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RESTORATION STRATEGIES FOR BLOCK CUT PEATLANDS : A HYDROLOGICAL AND PLANT COMMUNITY ANALYSIS

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ABSTRACT

Typical bog species naturally return to block cut peatlands after abandonment; however, they have a distinctly low level of *Sphagnum* cover. The objective of this study was to develop restoration strategies for the bryophyte community of these peatlands. We conducted two experiments to fulfill this objective: 1) modification of the hydrology through the creation of peat dams and 2) plant inventories and characterization of the rate of return of *Sphagnum* in a site dammed 6 years ago. The primary ditch dam positively affected the hydrology of the site. Water tables were higher (+10 to 15 cm) and soil tension lower within an area that extended between 30 and 150 m from the main ditch blockage. The effects of the secondary trench dams did not significantly enhance rewetting during the experiment. *Sphagnum* frequency increased to over 30% on portions of a second site which had been blocked for 6 years.

Les tourbières anciennement exploitées par la méthode de coupe par bloc peuvent être recolonisées par des espèces typiques des tourbières naturelles (bogs). Cependant, le couvert en sphaignes est beaucoup plus bas que dans les bogs, parfois même absent. L'objectif de cette étude était de développer des stratégies pour restaurer les communautés de bryophytes dans ce genre d'écosystème perturbé. Pour répondre à cet objectif, deux approches ont été utilisées : 1) la modification de l'hydrologie par le blocage des canaux de drainage (principaux et secondaires); 2) par l'inventaire floristique et la caractérisation du taux de recolonisation par les sphaignes d'un site remouillé depuis cinq ans. Le blocage des canaux de drainage secondaires n'a pas eu d'effet significatif. En fait, seul le blocage du canal principal a eu un impact sur l'hydrologie du site. La nappe phréatique était plus élevée (de 10 à 15 cm) et la tension du sol plus faible à l'intérieur d'une superficie s'étendant entre 30 et 150 m du blocage principal. Cette superficie « effective » (où le blocage a un impact sur l'hydrologie locale) est confirmée par la réponse de la végétation dans le site où les canaux de drainage principaux ont été bloqués depuis 5 ans.

1.0 GENERAL INTRODUCTION

Block cut peatlands show signs of positive regeneration, both in terms of vegetation cover and presence of typical bog species (Girard, 2000). The return of *Sphagnum* mosses is less successful and limited to secondary ditches, depressions and locations not exceeding known hydrological thresholds for their survival (Price and Whitehead, 2001). Functionally, within a bog ecosystem, *Sphagnum* sits at the center of a series of feedbacks that direct regeneration towards increased *Sphagnum* growth and the accumulation of peat (van Breemen, 1995). This thesis describes attempts to modify the hydrology of block cut peatlands to increase the area suitable for *Sphagnum* growth with the goal to restore the bryophyte dominated community typical of natural peatlands. By extension, this approach should help to restore carbon sequestration function of block cut peatlands by starting feedback mechanisms that would lead to peat accumulation.

Ecosystem restoration has at its core a problem of definitions. The two words that comprise this discipline are themselves difficult to define. Ecosystems can be defined by both the area that is bounded by similar biotic and abiotic features and as well by the interactions of those features (Erhenfeld and Toth, 1997). Restoration is defined as the bringing back to a former position or condition. Since ecosystems are themselves evolving systems, it presents the problem of attempting to restore to a former condition something whose conditions change and is without an original state – in all practical terms.

The Society for Ecological Restoration defines ecosystem restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2002). This definition works on an abstract level but fails to provide enough rigor to serve as a working goal.

Several questions quickly show why a more specific definition is required: Does re-vegetation of any kind on a highly disturbed site qualify?; Which is more important, dominant species that typify an ecosystem or rare species that do the same?; and are there functions (nutrient transfers, hydrology, physical structure) that are requisite for an ecosystem to be considered recovered? In practice, each attempt to restore ecosystems or gain further knowledge through the research of ecosystem restoration must narrow the general statements that typically define ecosystem restoration.

In general, restoration attempts work on one of three levels: populations (species specific), communities, and ecosystem function (Erhenfeld, 2000). In the case of peatlands there is a strong intersection of the three levels. Population specific restoration efforts focus on a key species and re-introduce the habitats and requirements of that species. These projects recognize the central role of that species, either in their historic contribution to defining the ecosystem or the role of these specific species in shaping the ecosystem on a disproportionately high level. Restoration activities aimed at populations typically are focused on animal species and often fall under the activities of conservation biology (Urbanska, 2000). Community level restorations typically focus on the plant community with the implicit assumption that returning the community to a state similar to the original natural ecosystem will provide much of the habitat required of the key species typically focused on in population specific projects. The third scenario attempts to restore the ecological function of ecosystems such as energy and nutrient transfers, hydrological regimes and in the case of peatlands accumulation of carbon.

1.1 *Sphagnum's* Role in Peatland Restoration

An understanding of the biology of *Sphagnum* and the interactions within a natural peatland help to illustrate the point that there is strong convergence of the three levels of ecological restoration when dealing with peatlands. Peatland restoration in eastern North America has been defined as the return of *Sphagnum* mosses (or brown mosses in the case of fens) and associated diplotelmic function (Rochefort, 2000). This definition works well because *Sphagnum* as a genus sits at the center of feedback mechanisms that favour its growth and hinder vascular species growth - once established (van Breemen, 1995). A brief synopsis of these interactions add great clarity to the assumption that bog restoration without the return of *Sphagnum* is not bog restoration (Figure 1.1).

Sphagnum growth and its biological, physical and chemical properties have three main effects: the release of polyuronic acids, efficient nutrient interception and slowly decomposing fibers. These in turn increase acidity, decrease nutrient availability and form peat, respectively (van Breemen, 1995). High acidity and low nutrient availability decrease vascular plant growth. Slowly decaying and low permeability peat creates water saturation anoxia which further depresses vascular growth. The resulting decrease in vascular plant growth increases available light for *Sphagnum* and decreases transpiration that further increases the position of the water table. These factors improve *Sphagnum* growth, starting the feedback cycle (van Breemen, 1995).

1.2 Limiting Factors to *Sphagnum* Establishment

Having defined the return of *Sphagnum* and the associated hydrological regime as the goal of peatland restoration, it is now instructive to examine known obstacles to natural peatland

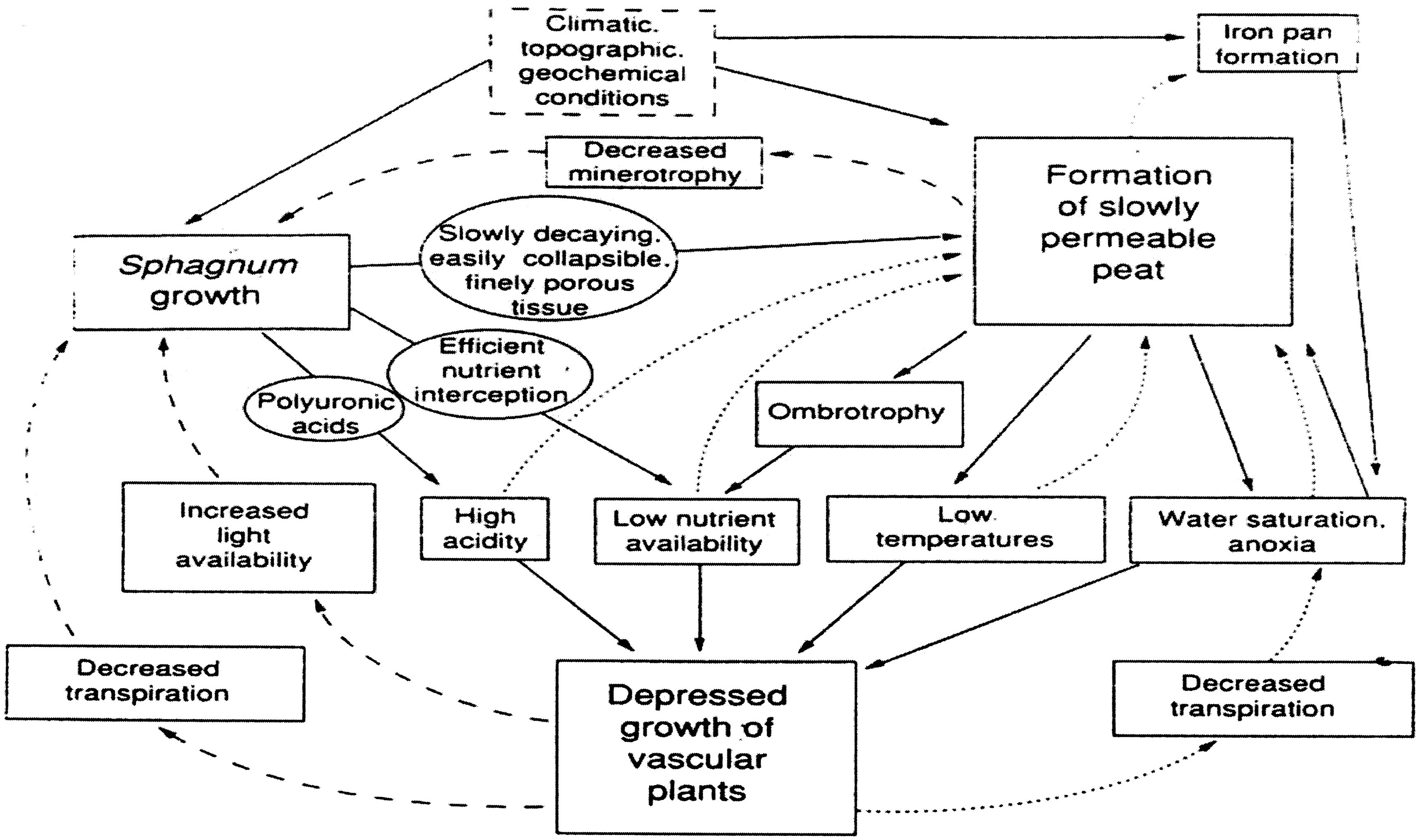


Figure 1.1 Sphagnum feedback processes from van Breemen, 1995.

regeneration. Current peat extraction practices begin with the removal and transport of the living layer off site. This introduces the first hurdle to natural peatland regeneration as it has been shown that many peatland species do not have strong wind transportability of their seeds (Campbell *et al.*, 2003, Poschold, 1995). Moreover, natural remnants left aside the mined area are small and linear, which does not favour natural recolonization from diaspores. In the case of *Sphagnum* mosses, vegetative reproduction is an important life strategy, responsible for most of expansion on a site and quite impossible if the living tissue is removed (Cronberg, 1991). After removal of the living layer, the second hurdle is introduced; the peatland is drained and harrowed for drying. This action has two effects shown to negatively affect *Sphagnum* and other peatland plants ability to grow: it lowers the water table and increases the surface soil water tension (Price, 1996, Price, 1997). After abandonment, the surface degrades further through the action of peat oxidation (Waddington & McNeil, 2002) that not only releases carbon to the atmosphere but also modifies the physical structure of the peat surface and further impedes seed germination success. In the event a seed is able to travel from its source, germinate on dry and oxidized conditions of the abandoned site, it still faces more obstacles. Blowing peat from actively extracted nearby sites has the potential to prevent growth if a wind storm or cumulative wind events re-deposits more than of 30 mm of peat (Faubert & Rochefort, 2002). If the newly emerging *Sphagnum* survives everything mentioned above, it must still live through the powerful action of frost heaving until it is more firmly anchored (Groeneveld & Rochefort, 2002).

The long list of obstacles to natural peatland regeneration in abandoned vacuum harvested sites stands in sharp contrast to the rather short list for block cut peatlands. Block cut peatlands have a characteristic topography that consists of alternating raised baulks, that are typically 2m wide, and low trenches that range from 6-15m wide (Desrochers *et al.* 1998). The process of block cutting is explained in greater detail in section 2.1, in brief, cutting did not transport the living material great distances nor did it drain the ditches to the same degree as current vacuum extraction methods. The quantity of exposed peat was much less, resulting in less peat to blow around and bury newly establishing plants. Further, it left a varied topography of baulks and trenches which introduced greater variability in the hydrological regime (Price *et al*, 2003). So while the majority of the site is unsuitable in terms of hydrology, block cut peatlands contain a few areas where the hydrological regime is suitable for *Sphagnum* recolonisation. As a result of these factors, vegetation re-growth on block cut bogs was often quick and successful. This quick regeneration further reduced oxidation and frost heaving making conditions more favourable for re-growth.

1.3 Post Extraction Communities

The results of these different peat extraction histories are telling. Botanical surveys of post-extracted sites have been conducted on both vacuum and block cut sites in Quebec (Lavoie and Rochefort, 1996, Desrochers *et al.*, 1998, Girard *et al.*, 2002). We see that in vacuum harvested sites there is often less than 10% vegetative cover nine years after abandonment, plant species that are found in these abandoned sites are not typically found in natural bogs and there is an almost complete absence of *Sphagnum* and other mosses (Bérubé and Lavoie, 2000). On block cut sites there is often full vegetative cover of species found are typical of natural bog assemblages after 3 to 6 years of abandonment, but there remains a conspicuous near absence of *Sphagnum*. In light of this genus' ability to engineer peat formation and its central role at the series of feedbacks outlined above (van Breemen, 1995), a bog without *Sphagnum* is in need of restoration.

1.4 Why Restore?

It has been noted that peatland extraction is occurring on a rather small percentage of the area of natural peatlands in Quebec and Canada. Approximately 11,000 ha have been utilized in Quebec and New Brunswick, which represent 0.3% of the total area of peatland in these provinces (Desrochers *et al.* , 2000) yet these areas of extraction are localized. In the Lower St. Lawrence region of Quebec, the area of this study, only 23% of the original peatlands remain untouched (Pellerin and Lavoie, 2000). Spontaneous bog regeneration has only been documented in very specific area of block cut peatlands. Natural re-growth of *Sphagnum* has been demonstrated in very wet climates (Joosten, 1995), low drainage points (Lavoie *et al.*, 2003) and near old drainage ditches (Price and Whitehead, 2001). Most block cut peatlands show signs of natural re-vegetation 5 to 30 years after abandonment, but most do not show signs of the return of *Sphagnum* dominance. It has been predicted without intervention *Sphagnum* dominance would be a long term proposition, if it were to occur at all (Joosten, 1995). Block cut peatland restoration aims to accelerate *Sphagnum* and dominance on these sites.

