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thesis entitled

The Effects of Hydrology, Microtopography and Water Chemistry on Northern White-Cedar Regeneration in Michigan's Upper Peninsula

presented by

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has been accepted towards fulfillment of the requirements for

Masters degree in Forestry

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Date July 14, 1994

THE EFFECTS OF HYDROLOGY, MICROTOPOGRAPHY AND WATER CHEMISTRY ON NORTHERN WHITE-CEDAR REGENERATION IN MICHIGAN'S UPPER PENINSULA

By

Rodney Allen Chimner

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTERS OF SCIENCE

Department of Forestry

1994

ABSTRACT

THE EFFECTS OF HYDROLOGY, MICROTOPOGRAPHY AND WATER CHEMISTRY ON NORTHERN WHITE-CEDAR REGENERATION IN MICHIGAN'S UPPER PENINSULA

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Many harvested cedar sites have not regenerated back to cedar, but have been colonized by species such as balsam fir (*Abies balsamea* M.) and tag alder (*Alnus rugosa* DuRoi.). A naturally regenerating cedar swamp on Michigan State's Upper Peninsula Tree Improvement Center (UPTIC), near Escanaba Michigan, was used to study this problem. Significantly more cedar regenerated in some areas of the study site while large numbers of alder and shrubs regenerated in other parts. Twenty-four plots (6m x 6m) where established to collect data on; hydrology, water chemistry, microtopography, stand composition and stem density. Density of cedar regeneration was positively and significantly correlated with high density of hummocks and greater unsaturated soil depths. Cedar regenerated best in drier conditions compared with alder and shrubs which regenerated best in the wetter areas of the swamp.

This research is dedicated to everyone involved with northern white-cedar, especially those who work long hours in cedar swamps.

ACKNOWLEDGMENTS

I would first like to thank Dr. Bud Hart for his assistance and guidance on my graduate program and research. Plus his ability to allow me the freedom to chase my educational dreams but yet still be there to keep me focused and in the right direction. I would also like to thank my committee members, Dr. King and Dr. Lantagne for greatly aiding me with my thesis.

I am deeply indebted to Ray Miller for all his help and insights on this project. Everything that I have learned about cedar, I owe to him in one way or another. I am also very thankful to the UPTIC staff of Brad Bender and Kyle Zuidema. This research project would have been impossible with out their hard work and help. I also owe thanks to Mike Zuidema for his cedar knowledge and flexibility to allow me to pursue my research while doing research for him.

I would like to thank U.P. Whitetails for helping fund my research and others like it. I commend you on your concern and ability to take action.

Thanks must be given to Andy Burton for all his help and ability to run the DC-Argon Plasma machine. I would like to thank all my friends in the Forestry Department who made graduate school a positive experience which I will never forget. Special thanks to Sigrid Resh and my family. They have always been there for me, even if they didn't know it.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Introduction

Northern white-cedar (*Thuja occidentalis* L.) occupies roughly 2 million acres of commercial forest land in the northern Lake states with three-fifths occurring in northern Michigan. The majority of northern white-cedar stands occur in forested wetlands with organic soil (peatlands). Usually northern white-cedar are intermixed with balsam fir (*Abies Balsamea* M.), black spruce (*Picea mariana* M.), tamarack (*Larix laricina* Du Roi) and black ash (*Fraxinus nigra*) (Johnston, 1977).

The demand for northern white-cedar forest products coupled with high browse demand by wildlife have caused a serious crisis. Most cut cedar sites have not regenerated back to cedar stands, but instead have been replaced by species such as tag alder (*Alnus rugosa* DuRoi), balsam fir and red maple (*Acer rubrum* L.)(Nelson, 1951; Zasada, 1952; Thornton, 1957). A recent Michigan Department of Natural Resources study shows that 50 years after cutting in a cedar swamp, cedar is still absent with tag alder and balsam fir dominating in the cut areas (Miller, Chimner & Zuidema, 1994). Because cedar regeneration success has been so low, a partial moratorium on cutting cedar has been instituted in the region by both state and federal agencies until suitable regeneration systems can be developed (Miller, Elsing, Lanasa & Zuidema, 1990).

Many reasons for such low cedar regeneration success have been suggested through the years. The reasons are mainly concerned with either silvicultural practices, or with over browsing by wildlife. Both of these factors are extremely important when trying to regenerate cedar. Hydrological processes are another area that must be understood if a complete picture of cedar regeneration is to be drawn. These hydrological processes have been largely ignored or only casually discussed in previous research.

