately every second day, such that the water level in the reservoir was raised to within 5 cm of the top of the ditch. Clearly, the seepage was effective at maintaining a high water table in the peat, 3 m from the peat/reservoir boundary. A water table (measured 3 m from the reservoir) could generally be maintained at about 40 cm from the peat surface, which is what was recommended by (Schouwenaars, 1988), as a requirement for restoration. The ability of the water table to be maintained above this level at this site was approximately 80% (Fig. 4), whereas for the natural site, passive seepage system, blocked and drained sites the equivalent values were 55, 50, 40 and 0%, respectively.

As noted in the introduction, an important consideration for *Sphagnum* regeneration is that the surface conditions are moist enough to keep water tension below about −100 mb. The position of water table was not a good indicator of this. In Fig. 1 it can be seen that the variability of the water table diminished after the water table depth dropped below about 60 cm. Thereafter, water losses to evaporation (381 mm from May to August), came from the zone above the water table. In the drained site, groundwater seepage losses continued, but the short-term response to episodic inputs is not visible. The evaporation loss (avg. 3.1 mm d^{-1}) caused little further drop in the water table where the ditch was blocked, which suggests the losses were supplied exclusively from the soil moisture store (i.e. above the water table). Soil moisture changes can offer a considerable quantity of water over the range observed (Fig. 5). This is amplified by the shrinkage of the peat that occurred above the water table, which caused fluctuations in the soil bulk density (Fig. 6). Soil moisture changes in a shrinking soil represent a grater quantity of water than similar changes in a soil of constant volume. The seasonal average soil moisture of the drained and blocked sites, is shown in Table 1, along with values from a blocked site with a straw mulch applied (2250 kg ha^{-1}). Soil water tension is also shown. Soil moisture was similar at the drained and blocked sites, although tension was greater at the blocked site. This is a consequence of the greater soil bulk density at the blocked site (Fig. 6), which was cut and harvested three years prior to the drained site, and likely suffered from more vehicle traffic. The seasonal average bulk density at the drained and blocked sites was 55.7±11.1 and 92.1±10.7, respectively. The result is a smaller pore diameter at the blocked site, and for an equivalent loss of moisture, the smaller pores will achieve a greater reduction in pressure. Also significant, is the considerable reduction in soil tension (less negative value) where straw mulch was used. The additional water resulted in a lower bulk density of 81.7±11.2. Without any expensive surface manipulations, mulch provided better conditions than the passive seepage experiment.

Table 1. Average±standard deviation of volumetric soil moisture and water tension measured in the top 3 cm of the cutover peat soil in 1995.

LOCATION	Soil Moisture (%)	Tension Head (mb)
Drained	0.40±.20	-129.5±44.2
Blocked	0.40±0.20	-152.5±82.9
Passive Rech.	-	-90±40
Pumped Rech.	0.44±.07*	-
Mulch	0.53±.19	-47±25.4

* Measured 3 m from ditch. Comparable values 1 and 5 m from the ditch are 0.58±.11 and 0.34±.07.

CONCLUSIONS

1. Blocking drainage ditches improved water retention on-site, but by itself did not adequately rewet the surface to provide good growing conditions for *Sphagnum* mosses.
2. A passive recharge system increased the seasonal water storage, and considerably improved the surface hydrological conditions, keeping the soil water tension within a more acceptable range.
3. The pumped recharge system was more effective than the passive recharge system in raising the water table. Soil moisture was also higher. There were no data, but the water tension there was almost certainly better (less) than in the passive recharge system.
4. Bulk density of the peat strongly affected the water tension. Greater tension (and bulk density) occurred where the peat had been cut and drained for an additional three years. Thus, restoration work should begin as soon as possible.
5. Straw mulch provided surface conditions better than the (passive) recharge system. Given the cost and disruption caused by excavation of the recharge systems, and the pumping costs of the pumped recharge system, there seem to be little advantage to these mechanical approaches.

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REFERENCES

Beets, C.P. (1990) The relation between the area of open water in bog remnants and storage capacity with resulting guidelines for bog restoration. In: *Peatland Ecosystems and Man: An Impact Assessment.* Bragg,O.M, Hulme,P.D., Ingram,H.A.P., Robertson,R.A. (eds.), Dept. of Biological Sciences, University of Dundee, Dundee, UK, 133-140.

Bragg, O. and Steiner, G.M. (1995) Applying groundwater mound theory to bog mangement on Puergschachenmoos in Austria. *Gunneria*, **70:** 83-96.

Bugnon, J.-L., Rochefort, L. and Price, J.S. (1997) Field experiment of *Sphagnum* reintroduction on a dry abandoned peatland in eastern Canada. *Wetlands*, **17**: 513-517.

Eggelsmann, R.R.F. (1988) Rewetting for protection and renaturation/regeneration of peatland after or withouth peat winning, *Proceedings of the 8th International Peat Congress*, 251-260.

Environment Canada, 1992. *Historical Streamflow Summary*, Quebec. Water Survey of Canada, Ottawa, 526 p.

Famous, N.C., Spencer,M., Nilsson,H. (1991) *Revegetation patterns in harvested peatlands in central and eastern North America*, D. N. Grubich, and T. J. Malterer (eds.) 48-66.

Hayward, P.M. and Clymo, R.S. (1982) Profiles of water content and pore size in *Sphagnum* peat and their relation to peat bog ecology. *Proc.R.Soc.Lond.*, **B215**: 299-325.

Heathwaite, A.L. (1994) Hydrological management of a cutover peatland. *Hydrological Process*, **8**: 245-262.