1.5 Carbon

Restoration of peatlands takes on a functional importance in addition to the restoration of plant biodiversity and community assemblages lost in the extraction process. It has been estimated that there are 455 $\times 10^{15}$ grams of carbon stored in the northern peatlands (Gorham, 1991), and *Sphagnum* is thought to incorporate a greater amount of carbon than any other plant genus (Hayward and Clymo, 1982). Annually, natural bogs store 29 grams of carbon per square metre or 0.29 tonnes per hectare (Gorham, 1991). While peatlands represent a large pool of terrestrial carbon, not all peatlands are carbon sinks. Conventional models of peat accumulation predict that most peatlands will become carbon neutral at the point where productivity at the surface is offset by decomposition through the peat column (Clymo, 1984). Recent work modelling peatlands development suggest that individual peatland systems can be carbon neutral at their climax, but also shift between carbon sinks and carbon sources depending on changes in the water regime (Hilbert *et al.* 2000). Removal of the living layer and drainage required for extraction change peatlands from either carbon sinks to carbon sources or increases the rate of efflux from peatlands that are naturally carbon sources (Waddington and Price, 2000, Waddington and Warner, 2001). If restoration actions can quickly re-instate a *Sphagnum* dominated ecosystem with associated carpet, it could lead to a change in site conditions from a source to a sink. However, carbon budgets cannot ignore methane, and it is recognized that a flooded peatland, even with the return of *Sphagnum,* may not return to a sink condition if methane rates increase dramatically (Strack *et al.*, 2003). While these systems have not yet demonstrated the full conversion from carbon source back to carbon sink, the prevention of the loss through oxidation and re-establishment of a plant regime on these surfaces is beneficial in slowing carbon loss.

1.6 Flooding

The diplotelmic layering of natural peatlands, physical structure of living and dead *Sphagnum* and physical shape of natural peatlands maintain a water table near the surface of the peatland but also quickly remove surface water (Ingram, 1978). Once this layering is destroyed in the process of extraction, a peatland is often left with the situation of too little water (water table deeper than 40 cm) or too much (surface flooding). It is well documented that too little water is detrimental to *Sphagnum* growth with the lack of water cited as the primary reason for the inability of sites to spontaneously restore (Meade, 1992, Poelman and Joosten, 1995). Further, under artificially controlled situations that mimic the diplotelmic layering found in nature *Sphagnum* can responds very quickly: in a greenhouse experiment, a 50% *Sphagnum* cover was established in 3 months and a full cover in 6 months after 10% of the surface area was covered in *Sphagnum* diaspores (Campeau and Rochefort, 1996). Year round saturated conditions or shallow inundation has been identified as the optimal condition for Sphagnum growth (Wheeler and Shaw, 1995) Shallow inundation in a Finnish cutover peatland resulted in increased typical bog species, particularly *Eriophorum* vaginatum and *Carex rostrata* (Tuittila *et al.*, 2000). *Sphagnum russowii* in this study increased from less than 0.1% to 4.7% mean cover within four years of rewetting. Restoration efforts in the Netherlands recognized that flooding greater than 50cm could be potentially limiting to Sphagnum growth and utilized floating peat rafts as a means to overcome the flooding concerns (Tommasen *et al.* 2003). A review of experiments on the restoration of cut-over bogs in Germany found similar results, long-contniuous flooding can be favourable to the growth of several species of *Sphagnum*, including some hummock species (Sliva and Pfadenhauer, 1999). In addition, it was determined that a mix of hummock and hollow species would provide the best chance for restoration, given the variable water table that is present on sites in the absence of an acrotelm. Some questions remain, is flooding a viable option?; is it necessary to recreate the diplotelmic hydrology prior to successful *Sphagnum* establishment?

Road construction caused large scale flooding in a black spruce swamp peatland, with a corresponding rise in water table of 55 cm (Jeglum, 1975). Vegetative studies of the area 23 years after flooding found that the area of increased water table had changed to a *Sphagnum* dominated open bog ecosystem while the adjacent drier area remained a forested swamp. In a second study, long term flooding as a result of the construction of a beaver dam in a forested wetland caused a change of the area to a *Sphagnum* dominated ecosystem (Mitchell and Niering, 1993). After flooding caused by the beaver dam, three main community changes were noted: a sharp decrease in tree cover, a change in the composition of shrub cover, including a seven fold increase in *Chamaedaphne calyculata* and the appearance of *Kalmia polifolia*, and an increase in *Sphagnum* from under 30% to over 90% cover. These examples demonstrate community level changes on the order of years to decades, from forested wetlands to bog dominated communities with a sudden flooding in natural systems. Recent work on degraded peatlands found that flooding of up to 1 month was not detrimental to *Sphagnum* growth and that even Sphagnum exposed to flooding produced more capitula than non-flooded fragments in their regenerative phase (Rochefort *et al.*, 2002).

1.7 Non-Flooding Methods for Rewetting

The five main forms of water management for restoration as detailed in Price *et al.* 2003 include: blocking ditches; bunds and terracing; establishing hydrological buffer zones; surface reconfiguration and reducing evaporative losses. In block cut sites, non-flooding methods that have been examined include the creation of open water (Beets, 1992) and the use of water management techniques external to the site (Schouwenaars, 1995). Open water techniques attempt to limit groundwater fluctuations by increasing the overall storage capacity of water of the site. Since in an abandoned bog the upper layers with higher specific yield are typically absent, the effects of evaporation and drainage on the water table become more pronounced. There are two possible ways to counteract this influence, reduce evapotranspiration or increase the specific yield of the site. With a specific yield of ~0.2, 1 mm of evapotranspiration results in a 5 mm drop in water table. Once this number reached 0.05, which may occur 3 years after being exposed (Price, 1996), the same 1 mm of evapotranspiration would cause a 20 mm drop in water table. In examining the effectiveness of open ditches for draining peatlands, a relationship between peat decomposition and extent of drainage was quantified. For medium to highly decomposed peat, drains were effective for 5 m, while in less decomposed, more permeable fibrous peat they can be effective for up to 50 m (Boelter, 1972). Beets (1992) attempted to quantify this relationship in terms of minimizing water losses in peatlands and found that to minimize groundwater fluctuations, the spacing of open water zones should be less than 5 m for moderately to strongly decomposed peat. Further, these open water surfaces should be greater than 50 cm deep and should have a maximum length of 20 m. A later study employed the creation of open water reservoirs as a means to improve the hydrological conditions on a site specifically for the reintroduction of *Sphagnum* (LaRose *et al.*, 1997). This experiment demonstrated improved hydrological conditions in the presence of open water reservoirs in water table position, volumetric moisture content and surface soil tension.

1.8 Study Objectives

The objectives of this study were to promote shallow flooding in a block cut peatland through the creation of small peat dams in the minor trenches as a means of improving the conditions for *Shagnum* colonization and to analyze the vegetation changes that occurred in a block cut peatland that had been flooded by a dam in the major trench. It sets out with two key questions: does small scale blocking of the secondary or primary ditches positively affect hydrological conditions in block cut peatlands?; and what are the plant community changes in a flooded block cut peatland 6 years after flooding? These questions are based on the definition of bog restoration as the return of *Sphagnum* dominance and the return of diplotelmic layering (Rochefort, 2000) and an understanding that water is the key limiting factor to *Sphagnum* growth in block cut peatlands.

This thesis comprises two main chapters corresponding to two separate experiments. Chapter 3 details the hydrological responses of a block cut peatland to small ditch dams. These dams were constructed as an attempt to re-distribute water and increase the area of the peatland suitable for *Sphagnum* growth. Chapter 4 examined the plant community response to restoration flooding in a nearby peatland. Botanical surveys were completed in 1995, prior to an attempt to restore a block cut site by flooding in 1995. Six years later, a survey was conducted on the same area using the same methods and comparisons of the plant communities to the 1995 data were made. Chapter 2 provides details on the location and topography found in the block cut sites studied. Chapters 5 and 6 are general discussion and conclusions, respectively. The short term information gathered by the hydrological study was integrated with the longer term trends of the plant surveys to develop strategies for block cut restoration.

2.0 STUDY SITES

The experiments described below took place at three nearby sites (within 100 m of each other) which are all part of the Rivière-du-Loup peatland and are now known as the St. Laurent section of peatlands industrial activities. Located on the southern edge of the town of Rivière-du-Loup, this peatland can be found at 47° 48' N, 69° W. Peatlands in the Rivière-du-Loup area have lost 62% of their surface area due to anthropogenic influences since 1920 (Pellerin, 2003). Activities that have impacted peatlands include forestry, drainage for farming, road construction and peat extraction for horticultural products. It has been harvested through both the block cutting method and the vacuum milling method. These experiments focus on areas that were harvested using the block cutting method. Exact site locations are provided in Figure 2.1.

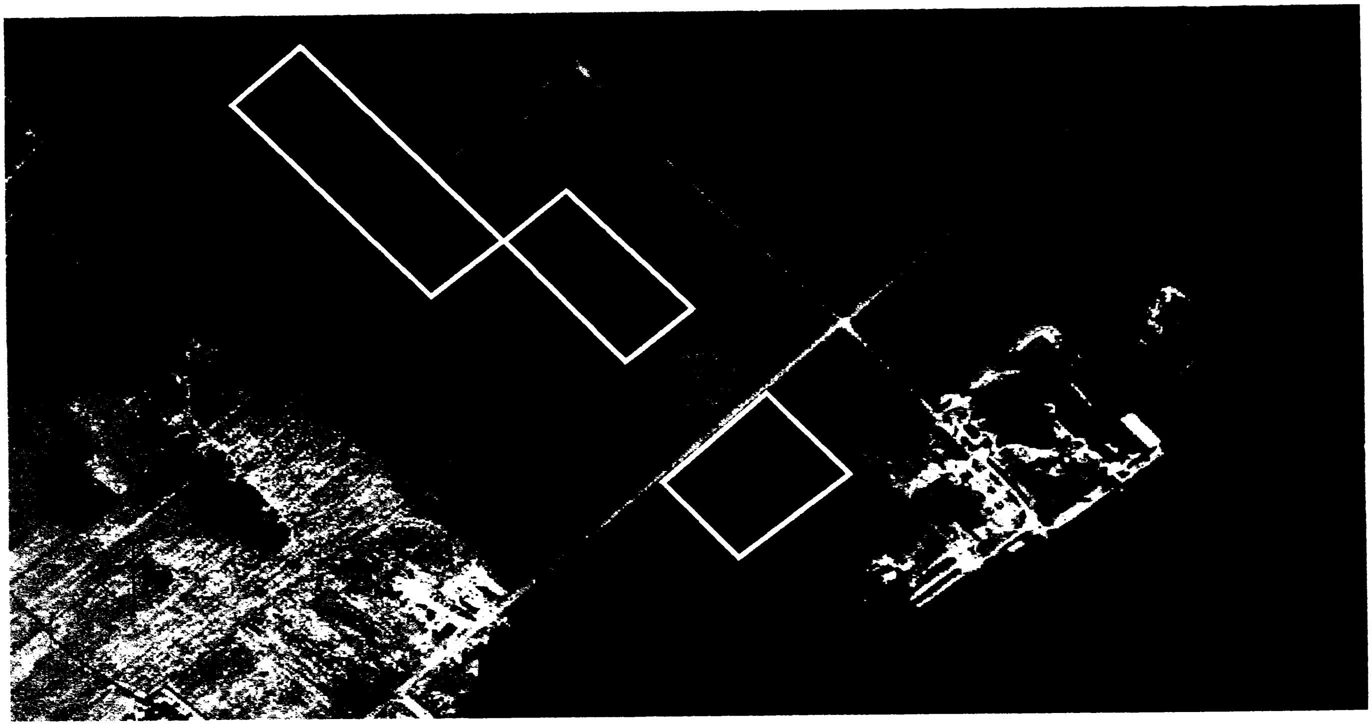
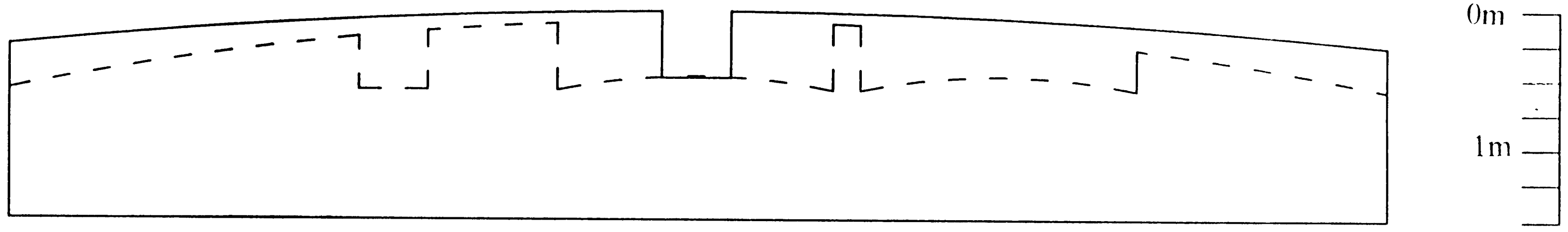
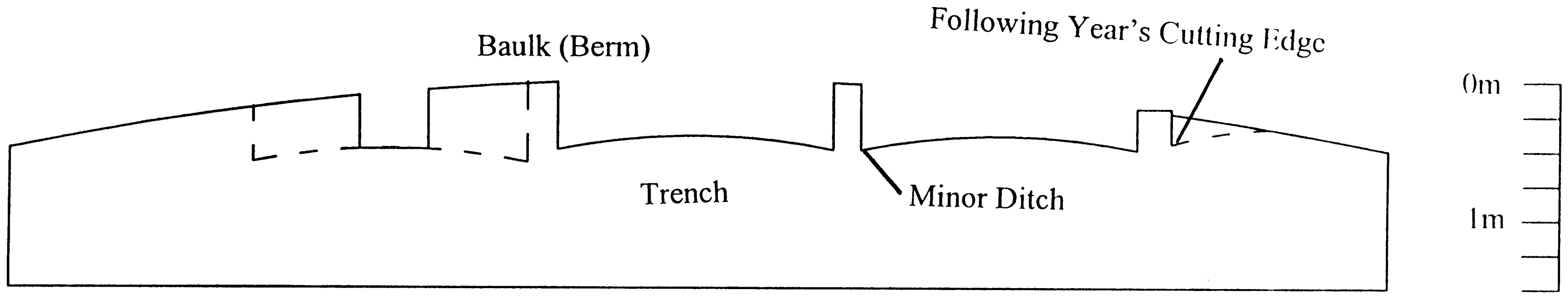


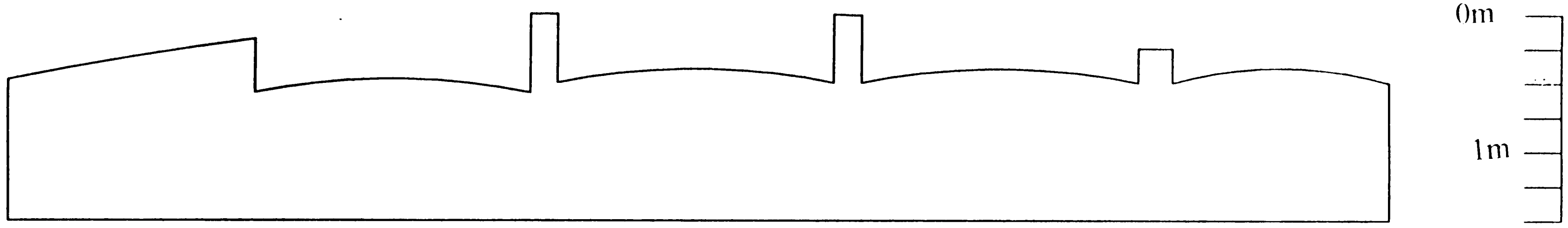
Figure 2.1 - Location of study site and experimental areas in Riviere-du-Loup Peatland, Quebec



First Cut – Drainage Ditch



Second Stage – Creation of Trenches



Final Block Cut Topography

Figure 2.2 – Process leading to typical block cut topography.