All natural wetland functions are a result of or are related to the hydrology of the wetland (Carter, Bedinger, Novitzki & Wilen, 1978). As a result, when dealing with forestry in wetlands, the hydrology must be taken into consideration along with normal silvicultural considerations and techniques. In fact, hydrology is probably the single most important process in determining the chemical and biological characteristics of wetlands (Mitch & Gosselink, 1986).

Another consideration that must be taken into account when working with wetland forestry is the microtopography of the area. Microtopography is micro relief (e.g., hummocks) that is common in peatlands. The microtopography throughout the wetland interacts with the hydrology creating many diverse micro habitats.

This research was conducted to follow up results of a preliminary study which found an increasing number of northern white-cedar regenerating near a railroad ditch. My objectives were to determine if hydrology, microtopography and water chemistry of the area affected northern white-cedar regeneration. In order to better understand the research results, a literature review on peatlands, peatland water chemistry, peatland hydrology and peatland microtopography follows.

Peatlands

Almost 15 million acres of peatlands have formed in the Great Lake States region since the end of the glacier period (Boelter & Verry, 1977). Peatlands are wetlands that accumulate organic material (peat) by creating more biomass than can be decomposed. The rate of peat accumulation is dependent on two opposing factors, rate of production and decomposition rate of plant matter (Romanov, 1961; Ivanov, 1981; Stanek & Worley, 1984; Winter & Woo, 1990).

Different origins of peat deposits can form slightly different physical properties. Peat is classified by its origins in four main categories; sedimentary (i.e. floating aquatic plants, algae), moss (remains of mosses), herbaceous (i.e. remains of cattails, sedges, reeds) and woody peat (i.e. remains of trees, shrubs). Peat deposits become parent material for organic soils (Histosols). As peat deposits weather, they decompose from identifiable plant material to unidentifiable material that resembles colloidal clay. Fibric is the least decomposed peat and can be identified by the characteristic that almost all the organic residue is identifiable. Hemic is partially decomposed where only part of the organic residue can be identified. Sapric material is the most decomposed with no identifiable organic residue. Organic soils are described by their degree of decomposition. If the organic soil is fibric, than it is referred to as peat soil. Sapric deposits are referred to as mucks, while hemic deposits are called mucky peats (Soil Survey Manual, 1993).

Many physical properties are determined by the level of peat decomposition (Table 1). The more decomposed the peat, the lower the hydraulic conductivity. Fibric peat has large pores which are easily drained while sapric peat has a consistency and hydraulic conductivity similar to that of clay. The rate of water movement through sapric peats are often a thousand times slower than that of fibric peats.

Table 1. Range of important characteristics of different decomposition levels of peat from the northern Lake States (Modified From Boelter and Verry, 1977).

Degree of Decomposition	Total Porosity (% volume)	Specific Yield (% volume)	Hydraulic Conductivity (m/d)	Bulk Density (g/cm3)
Fibric	>90	>45	>1.3	<0.09
Hemic	84-90	10-4	0.01-1.3	0.09-2.0
Sapric	<84	<10	<0.01	>0.20

As organic material begins to accumulate, the older more decomposed bottom layers become buried by the newer less decomposed top layers. This creates a vertical profile within peatlands. This vertical zoneation in peatlands is often delineated into two horizons, a relatively thin active layer (acrotelm) and a usually thick inactive layer (catotelm). The active layer is the upper most layer composed mainly of fibric peat. This layer is porous and has a high hydraulic conductivity. The acrotelm is subjected to frequent fluctuations of temperature, moisture and aeration. Most root systems do not penetrate below the acrotelm into the catotelm. The lower inactive layer is comprised of sapric and hemic peats. The catotelm has a very low hydraulic conductivity which allows very little water to flow vertically through peatlands. (Boelter & Verry, 1977 & 1978; Ivenov, 1981; Winter, 1988)

Peatland water chemistry

Peatlands can be classified by their hydrological inputs and chemical characteristics. Bog peatlands are isolated from the groundwater table (ombrotrophic) with precipitation as their only source of water input. Bogs generally have low pH, base status and nutrient levels. They are normally considered to have low biodiversity consisting mainly of black spruce (*Picea mariana*), sphagnum mosses (*Sphagnum* spp.), leather leaf (*Chamaedaphne calyculata* L.), blueberries (*Vaccinium* spp.) and sedges (*Carex* spp.). Fen peatlands have groundwater inputs (minerotrophic), and generally have a higher nutrient status and pH than bogs. Fens, therefore, have a greater diversity of species and higher productivity. Some species associated with fens include; northern white-cedar, tamarack, balsam fir, sphagnum mosses, sedges and numerous other species (Boelter & Verry, 1977; Brown, 1988; Crum, 1988; Cwikiel, 1992).