Keys, D. (1992) *Canadian Peat Harvesting and the Environment, Report No.1992-93*, North American Wetlands Conservation Council, Ottawa, Ont.), 29 p.

LaRose, S., Price, J.S. and Rochefort, L. (1996) Rewetting of a cutover peatland. Hydrological Assessment. *Wetlands*, **17**, 416-423.

Lavoie, C. and Rochefort, L. (1996) The natural vegetation of a harvested peatland in southern Quebec: A spatial and dendroecological analysis. *Ecoscience*, **3**:101 - 111.

Morin, G. 1981. *Atlas Régional du Saguenay-Lac-Saint-Jean.* Les Laboratoires de Géographie de L'université du Québec a Chicoutimi.

National Wetlands Working Group (1987) The Canadian Wetland Classification System, Environment Canada, 18 p.

Okruszko, H., 1995. Influence of hydrological differentiation of fens on their transformation after dehydration and on possibilities for restoration. In Wheeler, D, Shaw, S.C., Fojt, W.J., and Robertson, R.A. (Eds.), *Restoration of Temperate Wetlands*, John Wiley and Sons, Chichester, 113-120.

Price, J.S. (1996) Hydrology and microclimate of a partly restored cutover bog, Quebec. *Hydrological Processes*, **10**: 1263-1272.

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

Price, J.S., Rochefort, L., and Quinty, F. (1998) Energy and moisture considerations on cutover peatlands: Surface microtopography, mulch cover and *Sphagnum* regeneration. *Ecological Engineering*, in press.

Priestley, C.H.B. and R.J. Taylor, 1972. On the assessment of surface heat flux and evaporation using large scale parameters. *Mon. Weather Rev.*, **100**: 81-92.

Quinty, F. and Rochefort, L. (1996) *Plant reintroduction on a harvested peat bog*, CRC/Lewis Publishers, Boca Raton, FL, 133-145.

Rochefort, L., and Quinty, F. (1996) *La Restauration des tourbières exploitées: Le développement d'une stratégie intégrée au Québec*: Rapport Final. Université Laval, Québec, 119 pp.

Sagot, C. and Rochefort, L. (1996) Tolèrance des sphaignes a la dessiccation. *Cryptogamie* **17**, 171-183.

Schlotzhauer, S.M. (1998) *Modeling Soil Water Dynamics in Cutover Peat Fileds, Quebec: A Peat-Ditch Recharge System*, M.E.S. Thesis, Department of Geography, University of Waterloo, Waterloo, Ontario, 77 pp.

Schothorst, C.J. (1977) Subsidence of low moor peat soil in the western Netherlands. *geoderma*, **17**: 265-291.

Schouwenaars, J.M. (1988) Hydrological research in disturbed bogs and its role in decisions on water management in the Netherlands, *Proc. Int. Symp. on the Hydrology of Wetlands in Temperate and Cold Regions*, Joensuu, Finland, 170-177.

Schouwenaars, J.M. (1993) Hydrological differences between bogs and bog-relicts and consequences for bog restoration. *Hydrobiologia*, **265**: 217-244.

DEVELOPMENT OF DESIGN STANDARDS FOR SEDIMENTATION BASINS

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SUMMARY

Three experimental sedimentation basins were constructed on a peat mining site located on Lamèque Island, New Brunswick, Canada. The sedimentation basins were monitored over a period of fifteen consecutive months. Field data collected included precipitation, stream-flow, suspended solids, acidity and the rate at which peat accumulated in the basins. Peat sediment accumulation in the three sedimentation basins averaged 43 $m^3/ha/a$. A basin capacity of 25 m^3 per hectare of mined area appears adequate to keep the level of suspended solids below the 25 mg/L regulatory limit.

Keywords: peat, silt, sedimentation, basins

INTRODUCTION

Much of the peat mined in New Brunswick comes from the Acadian Peninsula, a low-lying headland that projects northeasterly into the Gulf of St. Lawrence (Fig. 1). The coastline of that area is characterized by shallow marine bays and lagoons commonly enclosed by sand spits and barrier beaches. Rising sea levels and rapid erosion of the land, produce peat cliffs along many kilometres of shoreline. The natural introduction of peat particles in the marine environment that results from the gradual retreat of peat cliffs is generally not considered a problem because peat particles on an open coast are rapidly dispersed by waves and currents. The situation can however be quite different in the case of drainage from peat mining operations where silt-laden waters collected over a large surface area are discharged through single exit points, at the head of a small estuary or into a protected embayment. In these situations, excessive peat sedimentation may quickly lead to local deterioration of marine habitat.

In 1990, the New Brunswick Department of Natural Resources and Energy initiated a series of field studies aimed at establishing standards for sedimentation basins used in association with peat mining operations. An initial study was conducted to establish the basic hydrological character of the peatlands in the area and to develop a theoretical model from which sedimentation basin standards could be derived (Gemtec Limited, 1991). The present paper summarizes the result of the field monitoring exercise that led to the development of design standards.

MATERIALS AND METHODS

The study site

Peatland 567 is a small commercially mined peatland located at the northern extremity of Lamèque Island (Fig. 1). It consists of a strongly domed ombrotrophic sphagnum bog of about 100 ha in surface area and approximately 7.5 m thick in its centre. It is underlain by discontinuous silty sands and glacial till overlying horizontally bedded sandstone bedrock (Gemtec Limited, 1993). Average humification of the peat is 4 on the von Post scale. Natural drainage is northwest and northeast into Miscou Harbour. The climate of northeastern New Brunswick is mid-latitude continental with an annual precipitation of about 1 000 mm of which 280 mm occurs between November and April as snowfall (Fig. 2). Mean monthly temperatures vary from -11°C in February to 20°C in August.