2.1 Block Cut Topography

To understand the site conditions, it is necessary to outline the process that formed block cut sites and its implications for drainage. Block cut peatlands were created first by the excavation of narrow trenches (Figure 2.2). Working outward from these trenches, living plant material was removed and thrown over the shoulder to the center of the trench creating a dome or skag. This doming of the trenches was a common practice, leaving the edges lower, closer to the water table and most likely to contain *Sphagnum* once abandoned. Once a trench was excavated to a uniform depth, a new layer was begun. Once cleared, peat was extracted and placed on raised baulks, also named berms, to dry and be transported to the processing area. The resultant area consists of a series of narrow raised baulks (1-2 m wide) between wide trenches (10-15 m) that are drained by secondary ditches. Abandoned block cut sites have two forms of drainage, primary and secondary ditches. The primary drainage ditches run perpendicular to the trenches and are up to 1.5 m deep. These drainage ditches provide an outlet for the secondary drainage ditches which are found on both sides of the trench and run parallel to the trench. The secondary ditches are typically 50-60 cm deep and drain water from within the trench. Blocking the main ditch effectively has been conducted at one site in Rivière-du-Loup and resulted in a rapid flooding of portions of the site. The secondary ditch drainage network provides an opportunity to attempt a new rewetting method for these sites.

3.0 HYDROLOGICAL RESPONSES TO DITCH DAMS IN BLOCK CUT PEATLANDS

3.1 Introduction

Bog peatlands have low base cations, pH, and water flow, low nutrient availability, near-surface water tables and *Sphagnum* dominance (Zoltai & Vitt, 1995). These ecosystems are characterized by plant litter accumulation that exceeds decomposition, resulting in the production of peat. It is the accumulation of peat that makes bogs important to the global carbon budget, storing an estimated 455 x 10^{15} grams of carbon (Gorham, 1991). It is also this accumulation of peat that makes peatlands a valuable natural resource as fuel, bioreactors for filtration, absorbent products, and a horticultural product. Presently there are approximately 17,000 hectares of peatlands under extraction in Canada for peat harvesting with the majority in the provinces of Quebec and New Brunswick. This activity accounts for less than 0.01% of the area of Canada (Daigle and Gautreau-Daigle 2001). The activities, however, are concentrated in the southern, accessible regions of the country where humans have already influenced the landscape in terms of biodiversity loss. Further, on sites where extraction is undertaken, the carbon balance changes strongly from a source to a sink (270-300% increase in CO_2 emission) (Waddington *et al.*, 2002). Waddington *et al.*, (2002) predict the overall balance of peatlands as sinks of carbon would disappear at 5.5% extraction, for a given area.

Peat extraction in Canada generally falls into two categories, vacuum extraction, the current method and block cutting, the historic method. Block cutting left a characteristic topography (Figure 2.2) due to the process employed and the rapid abandonment of sites after the introduction of vacuum extraction methods in the early 1970's (Rochefort, 2001). The less intensive process of block cutting resulted in a rapid (within 5 years) return of bog vegetation once operations ceased (Lavoie and Rochefort, 1996).

Block cutting had less impact than the limiting factors now known to exist on vacuum extracted sites: lack of viable seed sources (Salonen, 1987, Campbell et al., 2003, Poschold, 1995), burial by blowing peat (Faubert and Rochefort, 2002, Campbell and Rochefort, 2003) and frost heaving (Groeneveld and Rochefort, 2002), and especially on the hydrology (Price *et al.*, 2003). The process of block cutting included throwing the living top material back into the trench, greatly reducing distances for seeds to travel. Further, it did not require the same level of drainage or drying of peat prior to extraction, and operations were conducted on a much smaller scale – limiting blowing peat and burial. Thirdly, the smaller scale of operations did not require drainage networks to be as intensive as on vacuum operations. This left some areas with a suitable hydrological regime for partial re-establishment of even the bryophyte layer (Price *et al.*, 2003). These rapid re-establishments helped to prevent oxidation (Waddington and McNeil, 2002) and frost heaving (Groeneveld and Rochefort, 2002), both of which are prevalent on vacuum sites. Block cut sites exist as partially recovered sites and in the context of bog restoration provide an excellent opportunity to complete the restoration process (Lavoie and Rochefort, 1996).

Ecological restoration can operate on several levels: species, community or ecosystem (Erhenfeld, 2000). In the case of bogs, there is significant overlap of these levels of restoration so efforts directed at the species or genus will have positive benefits at both the community and ecosystem level. Specialized insectivorous plants (Drosera, Pitcher plant), the unique carbon accumulating function and hydrology, primarily result from the influence of *Sphagnum* mosses (van Breemen, 1995). *Sphagnum* has thus been considered obligate for bog restoration by several authors (Heathwaite, 1995, Joosten, 1995, Rochefort, 2000). Botanical surveys of post block cut sites show that greater than 90% of the surface is re-vegetated, with typical bog species and are resistant to invasion by non-bog species, but *Sphagnum* is often strikingly low (Lavoie and Rochefort, 1996, Desrochers *et* al, 1998, Girard et al, 2002).

Water has been considered the primary limiting factor to *Sphagnum* re-establishment on block cut sites. Position of the water table has been identified as one primary limit to *Sphagnum* re-growth, with a threshold of -40 cm identified (Schouwenaars, 1995), while other researchers demonstrated a negative correlation between water table depth and growth of two *Sphagnum* species (Glime and Liao, 1992). An investigation in eastern Quebec found that thresholds exist for soil water tension (-100 mb) and soil water content (50%) that explain *Sphagnum's* presence or absence in block cut peatlands better than the position of the water table (Price and Whitehead, 2001). On the basis of these thresholds, several experiments have been conducted to re-wet block cut sites and overcome the limiting factors on *Sphagnum's* establishment. These experiments have examined methods to increase overall specific yield, through the introduction of deep basins (LaRose et al, 1997) and studies of areas where natural congestion of the abandoned drainage system brought about increases in the water table (Robert et al., 1999). The objective of this rewetting experiment is to modify block cut trenches to positively influence hydrological conditions for *Sphagnum* growth with the following key question: how do small scale peat dams affect the hydrological conditions in block cut peatlands?

3.2 Study Site and Experimental Areas

The experiment was conducted on a section of abandoned block cut peatland, which is located near the centre of the Rivière-du-Loup peatland (47° 48' N, 69°W). This peatland is classified as a domed bog in the low boreal region (NWWG, 1997). Climatic data from the nearby St-Arsène weather station indicates that the average yearly temperature is 3.2°C with an average January temperature of –12.2°C and an average July temperature of 17.8°C. The average annual precipitation is 924 mm with 252 mm falling as snow. The months of April to October have an average temperature above 0°C and August is typically the wettest month receiving an average rainfall of 100 mm (Environment Canada, 1993). During the growing season of 2001 the region experienced a dry month of May receiving only 73% of the average precipitation for that period. The months June through August were near normal (Environment Canada, 1993) (Figure 3.1).

The experiment focused on a 10.1 ha block cut section of the peatland measuring 165 m x 615 m. The section contained 47 trenches with a mean width of 12 m, in between each trench there were raised baulks with a mean width of 1 m and approximately 1.5 m in height. Secondary drainage ditches run parallel, on both sides of the trenches and are typically less than 1m in depth (average 50-60 cm). Primary ditches that run perpendicular to the trench system and serve as outlets for the secondary ditches and are typically deeper than 1 m.

The experiment was set up in a randomized block design with 12 trenches selected for study and a buffer trench left between all study trenches for a total of 25 trenches covering a 350 m width

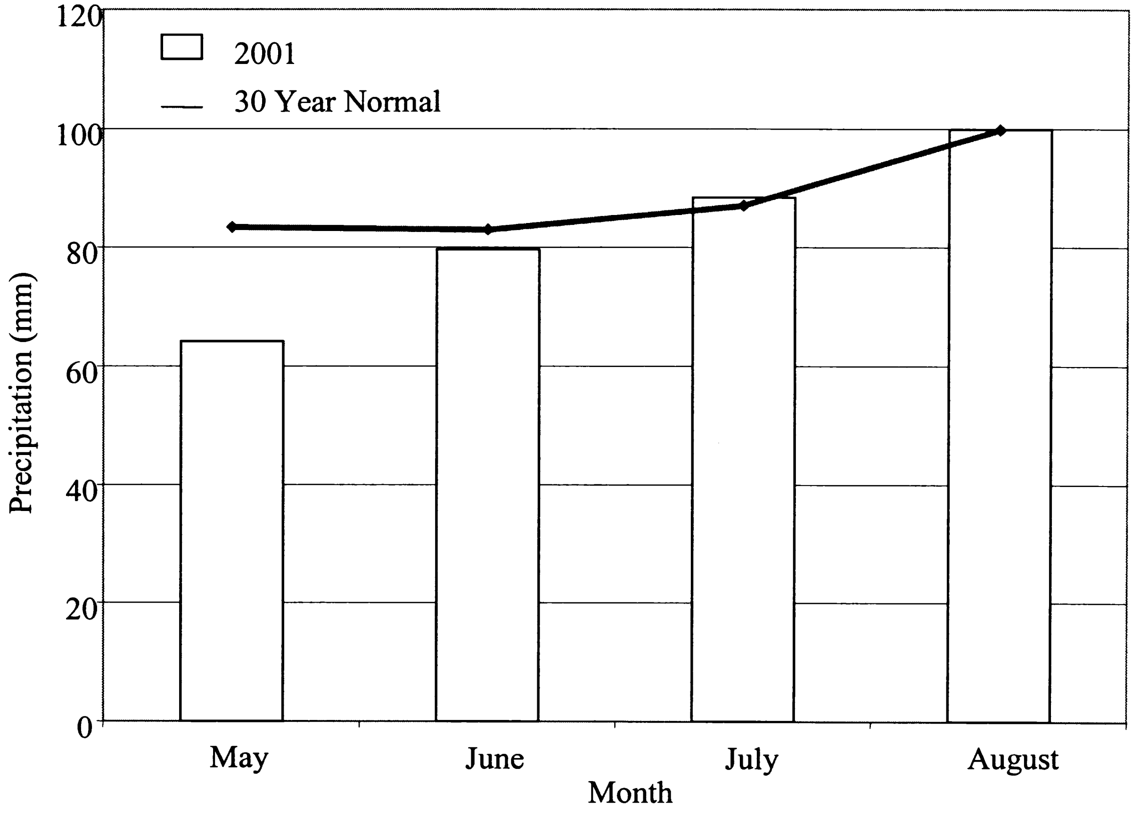


Figure 3.1 - 2001 monthly precipitation and 30 Year normals for the St-Arsene Weather Station, 47° N 57 ° W, 1963-1990.

of the available 615 m (Figure 3.2). Buffer trenches were used to minimize the effects of dams in one treatment on the adjacent trenches and were not monitored. Trenches were assigned one of the four possible treatments. No blockage (control), 1 blockage (150 m spacing), 3 blockages (50 m spacing) and 5 blockages (30 m spacing) perpendicular to the length of the trench. During October of 2000, the autumn prior to the collection of hydrological data, the dams were constructed using a backhoe and were approximately 70 cm wide. Prior to the blockage, the vegetation, including the rootzone, was stripped from the 70 cm wide area where the dams were to be installed and placed on the adjacent baulk. The plants were removed to ensure a strong seal with the underlying peat. The first 30-50 cm of peat was removed from a nearby pit and also placed on the adjacent baulk to minimize disturbance to the trenches. Peat from the lower (more humified) subsurface was then used to create the blockage, which completely filled the secondary ditches and extended across the trench at a minimum height of 10 cm above the existing surface. Once installed, an effective seal was created and it was not possible for water to circulate around the dam (Figure 3.3). The process necessarily created small excavation pools (approximately 2-3 m^2) and approximately 1.5 m deep. These pools were consistently dug on the upslope side of the blockage (Figure 3.4).

3.3 Methods

3.3.1 Hydrological Data

To assess the effectiveness of blockages in altering the hydrology of the site, water table position and soil tension were recorded. Data were collected during the 2001 field season from May 4th to October 16th for a total of 6 months of sampling covering the entire growing season. During the period from May 4th to September 7th hydrological variables were recorded two to three times per week, followed by a final data collection on October 16th at the end of the field season.