Peatland water chemistry is primarily determined by the source of their hydrological inputs. Bogs, which are fed by atmospheric deposition, have water chemistry similar in composition to that of rain water. The water chemistry of minerotrophic fens reflect the composition of the surrounding basin. The geology and soils of the area interact with the local groundwater and surface water, which in turn determines the water chemistry of the fen. For example, groundwaters in calcareous terrain contain large amounts of calcium and magnesium, while groundwaters in granitic basins contain low amounts of these elements. The nutrient status of fens located within these different watersheds would be very different (Verry, 1975; Shotyk, 1984).

Fens can be further classified by their water chemistry. Glaser et al. (1981, 1990) delineated peatland types by pH, specific conductivity and calcium groundwater levels (Table 2). A strong correlation was noticed in northern Minnesota between specific conductivity, calcium and pH levels of the groundwater and distribution of northern white-cedar with cedar being an extremely rich fen indicator species.

Table 2. Calcium, specific conductivity and pH levels for peatland types ((Glaser et al., 1981, 1990)

Peatland type	pH	Specific Cond (uS cm-1)	Calcium (mg/l)
Extremely Rich Fen	>6.8	>82	>20
Rich Fen	6.0-6.8	23-82	10-20
Poor Fen	4.3-6.0		3-10
Bog	<4.3	12-27	<3

Water flow and chemistry are primary factors in northern white-cedar distribution and growth (Pregitzer, 1990; Glaser et al., 1991). Many studies report that cedar are found in areas with neutral to basic pH levels (5.5 - 8.0), with high nutrient and oxygen levels (Curtis 1946; Nelson 1951; Satterlund 1960; Johnston 1990; Miller, 1992). It has also been reported that cedar are often found associated with areas of lateral flow and not in stagnate water (Johnston, 1990).

Wetland soils differ from upland soils by the presence of a high water table. As a result of the high water table, oxygen diffusion rates decrease and anaerobic conditions often occur. As the oxygen decreases, several chemical and biological changes take place. The resulting changes usually follow a sequential pattern caused by the oxidation and reduction of compounds within the wetland system. Oxidation-reduction reactions involve transfer of electrons from electron donors to electron acceptors. Oxidation is the loss of electrons while reduction is the addition of electrons. Reduction is usually accomplished through the respirational oxygen consumption of micro-organisms. The oxidation reduction cycle is reversible. Any compound that can be reduced can be reoxidized back to its original form. The redox state of each compound is important because reduced forms have different properties than oxidized forms (Patrick, 1978; Patrick & Jugsujinda, 1992).

As long as oxygen is in adequate supply, aerobic micro-organisms dominate the system keeping the other electron acceptors inactive. The elimination of oxygen from the system, by flooding or other reducing environments, brings into action other micro-organisms that can utilize alternate electron acceptors that are more difficult to reduce than oxygen.(Patrick, 1978; Sikora & Keeney, 1983).

In wetland systems, two distinct oxygenated zones are present. There is an upper oxygenated layer over a lower anaerobic layer (Patrick, 1978). The top layer of oxygenated water is often attributed to atmospheric mixing and photosynthesis. This oxygen rich layer can vary from 2 - 18 ppm oxygen and is often no more than a centimeter deep (Yoshida, 1975). This thin layer of oxygenated water plays an important role within the wetland by providing a place for aerobic chemical transformations and nutrient cycling to occur (Mitch and Gosselink, 1986). Without this upper oxygen rich layer, some compounds can become toxic in reduced conditions. For example, the upper aerobic zone plays an important part in the nitrogen cycle for wetlands. In reducing wetland systems, nitrate is reduced to ammonium, which in high concentrations can become toxic, but the thin layer of oxidized water allows for nitrification to take place reducing the amount of ammonium in the system (Mitch and Gosselink, 1986).