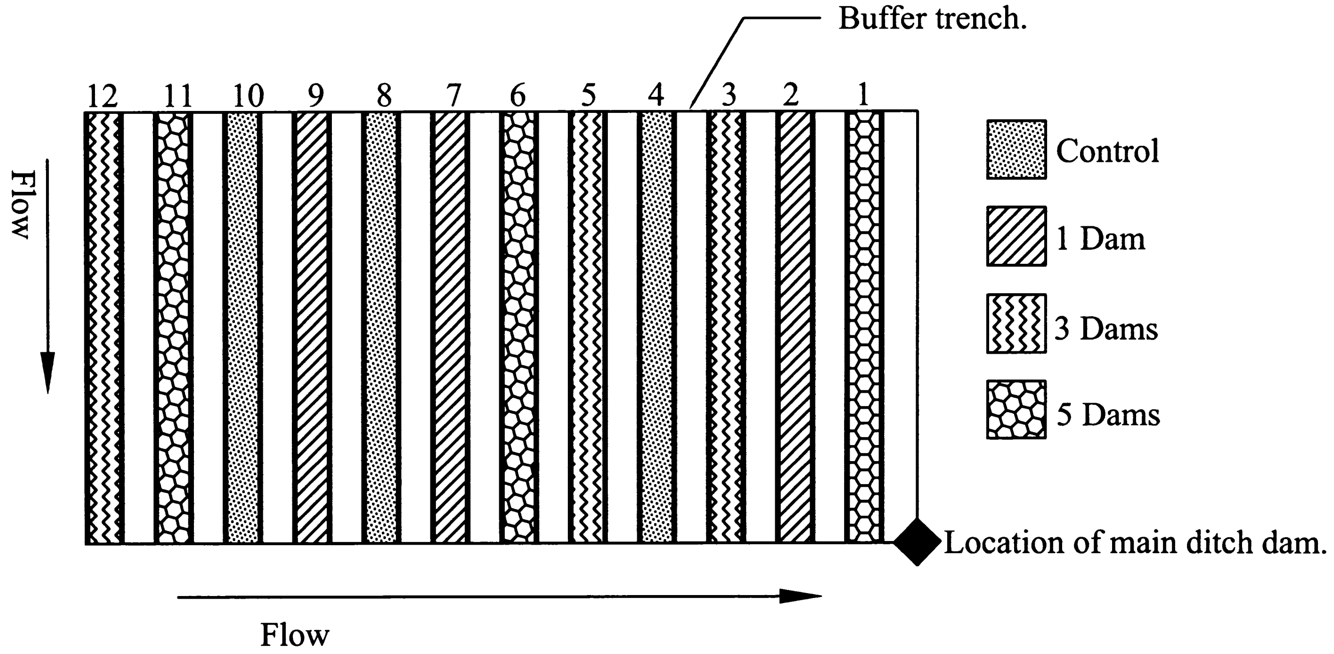


Figure 3.2 - Randomized block design showing locations of trenches and experimental design.

Figure 3.3 Photo showing a secondary ditch dams.

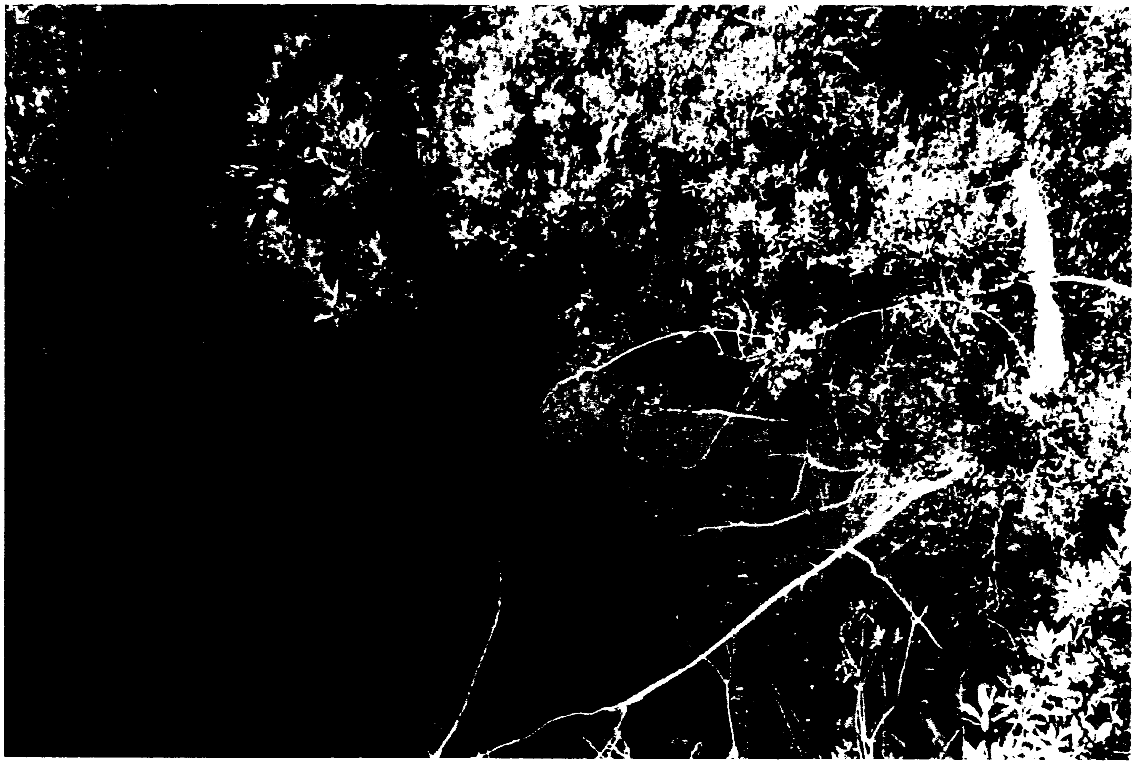


Figure 3.4 - Photo showing pools created as a result of installing secondary ditch dam.

A network of 96 wells was installed to monitor the position of the water table over a fine scale during the period May 4 to October 16, 2002. The wells were constructed from slotted PVC pipe (Schedule 40, 2 cm i.d.) covered with a nylon screens, and were inserted into the ground. In each of the experimentally modified trenches and four control trenches, 6 to 10 wells (2 m long) were inserted 1.5 m into augured holes perpendicular to the trench. The precise location of the well network is shown in Figure 3.5. Depth to water table was recorded using a piezometric beeper, a device that makes a beeping sound when water closes the circuit on the end lowered into the well, and height of the well above the ground was also measured concurrently.

Thirty-six tensiometers were placed in the experimental area. Tensiometers had a 90° elbow that was inserted horizontally 2 cm below the peat surface. During the month of May tensiometers were placed across the entire site. In this configuration three tensiometers were placed in each trench at 25, 75 and 125m from the main ditch. After preliminary results showed very high variability between the tensiometers and no significant relationship between treatments, these tensiometers were moved, at the beginning of June, to the four trenches closest to the main ditch dam to study the effects of the main ditch dam on soil tension. In this placement there were eight tensiometers per trench, the exact positioning of tensiometers is indicated in Figure 3.6. Measurements were recorded for the period May 4 until October 16, 2001 two to three times per week with a Soil Measurement System Tensimeter$^{\text{TM}}$. All values were adjusted to account for the height of the water column above the porous ceramic cup (1 cm water ~ 1 mb pressure).

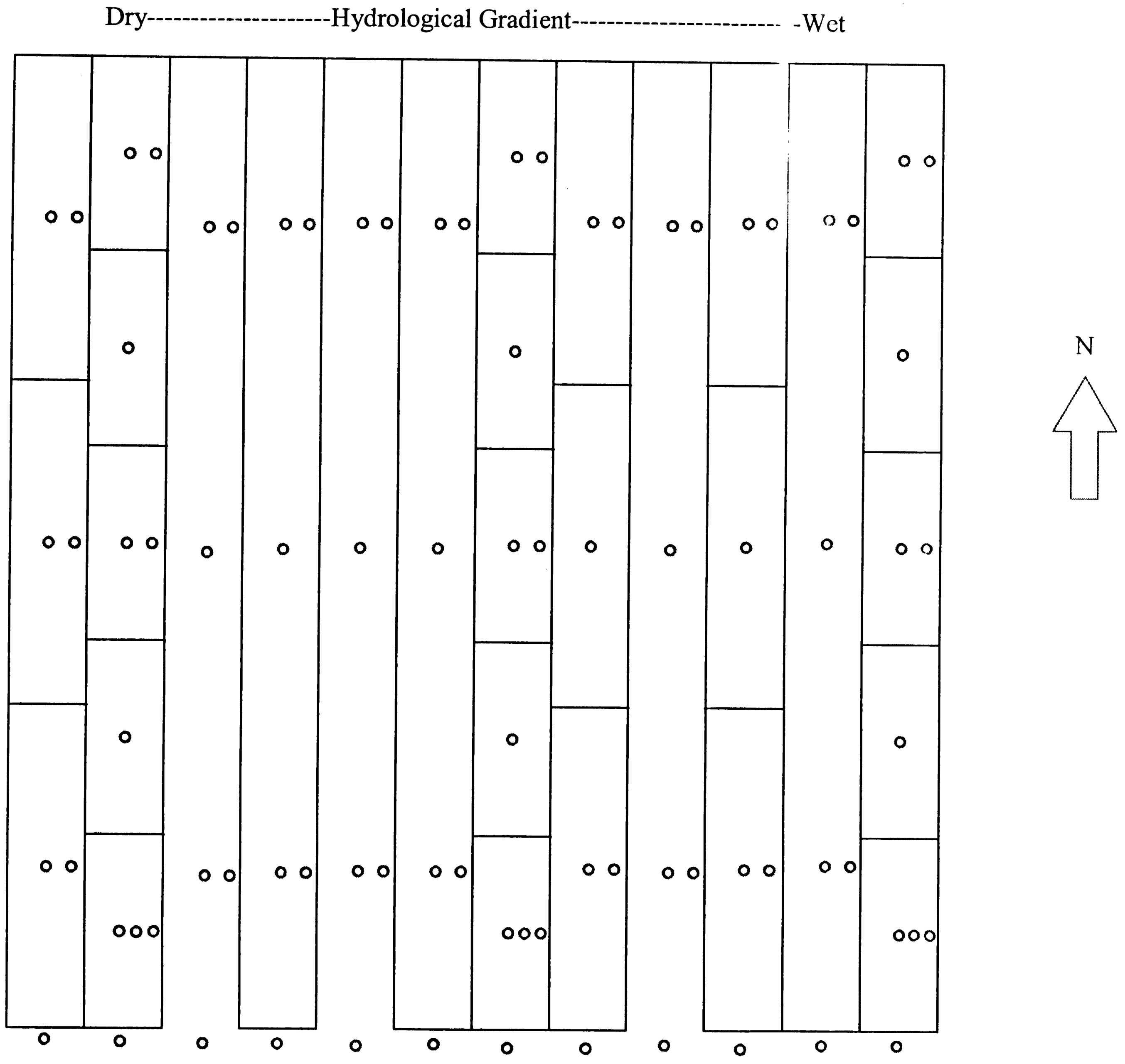
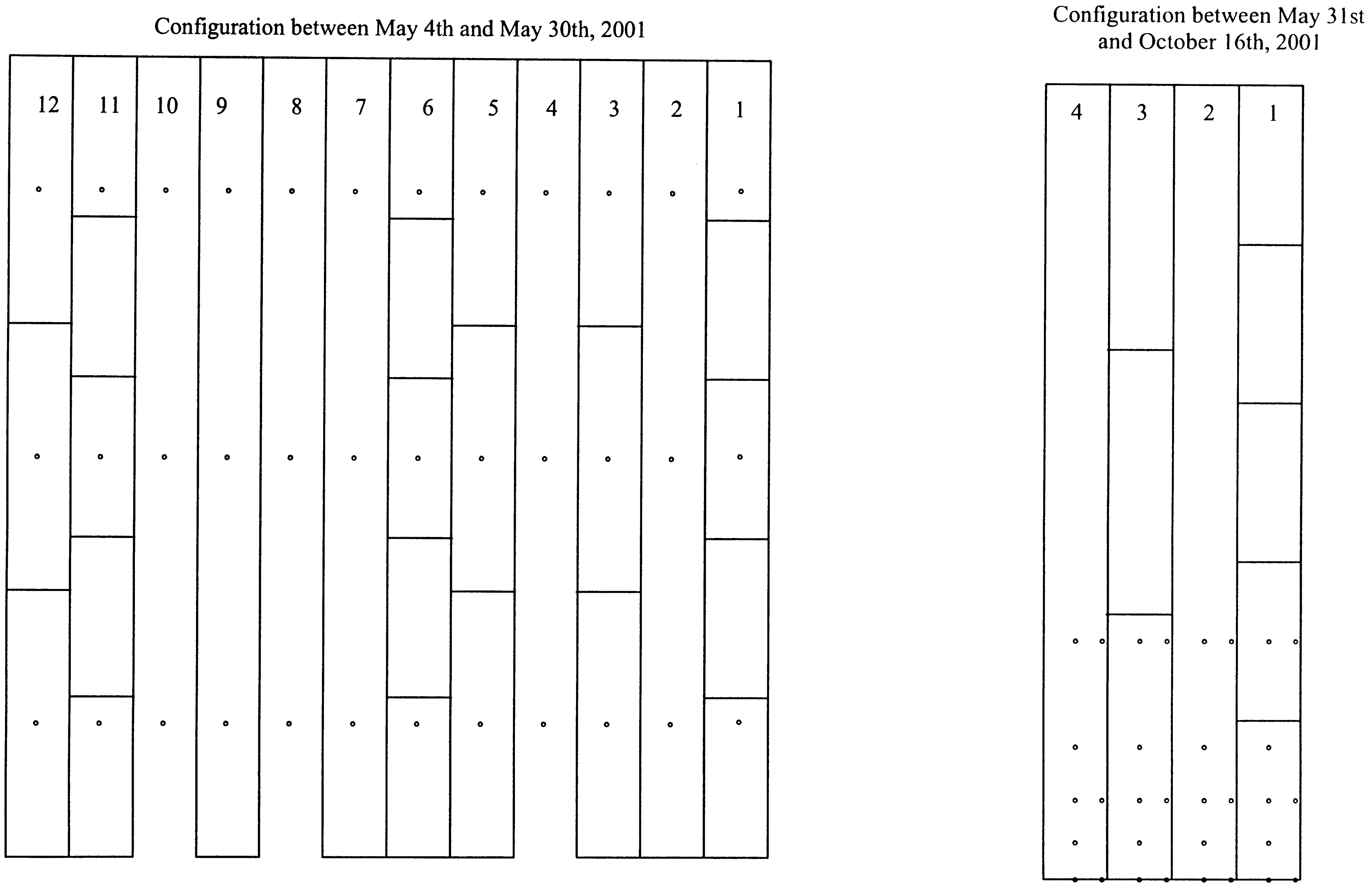


Figure 3.5 – Location of water wells within trenches. Buffer trenches not shown.


Configuration between May 4th and May 30th, 2001

Configuration between May 31st and October 16th, 2001

Figure 3.6 - Location of soil tensiometers within site. Buffer trenches not shown.

3.3.2 Statistical Analysis

Data were analyzed using the standard analysis of variance techniques. Depth to water table was analyzed using a randomized block design with the number of blockages used as the main factor. Since the site contained one main ditch dam at the downstream end of the main drainage ditch, there existed a hydrological gradient on the site with the area closest to the main ditch dam being the wettest. The trenches became progressively drier as the distance from the main ditch dam increased. To account for this, position within the hydrological gradient (wet, moist, dry) was used as the block. The level of significance was set at 0.05 for this statistical test.

Surface soil tension was analyzed separately for the period May 4 to May 30th, 2001 during which time tensiometers were installed in all experimental blocks (Figure 3.6). A complete randomized block ANOVA was performed with the number of blockages used as the main factor and the position in the hydrological gradient used as the block. As with the position of the water table, the level of significance was set at 0.05. In addition, two regression analyses were performed with semi-radial distance from the main ditch dam as the independent variable and mean water table and surface soil tension as the independent variables, respectively.

3.4 Results

3.4.1 Water Table Differences Between Treatments

The secondary dam treatments showed no significant differences between the number of dams for mean water table position (*P*=0.15) (Table 3.1). No significant effects were observed as a result of the number of secondary ditch dams during the wettest or driest period of the season (*P*=0.22 – wettest, *P*=0.37 – driest) (Table 3.2 and 3.3).

Table 3.1 – Analysis of variance (ANOVA- Complete Randomized Block Design) of mean water table depth according to the number of dams (0, 1, 3 or 5) at the experimental site during the period May 4, 2001 to October 16, 2001. Factors marked with an asterisk (*) are significant at *P*=0.05.

Source	Df	Mean Square	F	*P*
Block	2	99.8	7.5	0.02*
Number of Dams	3	33.2	2.5	0.15
Error	6	13.2		
Total	11			

Table 3.2 – Analysis of Variance (ANOVA – Complete Randomized Block Design) of water table depth according to the number of dams (0, 1, 3 or 5) at the experimental site on June 6th, 2001, the wettest period of the year. Factors marked with an asterisk (*) are significant at *P*=0.05.

Source	Df	Mean Square	F	*P*
Block	2	90.9	5.5	0.04*
Number of Dams	3	32.4	2.0	0.22
Error	6	16.4		
Total	11			

Table 3.3 – Analysis of Variance (ANOVA – Complete Randomized Block Design) of mean water table depth according to the number of dams (0, 1, 3 or 5) at the experimental site on August 16, 2001, the driest period of the year. Factors marked with an asterisk (*) are significant at *P*=0.05.

Source	Df	Mean Square	F	*P*
Block	2	102.7	6.2	0.04*
Number of Dams	3	21.0	1.3	0.37
Error	6	16.6		
Total	11			

This lack of significant difference manifested itself on the site in several measurements. An examination of the mean difference between the water table outside the blockage and the nearest well inside show that the range of difference was –5cm to +10 cm, with 9 of the 14 trenches having a difference of less than ± 2 cm (Figure 3.7). Further in 8 of the 14 trenches, the water table was actually slightly higher outside the blockage. Over the course of the summer there was no significant storage of water behind the blockages.

3.4.2 Mean water table position

Water table position varied through the season as expected, rising after rain events and falling during periods without precipitation (Figure 3.8). There was a general trend of increasing water tables through the month of May with water table position reaching its highest level in early June. Between the beginning of June and the middle of August there was a general trend of lowering water table positions. High levels of precipitation at the end of July did result in an increase in water table positions almost to the levels observed at the beginning of May, however these levels dropped quickly to their lowest levels by the middle of August. Precipitation events at the end of August corresponded with increasing water table positions, though the rate of return was less sharp than after the decline seen at the end of July.

A comparison of relative water table position regressed against relative topographic position shows extremely high correlation (r^2=0.91) with a curve that approaches 1:1 (Figure 3.9). A correlation of this type indicates the water table was flat and the majority of change we observed between different wells was the result of topographic differences between those wells. The finding of a flat water table agrees with the work completed by Price and Whitehead, 2001, on the nearby Cacouna block cut peatland. One possibility that this study cannot rule out is that

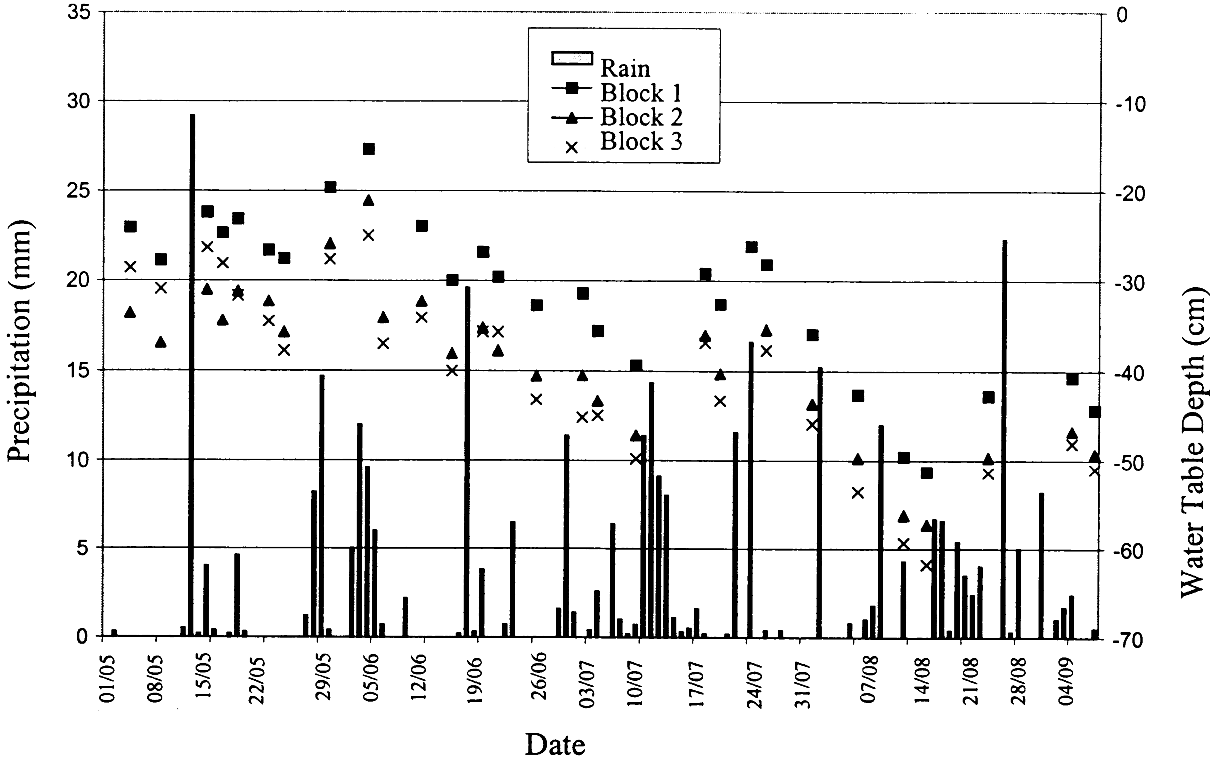


Figure 3.8: Precipitation and mean water table position by block – 2001.

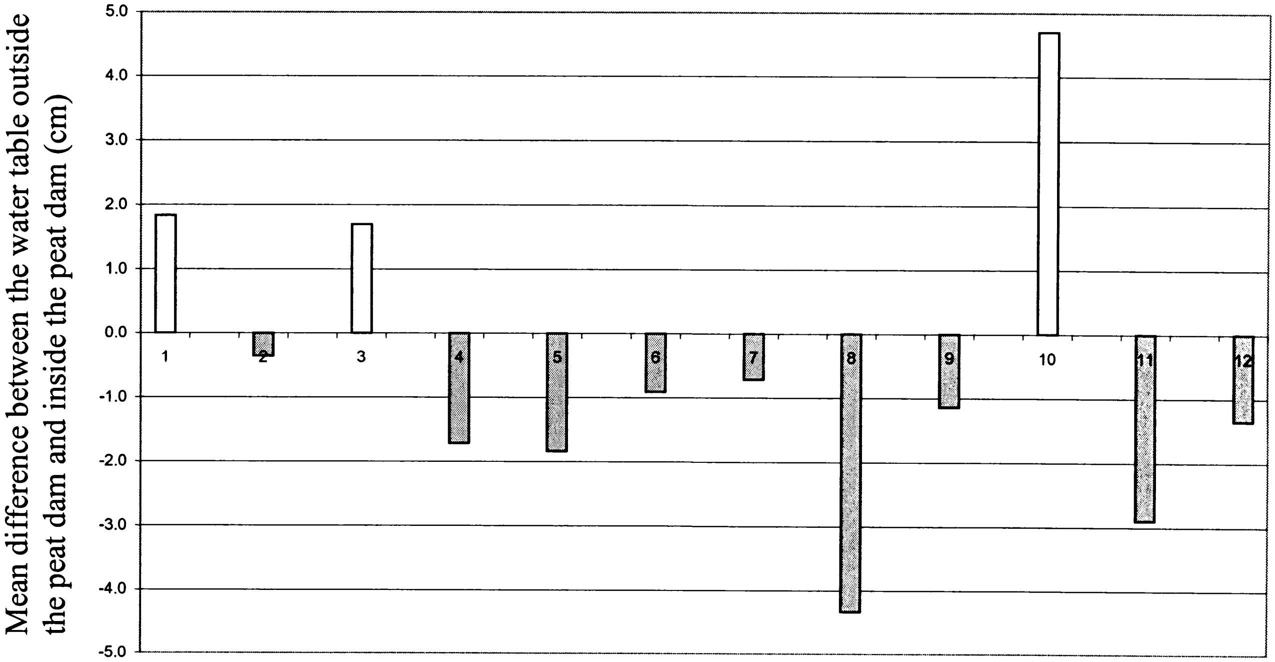


Figure 3.7: Comparison of water table levels inside and outside dams in the minor ditch nearest the main ditch.

Shaded bars indicate that the water table was higher inside the dam, empty bars indicate the water table was higher outside the dam.

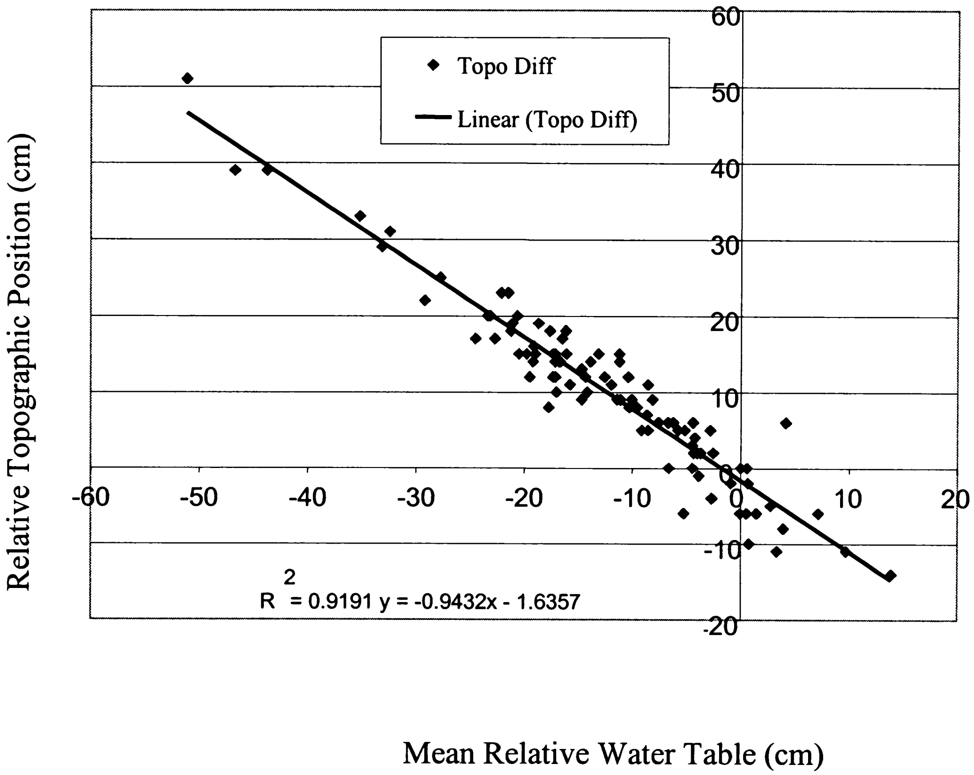


Figure 3.9 – Regression of the mean water table position as measured in the field vs. the topographic position.

water was retained by the dams after the spring melt and increased the recharge to the site. If this occurred, the water would have been re-distributed subsurface and increased water table levels at the control trenches as well as in the dammed trenches. Based on the absence of significant localized water table differences between trenches, regardless of the number of dams, the trenches were considered to be unaffected by the installation of secondary ditch blockages and the data were grouped to analyze the effects of the main ditch dam.