Underneath this oxidized layer is a zone of reducing conditions. Some studies have found that conditions become more reducing with depth, while others have shown cases where bogs have an oxidized layer where it comes in contact with the groundwater table (Shotyk, 1984). In effect, unsaturated peat profiles can have an oxidizing layer at the top and bottom and have reducing conditions in the middle.

Peatland hydrology

Depth to the water table is an important aspect in tree germination, growth, survival and stand composition. Research in Finland reveals that root growth, survival and tree height of lodgepole pine (*Pinus Contorta*) within a peatland are related to the depth to the water table. The lower the water table, the better the conditions for lodgepole pine (Boggie, 1972).

In Minnesota, Lieffers (1989) found increases in basal area growth for black spruce and tamarack were negatively correlated with depth to the water table. He concluded that average depth to the water table should be at least 50 cm for optimal basal area increment.

Water table depth is important for tree growth and regeneration for several reasons. High water tables decrease aeration of the soil restricting root growth and lower redox potentials which alters nutrient availability. McKee (1970) found that the depth to the water table is strongly correlated with redox potentials. According to Burke (1967), soil aeration is the most important factor involved in tree growth and survival in poor drainage areas. Most trees species that grow in peatlands, cedar included, have the majority or their roots within 20-30 cm of the surface (Vompersky, 1968). Satterlund (1960) reported that northern white-cedar roots normally do not penetrate much below the average high water table depth in the growing season.

A convenient way of studying the effects of water table depths on tree growth is to observe tree growth perpendicular to a drainage ditch. Northern white-cedar has long been reported to have better growth near ditches. In 1930, Zon and Averell recorded excellent diameter growth increases for cedar after ditching. The increased growth decreased rapidly as you moved away from the ditches, and disappeared completely around 150 feet from the ditch. The percent increase in growth next to the ditches varied from 78% on excellent sites to 126% on good sites with poor sites increasing 113%. LeBarron and Neetzal (1942) found increased diameter growth for cedar in a swamp up to 200 feet away from a road ditch.

The distance which a ditch can lower a water table is influenced by the degree of decomposition of the peat. The more decomposed the peat, the lower the hydraulic conductivity and hence the shorter the distance of ditch drawdown. Highly decomposed sapric material will have a very short ditching distance compared to less decomposed fibric peat. The vertical zoneation of peatlands creates two different hydrological conditions. The upper acrotelm allows rapid water movement while the lower catotelm restricts water movement. Rapid removal of water by runoff or draining can occur when the water table is above the catotelm but is reduced dramatically when the water table drops into the catotelm (Boelter, 1972; Crum, 1988).

Boelter (1972) reported that in a northern Minnesota bog, the water table was lowered only at a distance of five meters or less when the water table was in the hemic peat (catotelm), while the upper fibric layer (acrotelm) was effectively drained at a great distance.

A high water table can do more than slow growth. Excessively high water tables can kill cedar. For example, roads with poorly constructed culverts have impeded drainage, raising water table levels which killed trees or drastically reducing their growth on thousands of acres in forested peatlands in the Great Lakes region (Johnston, 1977).

Besides poor road building, timber harvesting can cause water tables to rise in peatlands. In general, the heavier the harvest the higher the water table will rise. The rising water table is due to lower rainfall interception and decreased transpiration. Clearcuts have been reported as rising water table levels up to 10-40 cm, while thinnings caused a smaller rise from 1-10 cm depending on the degree of thinning (Heihurainen, 1968; Heihurainen & Paivanen, 1970). But not all not all clearcuts cause a similar rise in water tables. Verry (1980) reported very little rise in water table levels after harvesting in Minnesota.

Besides raising water table levels, clear-cutting on peatlands has also increased the number of grasses and sedges occupying an area (Verry, 1980). Grasses and sedges compete directly with cedar seedlings (Nelson, 1951). Therefore an increase in herbaceous plants would be detrimental to northern white-cedar seedling establishment.

Peatland microtopography

Anyone who has ever been in a peatland knows that the surface is very rarely even, but instead has an undulating morphology. This undulating surface creates areas of elevated hummocks and depressional pools or hollows. Such diverse microtopography allows for tremendous variation in habitat, species composition, hydrological regimes and chemical conditions throughout peatlands (Pregitzer, 1990).