3.4.3 Effect of the Main Ditch Blockage on Water Tables

The effect of the main ditch blockage was examined by comparing the relationship between distance from the main ditch blockage and the mean water table (Figure 3.10). The values used in this regression have been corrected for topography which has been shown on this site to be the primary reason for differences in water table position. To correct for topographic distances, the height of the ground at the first well in trench the first trench was set to zero. The topographic position relative to this arbitrary zero was measured at the ground level of each well. Water table depths were corrected by subtracting the relative difference in topography from the measured water table depth.

In this regression we observe two trends. The first is a logarithmic decrease in water table position with increasing distance from the main ditch dam. Further, the degree of scatter increases with increasing radial distance from the main ditch dam. While it is not possible to set an exact limit for the point where the effect of the main ditch dam ceases to be effective, the degree of scatter increases greatly beyond 100 m and the majority of points beyond 150 m are below -40cm.

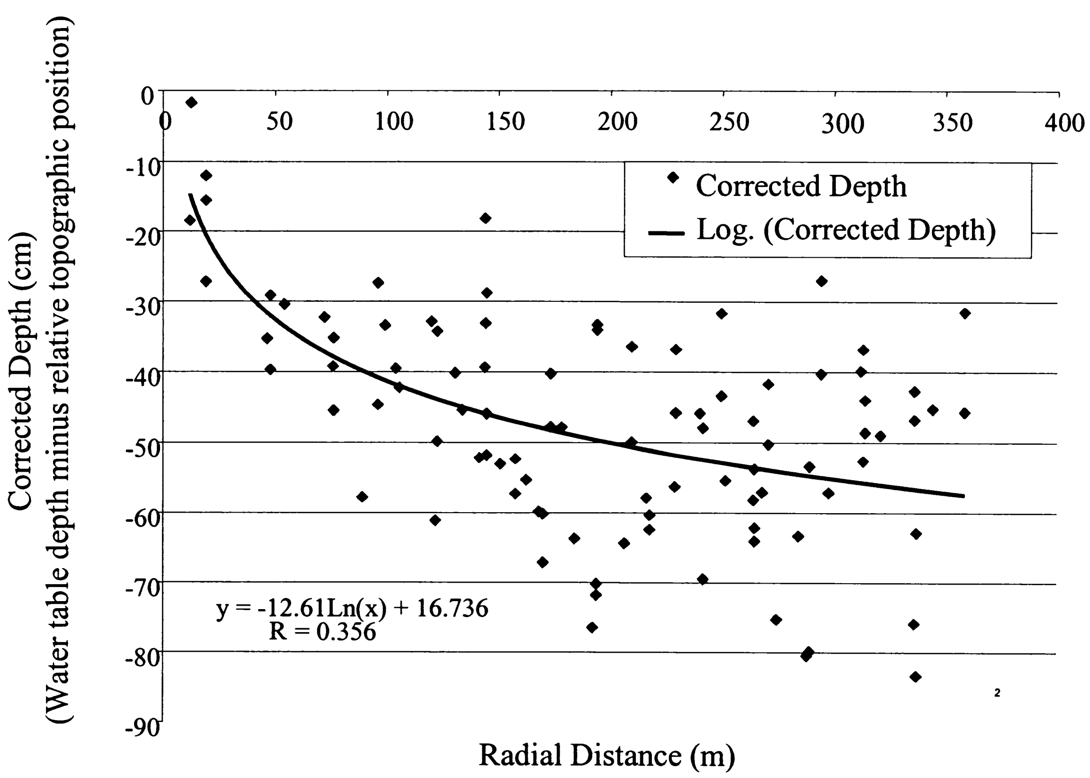


Figure 3.10 - Regression of the corrected mean water table depth versus radial distance from the main ditch dam.

3.4.4 Soil Water Tension

During the month of May, mean soil tension 2 cm below the surface was not significantly affected by either the number of dams installed or the position within the hydrologic gradient (Table 3.4). Consequently, tensiometers were moved into the area closest to the main ditch blockage. A comparison of the mean soil tension during the period June 4 to October 16, 2001 shows that soil tension increased with increasing distance from the main ditch dam for the 100 m studied in this experiment (Figure 3.11).

This significant relationship was observed only for the center of the trenches where the range of measured values was lower than the areas near the secondary ditch. The standard deviation of surface soil tension in the areas near the secondary ditch was quite high and resulted in no significant relationship between soil tension near the secondary ditches and distance from the main ditch dam. Soil tension at the center of the trench was higher in the area within a radial distance of approximately 30 m (Figure 3.12), however there were no points with mean soil surface tension less than -100 mbs.

3.5 Discussion

To our knowledge, *Sphagnum* mosses should grow if a stable and shallow water table does not drop below the generally accepted thresholds of –40 cm water levels (Schouwenaars, 1995), -100 mbs soil tension and 50% soil moisture content (Price and Whitehead, 2001). The more difficult problem is how to achieve this task. Small scale damming did not provide the solution that was hypothesized. The water table quickly dropped below the surface after the spring snowmelt with the result that surface modifications to intercept water became ineffective. Water tables were found to be generally flat on the scale of this site, responding to precipitation

Table 3.4 – Randomized Block Design ANOVA of mean soil tension at the experimental site during May 4 to May 30, 2001. Factors marked with an asterisk (*) are significant at *P*=0.05.

Source	df	Mean Square	F	F-critical
Effects of the Experiment				
Block	2	110.2	0.5	5.1
Number of Dams	3	51.4	2.2	4.8
Error (Block * Number of Dams)	6	50.1		

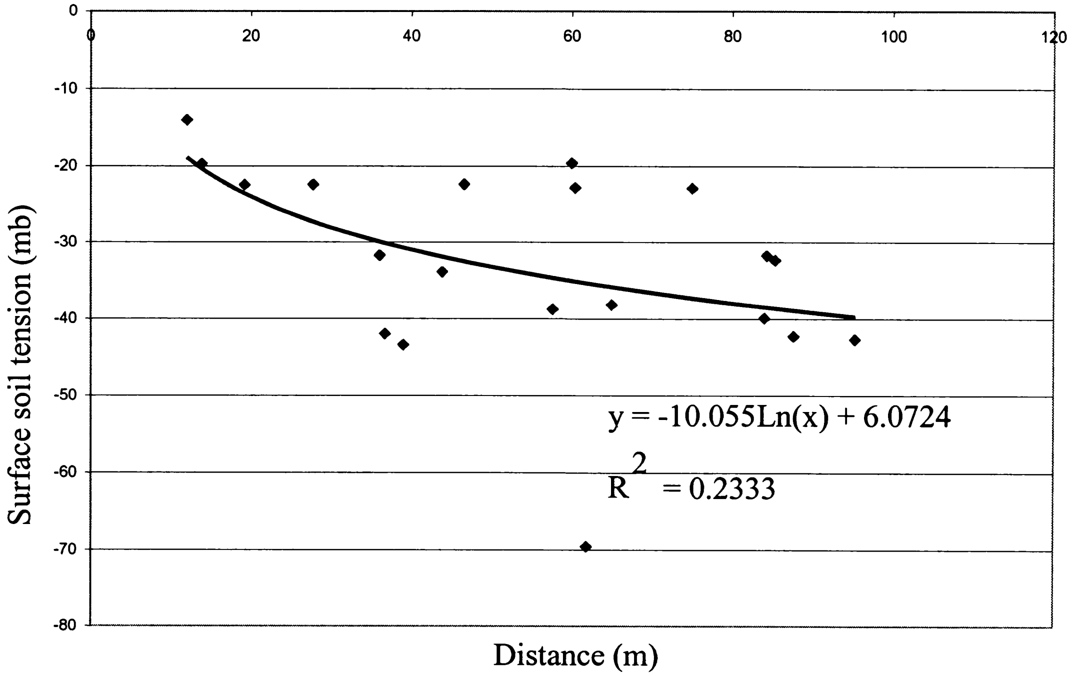


Figure 3.11 - Regression of mean soil tension in the center of then trenches versus radial distance from the main ditch dam.

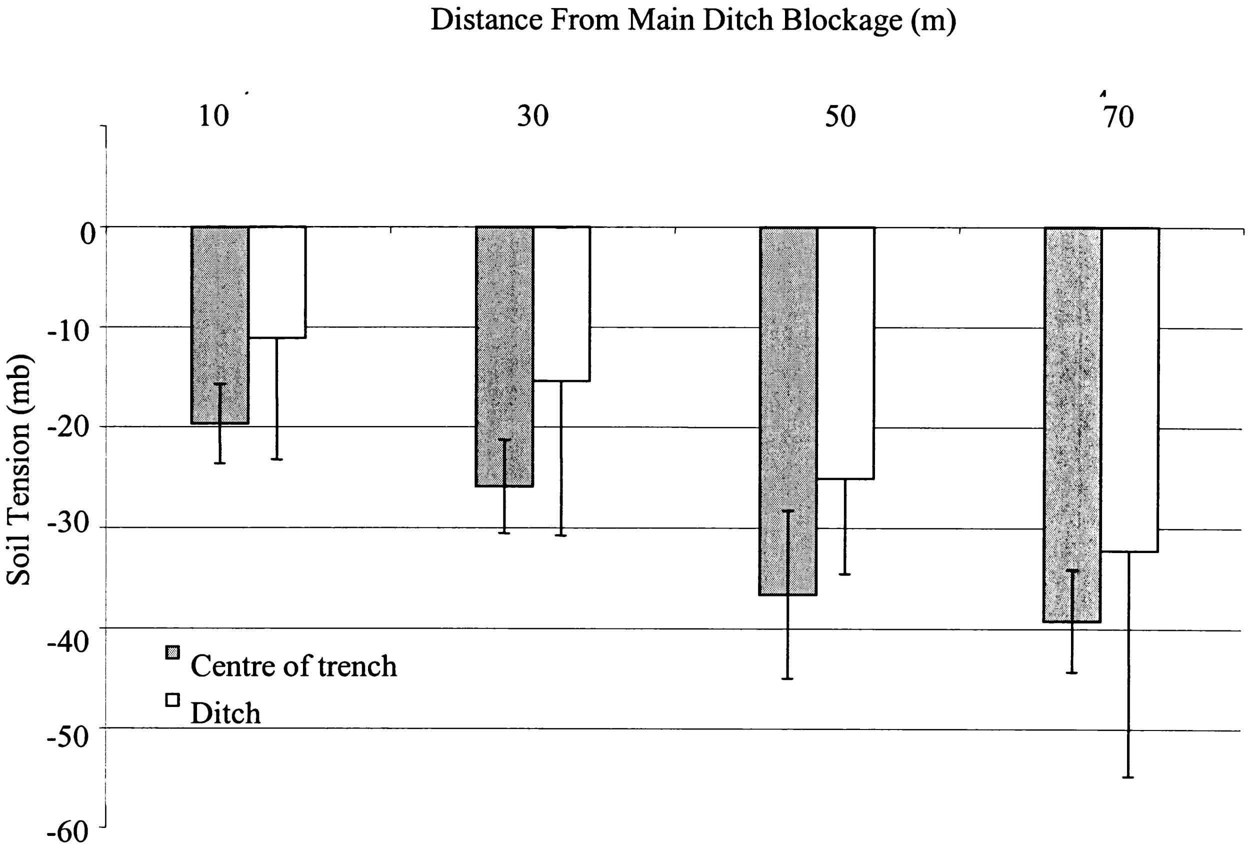


Figure 3.12 – Comparison of the mean soil tension taken at the centre of experimental trenches and in the adjacent ditches as a function of dam spacing.

and evaporation being the primary sources and losses of water respectively. This is consistent with the water balance presented by Van Seters and Price (2001) showing that evapotranspiration losses accounted for ~80% of water losses on a block cut site.

Observations on this site found a radial influence of the main ditch dam on both the position of the water table and surface soil tension in the center of the trenches. Improvements in these variables are not enough though, if they do not improve the site beyond the thresholds to *Sphagnum* growth. In absolute terms, the importance of the differences in water table levels across the blocks is related to the delay in dropping below the -40 cm threshold during the growing season. In the driest block this threshold was crossed in late June, in the moist block it was crossed early in July while in the wettest block this threshold was reached a month later. The water table at the experimental site was lower than -12 cm for all of the season and below – 40 cm after the beginning of August for the entire site. The experimental site was not flooded and its hydrology did not appear to be conducive to large scale *Sphagnum* growth.

This study suggests that it may be more profitable to concentrate solely on the main ditch blockages. The main ditch dam were found to be effective in a limited, radial area but did not achieve the proper flooding to rapidly induce the return of *Sphagnum.* The most rapid return of *Sphagnum* dominance has been demonstrated on flooded sites (Jeglum, 1975, Rochefort et al. 1995, Mitchell and Neiring, 1993, Mawby, 1995). A full understanding of the existing topography is necessary for any decision to be made about the best course of action in restoring block cut peatlands. Both lowering the surface and the creation of main ditch blockages would improve the hydrology on a relatively small scale. Careful main ditch damming that induces flooding has the most potential for rapidly returning *Sphagnum* dominance. After that initial improvement, as in many restorations, time must be allowed to complete the task.

3.6 Conclusions

Secondary ditch dams in the trench system were ineffective during the time frame studied but the main ditch (1.5 m deep) blocking provided improvement of hydrological variables (water table and soil tension) in the area closest to the main ditch dam. Soil tension in this experiment matched results presented in earlier work, in that it was significantly lower in areas closer to ditches than at the center of the trenches. The water table was flat, relative to the ground, surface indicating that changes in its position responded to regional inputs and outputs (precipitation and evapotranspiration).

4.0 VEGETATION RESPONSES TO MAIN DITCH BLOCKAGES IN BLOCK CUT PEATLANDS

4.1 Introduction

Peatlands, according to the Canadian classification system, are a type of wetland that has accumulated greater than 40 cm of peat. Within this broad category there exist a range of hydrological regimes, soils chemistry and plant communities on a continuum from swamp to fen through bog (Zoltai and Vitt, 1995). Bogs have unique properties and characteristics that make them important regionally, nationally and globally. Globally, one of bogs greatest importance is in their ability to sequester carbon for long periods of time. Estimates of the global carbon balance place the reserves of carbon in northern peatlands at 455 x 10^{15} grams of carbon, one third of the worlds terrestrial carbon storage, with a further 2.9 tonnes per hectare added every year (Gorham, 1991). Long term storage of plant remains in bogs has the second global benefit of providing a source of paleo-ecological information.