The depth to the groundwater has a strong effect on the establishment and growth of individual tree species. Thus microtopography also has a strong effect by altering the relationship between groundwater levels and the trees. Elevated hummocks provide an aerated unsaturated growing medium in an area surrounded by saturated conditions. These drier spots are often the only places regeneration of trees, alder excluded, takes place within peatlands. Trees are often found in dense clumps on the hummocks while the pools are usually uninhabited by trees (Vompersky, 1968).

Satterlund (1960) found that hummocks in forested peatlands in the Upper Peninsula of Michigan, are the most favorable microtopography type for regeneration and growth of forest trees. Flat (intermediate) areas are moderately favorable sites while depressions (pools) are very unfavorable sites for tree growth. Hummocks are the only favorable sites for tree growth and regeneration when the water table is shallow (< 46 cm below average surface elevations). However, when the water table remained more than 46 cm below mean surface elevation, flat areas became favorable sites for trees along with hummocks. Depressional areas were found not to be favorable sites for trees at any water table depth in peatlands.

Microtopography can be used to increase seedling growth and survival. Artificial hummocks (i.e. beds) can be built within wetlands to provide habitat for seedlings. This practice creates an effect similar to draining, but instead of lowering the water table, seedlings are elevated on artificial hummocks. This effectively increases the amount of aerated soil in the seedling root zone by increasing the distance seedlings are above the water table. Once seedlings become established they are capable of lowering the water table through transpiration further improving their growth (McKee, 1970; Smith, 1986)

Northern white-cedar germination

Northern white-cedar seedlings germinate in a variety of moist mediums but become established only on a few. The main requirements for establishing cedar seedlings are constant unsaturated moist conditions and warm temperatures (Johnston, 1990). In Nelson's (1951) study on reproduction of northern white-cedar, seedling mortality was caused by various factors (in decreasing order of significance): desiccation, spring frost, root rot, litter and duff smothering, poorly developed root systems and competition from grasses. Nelson (1951) also noticed that seedlings do not germinate on alder litter. His opinion was that the alder litter dried out in the summer creating unfavorable conditions for cedar seedlings. He also noted that northern white-cedar seedlings are found most often on decayed logs, but were also found on moss mats, mineral and organic substrates.

Curtis (1946) also made several observations on cedar seedling mortality. Seedlings are less likely to survive on top of old stumps and high hummocks (due to desiccation) than they are in rotted wood on the forest floor. Sphagnum mosses, when they become deep, can smother and kill seedlings (Curtis, 1946).

Browsing is a serious threat to cedar seedlings. Cedar is a valuable food source for white tailed deer (*Odocoileus virginianus*). Northern white-cedar is the only food source in northern Michigan from which deer can get all their nutritional needs during the winter (Verme, 1965). Cedar swamps are in high demand as deer yards in the winter not only for food, but also because they provide shelter from the elements. Because of slow growth, cedar are vulnerable to browsing for many years (maybe up to 20 years). Slow growth and high browsing demand makes cedar hard to regenerate. It is well documented that cedar seedlings in the browse size class are hard to find if not completely eliminated from many stands (Curtis, 1946; Nelson, 1951; Miller et al., 1994).

In summary, cedar regeneration after harvesting is often unsuccessful, leading to stands of tag alder and balsam fir. The reason for this is not understood very well, but since hydrology is the main controlling agent in a wetland system, cedar regeneration might be tied in with hydrology. Research in this area is lacking with more known about the silvics of northern white-cedar than it's relationships to hydrology.

CHAPTER 2

OBJECTIVES AND METHODS

Site location, history and preliminary study results

This study was conducted at Michigan State University's Tree Improvement Center (UPTIC), near Escanaba Michigan (Figure 1). Property lines were cut and surveyed through the southern area of UPTIC during the winter of 1991/1992. While surveying this area, it was discovered that a clear cut from an adjacent property extended partially on UPTIC's property. Looking over this area, the survey team noticed a great difference in the density of cedar regenerating along the property line. Large numbers of regenerating cedar were encountered near the railroad tracks and accompanying ditch, but numbers declined rapidly as you moved away from the tracks.

In the following summer of 1992, a small exploratory study was done by Joe Feldman and the UPTIC staff to determine if there was indeed a statistical difference in the number of regenerating cedar within the study site (Figure 2). Six transect lines, about 30-35 meters apart, were cut roughly parallel to the ditch along the railroad tracks (Figure 3). On each of these transect lines, four plots (6 m x 6 m) were established at roughly 15 meter intervals. At each of the 24 plot locations, the number and type of trees and shrubs over one foot in height were

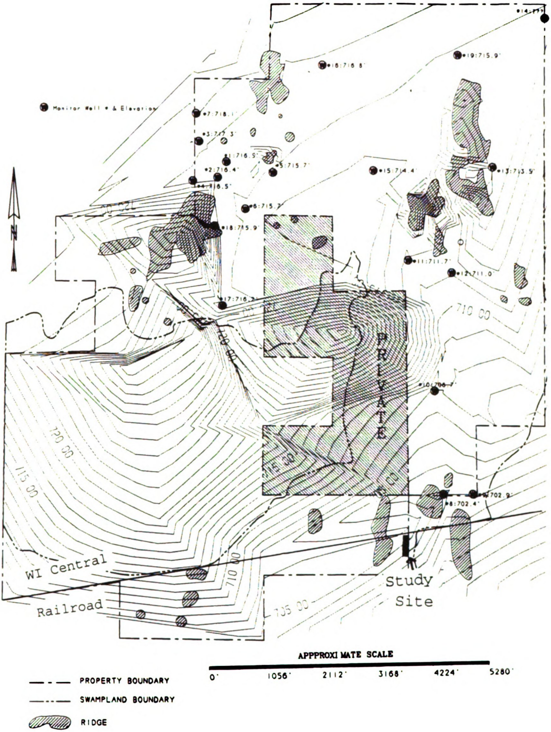

Figure 2. Location of cedar study site within UPTIC wetland complex (lower right) and estimated surface contour lines.