Nationally and regionally bogs contribute to biodiversity, as they are home to rather specialized carniverous plants (*Drosera, Sarracenia*), large mammals (Moose), birds (Palm warbler) and insects (dragonflies) (Poulin et al, 1999, Calme et al, 2002, Mazzerolle *et al.*, 2001). Bogs provide recreational activities for local residents in the form of hunting, hiking and berry picking (Rochefort, 2001). Bogs also contribute to the national and local economies through the sale of the slowly decomposing peat as a horticultural product. Sales in 1999 equaled $170 million, with 17,000 hectares under active extraction in Canada (Daigle and Gautreau-Daigle, 2001).

Actual methods of extraction are vastly different from those employed 30 years ago. Current methods require the removal of the living layer over large surface areas, the installation of deep drainage systems, raking and harrowing the soil to facilitate drying. The peat is extracted by driving a large tractor with vacuums over the loose dry peat (Rochefort, 2001). The general approach to restoring these systems is to re-create wet and suitable microclimate conditions along with the reintroduction of diapsores. Microclimate alterations range from introducing nurse plants (Grosvernier et al, 1995) to the addition of a protective cover for the mosses (Rochefort et al, 2003). A summary of the North American efforts toward the restoration of these sites and the methods are explained in great detail in Rochefort, et al 2003. Prior to the utilization of these tractor-drawn machines, peat was extracted by an assembly line of people working with shovels. Because this process operated on much smaller scales, seed sources were never moved very far when the living plant material was removed. Also, sites were not drained as effectively as for the vacuum extraction process. These different extraction methods resulted in different regeneration abilities on both sites. Vacuum extracted sites will often have only 10% plant cover, usually cottongrass, even 20 years after abandonment (Lavoie et al., 2003). They are also prone to birch invasion and do not show signs of spontaneous *Sphagnum* colonisation (Bérubé and Lavoie, 2000). A nearby block cut site showed 90 to 100% plant cover with a diversity of bog species and have shown themselves resistant to birch invasions (Girard et al., 2002). Despite these positive results, there is a conspicuously low abundance of *Sphagnum.* Pockets of *Sphagnum* are often found on block cut sites in the wettest areas of block cut sites (old blocked ditches, low reliefs) with sites averaging 10% cover of *Sphagnum* (Table 2 *in* Desrochers *et al.*1998).

It is also known that when natural forested wetlands are flooded (road construction, beaver damming) there can be rapid changes in vegetation communities towards *Sphagnum* dominated systems (Jeglum, 1975, Mitchell and Neiring, 1993). Flooding has been used as a restoration tool for bogs in Europe on many occasions (Meade, 1992, Mawby, 1995, Tuitilla *et al.*, 2000). Under flooded conditions, the species' most likely to occupy the bog surface are hollow species. It is suggested that these species will form rafts and infill the bog, similar to the process of terrrestrialization, but this process has not yet been demonstrated for restored bogs. Two concerns identified with flooding are wave erosion and constant displacement of material where flooding conditions are present and etiolation in growth (Rochefort et al. 2002). Despite these concerns, the strong responses of spontaneous *Sphagnum* growth demonstrated after flooding events in other peatland communities demonstrates the potential for flooding to be used as a restoration strategy in block cut peatlands.

This study examines the community vegetation changes in a flooded block cut peatland in eastern Quebec. In particular, the study objectives are to examine the effects of two sites (one flooded, one not) both before and after a primary ditch blockage that induced flooding; second to examine spatial patterns in community changes observed.

4.2 Site Description

The experiment was conducted on sections of formerly block cut areas which are located in the centre of the Riviere-du-Loup peatland (47° 48' N, 69° W). This peatland is classified as a domed bog in the low boreal region (NWWG, 1988). Climatic data from the nearby St-Arsène weather station indicates that the average yearly temperature is 3.2°C with an average January temperature of –12.2°C and an average July temperature of 17.8°C. The average annual precipitation is 924 mm with 252 mm falling as snow. The months of April to October have an average temperature above 0°C and August is typically the wettest month receiving an average of rainfall 100 mm (Environment Canada, 1993)

Plant surveys were conducted at two sites during the summer of 2001: the Major site, which has its former primary drainage system effectively blocked and has been flooded since 1996 and the Minor site, which had small secondary drainage ditch obstructions and was not intensively flooded. Primary ditch blockage at the Major site was completed using a backhoe to excavate humified peat and create a dam at the drainage outlet. This dam was approximately 2 m wide and extended across the main ditch. Peat was compacted using the bucket to ensure an effective seal. The Minor site was partially blocked as a result of slumping peat and vegetation growing in the trenches over time. Both sites were within 100 metres of each other and the peat was extracted by the block cutting method. The sites were abandoned more than 20 years prior to the pre-flooding survey in 1995.

The block cutting method results in a characteristic, baulk/trench topographic profile. This profile creates very different plant communities over very short distances perpendicular to the trench, with less variation parallel to the trench system. Lichens growing on dry peat can sit only 1 metre from *Sphagnum cuspidatum*. Further, the narrowness of the baulks mean they contribute only a small amount to the overall site conditions ~10%. As a result, this study chose to focus on the trenches, which make up ~90% of the area of this block cut bog. This rapid change in one axis also dictated that sampling points be distributed more densely perpendicular to the trenches than parallel to the trench.

4.3 Methods

This study makes use of data collected in 1995 for both sites. In the case of the Major site, this was prior to the blockage and flooding. These inventories used the point-survey method, noting all plants that touched a thin wooden spike at 10 equidistant points perpendicular to the trench and 10 equidistant points parallel to the trench (Poulin et al., in prep.). This resulted in 100 sampling points per trench. Follow-up inventories were conducted using the point-survey method during the summer of 2001, that is 6 years after the initial survey. For all sites, all plants touching a thin (5 mm diameter) wooden rod were counted every metre across the trench and every 15 metres along the trench. Trenches were on average 150 long and ~10 m wide so with 15 m spacing parallel to the trench and 1 m spacing perpendicular to the trench, this survey method provided 100 data points in an average trench, a similar resolution to the 1995 studies. Plant presence was converted to frequency by dividing the number of points where a plant was found by the total number of points in a trench. These values were then averaged for the site as a whole. Frequency calculations were completed for 1995 and 2001, and comparisons were made based on the changes in percent cover. Twelve trenches were surveyed the Major and twelve trenches were also surveyed at the Minor site. In order to determine if either the Major, Minor or both sites were regaining the typical vegetation cover of *Sphagnum* dominated peatlands, results of these surveys were compared to plant percentage results from the nearby natural Bois-des-Bel peatland (Lavoie & Lachance unpublished data).

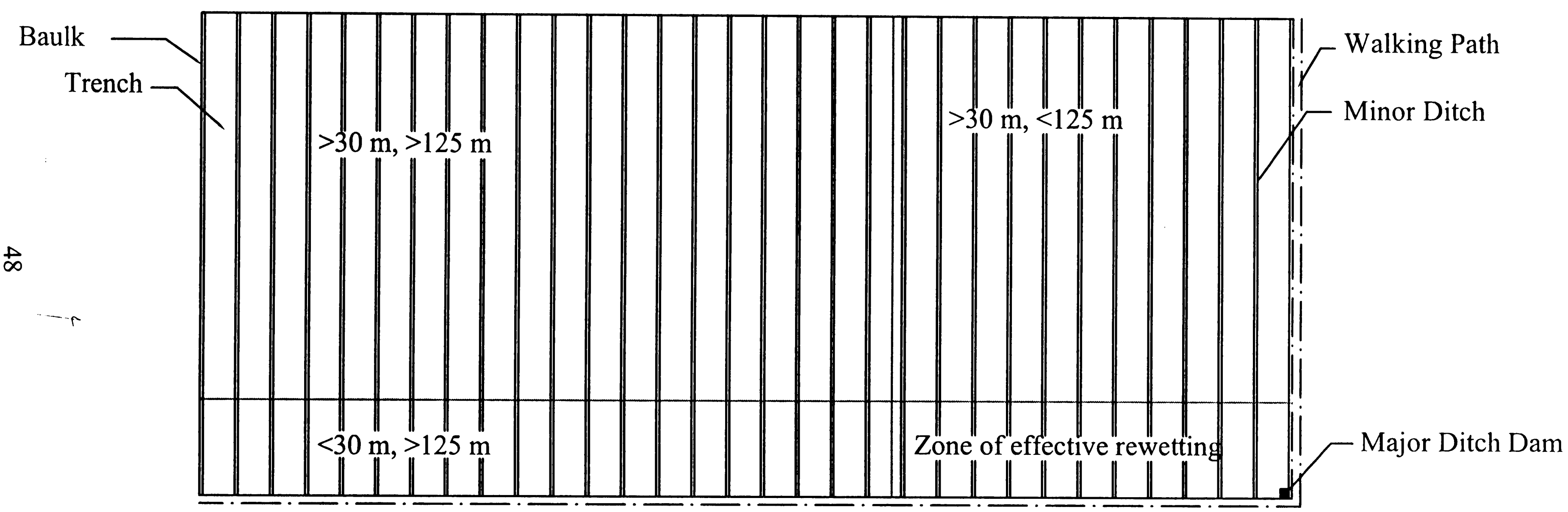
A posteriori second analysis examined the effects of the zone of effective rewetting, the radial area around a main ditch dam that has its hydrology modified. In chapter 3 we observed that a main ditch dam has the potential to affect water table position up to 150 m. An examination of this site found that water table position was above the surface in the spring in an area that measured 30 m parallel to the trench and 125 m perpendicular to the trench. For this site and study, the zone of effective rewetting was determined to be 30 m by 125 m. The flooded site was divided into four quadrants, inside the zone (30m by 125m), outside 30 m but inside 125m, outside 125m but inside 30m and outside both 30m and 125m (Figure 4.1). Frequency of occurrence calculations were completed for each zone and the results were compared with the overall site and the natural bog community. Since the Minor site did not exhibit a flooded zone of effective rewetting the same analysis was not completed.

4.4 RESULTS

4.4.1 Major Site

At the Major site we observed the following community changes: a decrease in frequency of trees, a decrease in ericaceous shrubs presence, an increase in herbaceous plant occurrence, an increase in frequency of *Sphagnum* in the group Cuspidata, a decrease in frequency of lichens while other mosses remained stable (Table 4.1). The cover of both *Larix laricina* and *Picea glauca* decreased by 50-60%. At the Major site the frequency of *Kalmia angustifolia, Ledum groendlandicum* and *Vaccinium angustifolium* all decreased, while the frequency of *Rhododedron canadense* increased and *Chamaedaphne calyculata* remained stable. Herbaceous plants increased substantially at the Major site over the six year period. In particular, the frequency of *Eriophorum spissum* increased from 1% to 7% while *Rubus chamaemorus*, which was not found in the 1995 survey was encountered at 4% of the survey points in 2001.

The most drastic changes occurred with *Sphagnum* both inside and outside the zone of effective rewetting. Species in the group Cuspidata, which are typically associated with wetter areas increased in three zones. In the area closest to the main ditch, but greater than 125 m away from the dam, Cuspidata species were found at 7% of the surveyed points. In the area within 125 m of the main ditch and beyond 30 m (perpendicular to the main ditch), Cuspidata species were found at 5%.



Scale 1 mm = 2 m (1:2000)

Figure 4.1 - Diagram showing the areas used in the quadrant analysis and the zone of effective rewetting.

Table 4.1 - Vegetaton community surveys in 1995 and 2001 for the Major site, Riviere-du-Loup, Quebec. Bois des Bel survey results included for comparison.

	1995 % Frequency of Occurrence									
	Major Site	<30m<125m	<30m>125m	>30m>125m	>30m<125m	**Natural**	Major Site	<30m<125m	<30m>125m	>30m>125m	>30m<125m
TREES											
Larix laricina	**8**	3	8	9	14	**15**	4	0	0	3	11
Picea mariana	**6**	2	4	9	9	**85**	2	0	0	5	3
SHRUBS											
Kalmia angustifolia	**60**	92	59	64	83	**73**	36	14	30	45	47
Ledum groenlandicum	**44**	48	51	57	49	**65**	31	16	30	42	35
Rhododendron canadense	**6**	7	12	6	6	**29**	13	8	15	7	15
Vaccinium angustifolium	**14**	7	30	20	7	**55**	6	1	0	16	12
Chamaedaphne calyculatta	**15**	2	22	22	16	**43**	16	37	15	12	12
HERBACEOUS											
Eriophorum spissum	**1**	0	4	2	0	**2.7**	7	22	7	1	5
Rubus chamaemorus	**0**	0	0	0	0	**9**	4	0	7	1	1
SPHAGNUM											
Acutifolia hummocks	**4**	5	9	5	3	**67.9**	3	18	0	4	4
Cuspidata lawns	**1**	0	0	3	0		8	34	7	1	5
OTHER MOSSES											
Dicranum polysetum	**2**	0	0	2	7	**29**	1	0	0	1	1
Polytrichum strictum	**2**	0	2	4	0	**15**	2	11	0	2	4
Pleurozium schreberi	**6**	0	2	6	14	**66**	8	5	7	12	8
LICHENS	10	0	10	10	20	-	3	1	0	11	6

In 1995 no species of the group Cuspidata were found in any of these zones. Within the zone of effective rewetting the percentages increased very sharply – from 0 to 34% in six years. Species in the group Acutifolia declined overall on the Major site, but these species increased sharply in the zone of effective rewetting (from 5-18%). In areas greater than 30 m from the main ditch, their levels remained stable while they decreased to zero in the area within 30 m of the main ditch but greater than 125 m from the dam.

4.4.2 Minor Site

Over the period of 6 years, from 1995 to 2001, the Minor site's vegetation community changed in the following manner. The cover of *Larix laricina* and *Picea mariana* found on the site increased but their cover remained well below the natural levels found at the Bois-des-Bel peatland, a nearby natural peatland (Table 4.2). Every species of ericaceous shrub decreased by a large margin during the six years. The 1995 levels were close to the natural bog percentages and the change to lower ericaceous shrubs represents a trajectory away from a natural bog. Very few herbaceous species were encountered in either year, though *Eriophorum spissum* did appear at 1% cover in the 2001 survey. There was an increase in the cover of *Sphagnum* between 1995 and 2001, but the 4% cover found in 2001 was well below the value found in natural peatlands. Excluding *Sphagnum*, moss percentages did not vary strongly between 1995 and 2001.

4.4.3 Comparison of Vegetation Between Two Rewetting Methods

The Minor site was rewetted as a result of secondary ditch obstructions. This is similar to the process employed in Chapter 3 and while it did not produce significant localized effects at the experimental site on the water table, we could not discount the possibility that overall site recharge was being improved. The Major site was rewetted more intensively in an area near the primary ditch dam and

Table 4.2 - Vegetation community surveys in 1995 and 2001 for the Minor Site, Riviere-du-Loup, Quebec. Bois des Bel survey results included for comparison

	% Frequency of Occurrence		
	1995	2001	**Natural**
TREES			
Larix laricina	5	7	**15**
Picea mariana	2	5	**85**
SHRUBS			
Kalmia angustifolia	78	48	**73**
Ledum groenlandicum	52	21	**65**
Rhododendron canadense	19	18	**29**
Vaccinium angustifolium	31	9	**55**
Chamaedaphne calyculatta	22	11	**43**
HERBACEOUS			
Eriophorum spissum	0	0	**2.7**
Rubus chamaemorus	0	1	**9**
SPHAGNUM			
Acutifolia hummocks	2	4	**Total**
Cuspidata lawns	0	0	**67.9**
OTHER MOSSES			
Dicranum polysetum	1	4	**29**
Polytrichum strictum	4	0	**15**
Pleurozium schreberi	7	9	**66**
LICHENS	13	8	-

produced an area of effective rewetting. Plant community changes in the Minor site did not vary spatially throughout the site, however, in the Major site significant changes were observed within the zone of effective rewetting. The following changes occurred in the zone of effective rewetting during the six years between the surveys: a complete loss of trees; very sharp decreases in ericaceous shrubs, a sharp increase from not being present in 1995 to 22% in 2001 for the species *Eriophorum spissum*, sharp increases in *Sphagnum* and an increase in *Polytrichum strictum.*

Both tree species decreased to zero inside the zone of effective rewetting but their decline was not restricted just to this area. At all points within the zone of effective rewetting, all trees encountered were dead. In the areas beyond this 30 m mark, tree populations declined at the Major site over the six years, but not to zero. The reduction in trees must be interpreted cautiously as the site had dead trees removed by the property owner after flooding. It is not possible to determine in this study whether living trees were removed as part of this program. This differs from the Minor site where the percentage of trees found in the survey increased. Ericaceous shrubs outside the zone changed in a similar manner to the Minor site with all species declining except *Rhododendron canadense.* Inside the zone of effective rewetting, the declines were more rapid but one species *Chamaedaphne calyculata* increased from 2% to 37%. Hebarceous plants outside the zone were similar to the Minor site as well.

4.5 Discussion

The goal of bog restoration has been defined as the return of *Sphagnum* dominance and diplotelmic layering that are required for peat accumulation and bog function (Rochefort, 2000). It must be recognized that these goals take place on temporal scales that are far greater than is available in the course of this study. In its place this study examines trajectories (SER 2002). The goal is a natural bog and changes in plant communities are measured to see whether they are moving towards or away from the natural model community. Motion towards the model community is interpreted as successful restoration and motion away from the model community is interpreted as unsuccessful. If a series of vegetative indicators all point in the direction of change towards a natural bog community it can be stated that there has been successful restoration of the site and that time should take care of the rest. In any study that uses reference ecosystems there is an inherent limitation in comparison. An ideal reference system would include a variety of sites from the region which would tend to average the non typical results found at any one site.

Examining both sites, we see that in the Minor site six species changed in a direction towards a natural bog during the six years while seven species moved away from a natural bog. At the Major site, six species moved towards a natural bog while six moved away and one did not change. Lichens were not included in the study as our study did not differentiate between species and the survey of the natural peatland did, as a result it was not possible to compare our results to the natural peatland. While it is true that same number of species are moving in the direction of a bog at both sites, there are differences in which types of species are moving towards a natural peatland. At the Minor site the species which are moving towards a bog are trees, *Rubus chamaemorus, Sphagnum* in the group Acutifolia and other mosses. While at the Major site, two species of ericaceous shrubs (*Rhododendron canadense* and *Chamaedaphne calyculata*), both vascular species, *Sphagnum* in the group Cuspidata and *Pleurozium schrebieri* are moving towards a natural peatland. The key difference here is in the preferred habitat of the species moving towards a bog – at the minor site, they are drier species, while at the Major site they are wetter. The magnitude of changes of both sites, as a whole, was not large with the possible exception of the strong increase in *Sphagnum* in the group Cuspidata at the Major site. Since *Sphagnum* is typically a wetter species and a keystone to bog formation, this one increase alone moves the site toward a more restored bog.

Using the trajectory towards a natural bog model considering only the area inside the zone of effective rewetting we observe that six species were changing towards a natural bog while six were moving away from the community as seen in the Bois-des Bel peatland; one did not change. As with the Major site as a whole, the species which changed towards a natural bog were wetter species and the changes within the zone of effective rewetting were responsible for a large percentage of the changes of the Major site as a whole. The scale of changes observed in the zone of effective rewetting were much greater than in any other area on either site, the key examples being the sharp decreases in some ericaceous species and the sharp rise in *Sphagnum* in the group Cuspidata. Within the zone of effective rewetting the area is moving more quickly towards a wet open bog community.

Peatland communities exist on a continuum from open bogs with many pools to dry treed bogs. For this reason, using only one reference site has limitations. An alternative to using one nearby reference site is to compare the results to an average peatland in the region. The block cut peatland we observed were moving towards both, depending on the level of human intervention. The minor site showed positive change towards a community that resembled a bog community but was lacking in the wetter species we typically find. The Major site and the zone of effective rewetting in particular, showed positive change towards a community that resembled a bog but was lacking the drier species of a natural site. The fact that all areas are moving towards a type of natural bog ecosystem is consistent with work conducted in the area over the past ten years. Girard, (2000), Lavoie et al, (2003), Robert, (1997) and this work support that natural processes in abandoned peatlands contribute to a slow change towards bog regeneration – at least in some areas. While the above mentioned studies have not examined process level causes, one distinct possibility emerges. After abandonment, drainage ditches gradually infill, either from slumping or over-growth of plant material (van Seters and Price, 2001). As the efficacy of drainage ditches decreases, available water increases on site and in the lowest areas or areas of increased water content, *Sphagnum* returns. The increased rate of return exhibited from human induced blockages is an acceleration of the natural processes already being demonstrated at block cut sites.

4.6 Conclusions

Flooding by blocking the primary drainage ditch at one location caused significant improvement in the plant community within a nearby zone of effective rewetting. Key community changes within this area included a loss of trees, a reduction in the frequency occurrence of ericaceous shrubs and an increase in *Sphagnum*, especially in the group Cuspidata. During the six years between inventories, both the Major site and Minor sites plant communities changed towards simplified communities that contained many of the species typically found in bogs. The Major site moved towards a wetter bog community while the Minor site moved towards a drier bog community. The changes with the zone of effective rewetting were more rapid than either site as a whole and represent an opportunity for accelerated restoration of block cut peatlands. Multiple main ditch dams have the potential to induce the responses observed near the main ditch dam at multiple locations.

5.0 GENERAL DISCUSSION AND CONCLUSIONS

Three strategies for restoring block cut peatlands were examined during the course of our two studies. These studies used the definition of peatland restoration provided in Rochefort (2000), a return of *Sphagnum* dominance with the return of diplotelmic layering, to evaluate the success or failures of these strategies. Specifically, the strategies were 1) the damming the secondary ditches and blocking the outflow at an 165 m x 615 m experimental site, 2) the effective damming of a primary ditch, this was completed by the peat company (hereafter called the Major site) and third strategy 3) was only to assess natural regeneration of a block cut site without any intervention (hereafter called the Minor site). Secondary ditch dams were installed in the fall of the year 2000 and hydrological parameters were studied during the growing season of 2001 to examine the hydrology of the site, measurements began after the snowmelt period. Secondary ditch dams were ineffective in altering the hydrology to a significant degree. It was not possible to analyze community changes as a result of the secondary ditch damming intervention due to the short time frame of the study. The damming of the main ditch had been done in both the experimental site and the Major site, the Major site providing a comparison of hydrological differences and plant community changes. The Major site that was actively restored was not monitored for hydrological parameters and produced results only on the community changes over time.

The damming of secondary ditches (experimental site) on formerly block cut peatlands was not successful in altering the hydrology in a positive manner at the trench level. Hydrologically, different numbers of dams of secondary ditches per trench did not significantly affect water table position or soil tension in the trenches studied. In the absence of improved hydrology, it is unlikely that this measure would improve the conditions to a point that would cause the return of

Sphagnum, our desired outcome. Reasons for the ineffectiveness of these dams became apparent when the water level quickly became subsurface on the site. Surface runoff was not effectively trapped for any extended period of time behind the dams and the position of the water table was highly correlated with topographic differences on the site. As noted, one possibility that cannot be discounted by this study is that water was trapped by the secondary ditch dams after the spring melt and that this water was evenly distributed beneath the surface. If this occurred the site would be improved in terms of hydrological parameters when compared with sites without these dams, however this improvement, if it occurred, could not maintain the water table above 40 cm below the peat surface – a critical value for the regeneration of a *Sphagnum* carpet.

The main ditch dam at the Major Site did affect the position of the water table and soil tension positively within a semi-radial area. Without knowing whether the secondary ditch dams improved water retention of the site as a whole during the snow melt period, we do know that they were ineffective in significantly affecting the local water table position of individual trenches. The potential success of the main ditch dam at this location is offset by the fact that water tables at all distances from the main ditch dam were below the -40 cm threshold necessary for *Sphagnum* survival, for a significant time at the end of the summer. The main ditch dam that flooded a portion of the Major site caused a widespread change in the plant community that included a sharp return of *Sphagnum*. By our definition, this increase in *Sphagnum* is a success as it forms one of the keys to peatland restoration, but we have not yet obtained *Sphagnum* dominance on the site as a whole. The process of restoration involves time and as such we need to find surrogates for measuring success. In our study we used surveys that were completed before and after the flooding and compared how plant community's changes compared to a nearby natural peatland. All changes that were closer to the natural peatland were considered positive, while those that changed away from a natural peatland were considered negative. What we found was that neither site was moving towards or away from a natural peatland - they both were moving towards simplified versions of natural peatlands. In the site that did not have a main ditch dam, drier species percent cover values were moving towards a natural peatland model while typically wetter species cover values were moving away the natural model. At the site where the main ditch dam was found the opposite was true; wetter species percent cover values were moving towards a natural peatland model while drier species values were moving away from the natural model. The rate of change for both sites as a whole was not strongly different but the path they were on certainly was.

Our study was consistent with other work undertaken on block cut peatlands in Quebec and internationally. Cutover bogs in north-west Europe were re-colonized by dry heathland species prior to rewetting (Salonen, 1990) while a block cut site in Ontario that had been abandoned for 24 years was re-colonized by an ericaceous-*Sphagnum* community (Jonsson-Ninniss and Middleton, 1991). This is similar to the Minor site where, without active intervention, it was re-colonized by dry bog species. *Sphagnum* was found on the site, but typically it was associated with the wetter drainage ditches, as was the case in other block cut peatlands in Quebec where *Sphagnum* only grew in limited areas where hydrological thresholds were not crossed (Price and Whitehead, 2001, Lavoie *et al.*, 2003,). *Sphagnum* re-colonization, without intervention, was documented in sites in eastern Canada where succession from isolated instances of *Sphagnum,* either in trenches or in association with nurse plants, lead to its dominance (Robert *et al.*, 1999). Our study did not observe these levels of *Sphagnum* cover on any site without surface flooding. A general study of block cut peatlands in eastern Canada found *Sphagnum* percentages on these sites generally higher than on the Minor site (Desrochers *et al.*, 1998). Regionally, *Sphagnum* covered 10 to 30% of block cut trenches, while at the Minor site, this value was only 4%. The Major site was consistent with other flooded sites in *Sphagnum* in the group Cuspidata rapidly filled in the areas of shallow flooding (Joosten, 1995).

What does this leave us with as we attempt to discern the best means of restoration? First, we have good evidence to believe that secondary ditch modifications will not provide the solutions required. There remains the potential that greater retention of snow melt occurred and with time improved rewetting could occur. Main ditch dams can provide the means to bring back *Sphagnum* quickly if they provide a strong seal and flooding during most, if not all, of the growing season. Without human intervention, block cut peatlands will likely continue on a progression towards an ecosystem that resembles a natural peatland but is dominated by drier species typically found in a natural peatland. With the addition of a main ditch dam that creates flooding, the block cut peatland will likely continue on a progression towards an ecosystem that resembles a natural peatland but is dominated by wetter species typically found in a natural peatland. In our study one dam was limited in its ability to alter the site composition as a whole. The best chance of rapid restoration success comes from a strategy that uses multiple main ditch dams to create several flooded zones that produce the rapid vegetation community changes observed at the Major site.

To conclude, no significant effects were demonstrated on either the position of the water table or the soil tension throughout the site as a result of the number or location of secondary ditch dams built on the secondary drainage system. Placement of a primary ditch blockage on the main drainage system did have a significant and positive effect on the position of the water table within a zone of effective rewetting. This zone of effective rewetting extended between 100 and

150 m in a radial fashion from the main ditch dam. Soil tension was also positively influenced with its proximity to the main ditch dam.

Vegetation changes towards bogs were observed at both block cut sites with a main ditch dam and without main ditch dams. The species that were moving towards a natural bog on the absence of main ditch dams were drier peatland species, while in the presence of a main ditch dam wetter bog species were moving towards a bog. On the site where flooding was induced, the rate of change within a 30 x 150 m zone of effective rewetting were considerable more rapid than in either site as a whole. Multiple main ditch dams that induce flooding provide the best opportunity for quickly re-establishing *Sphagnum* dominance on block cut peatlands.

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