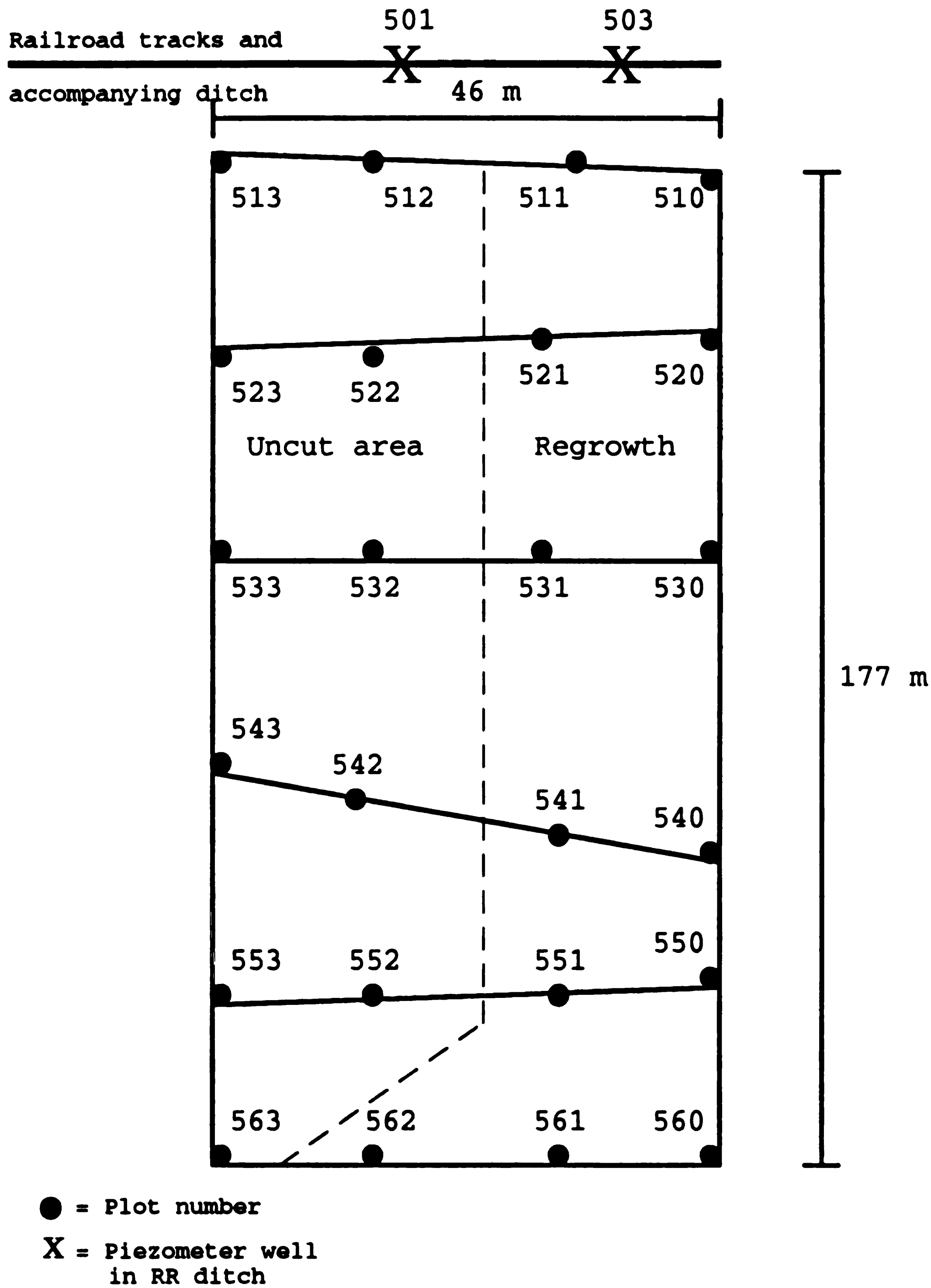

Figure 3. Study site layout.

counted. Also at each plot location, the depth of organic soil was measured at one spot by inserting a long rebar into the organic soil until mineral soil was encountered. During the winter of 1992/1993, the average elevations for each plot were surveyed.

The exploratory study found a significant difference in the density of regenerating cedar near the tracks with the highest density of cedar occurring near the tracks. It was concluded that the difference seen in the number of cedar regenerating was due somehow to the influence of the railroad ditch along side the tracks (Ray Miller, personal communications). This study was conducted to follow-up on these preliminary findings.

Objectives and hypothesis's

The main objectives of this study were to determine factors related to cedar regeneration at this study site and suggest methods to successfully regenerate northern white-cedar. This was accomplished by looking at wetland hydrology, water chemistry and microtopography and their relationships to northern white-cedar regeneration.

The hypotheses were:

1) The ditch will lower the water table to a measurable distance away from the tracks.

2) The density of northern white-cedar regeneration is related to the depth to the water table.

3) Increased density of hummocks is associated with areas of higher northern white-cedar regeneration.

4) Calcium, pH, specific conductivity and dissolved oxygen levels are related to higher levels of northern white-cedar regeneration.

Research methods

The experimental design of the original preliminary study was used (Figure 3). Plot size and placement where not changed for this study. Data from the preliminary study used for this research include; stand composition of each plot, depth of organic soil at each plot, and average surface elevations at each plot. Additional measurements were taken on hydrology, water chemistry and microtopography.

Hydrology

To measure the groundwater of the area, 26 piezometer wells were built, inserted and surveyed within the wetland study site. Piezometer wells were built by cutting 2" PVC pipe into 2' lengths, drilling them full of holes and gluing a cap on the bottom. Piezometer wells where inserted by auguring a hole in the organic soil with a bucket auger and pushing the wells vertically downward. One well was inserted near the center of each of the 24 previously established plot locations, and 2 additional wells were placed in the railroad drainage ditch adjacent to the site (wells 501 & 503, Figure 3).

The groundwater levels were recorded every few weeks throughout the summer and fall of 1993 by inserting a modified meter stick into the piezometer wells. To minimize error, the meter stick was lowered until it was just touching the water surface and then read. Water table elevations were determined by subtracting the distance to the water table from the top of the piezometer well.

Water chemistry

Water samples were collected once during summer and again in the fall. The unfiltered water samples were immediately taken to a field laboratory where pH, specific conductivity, and dissolved oxygen levels where measured using a portable ICM-51601 water analyzer. The water samples were than refrigerated and taken to a Michigan State University laboratory for calcium analysis using DC-Argon plasma atomic emission spectrometry. The water was centrifuged for ten minutes to remove suspended sediments.

Water samples were collected from surface pools at each of the 24 plot locations plus two in the ditch. The only exception was during periods of low water when the pools were dry and water samples were collected from piezometer wells. The very low hydraulic conductivity of organic soil caused problems when trying to collect water from the Piezometer wells. When water was removed from the piezometer wells, it took several days for the well to refill, making it impractical to purge the well and then get clean water samples. It also made it difficult to record groundwater levels for several days.

Microtopography

Microtopography was classified into three main types: hummocks, pools and intermediate areas (Figure 4). For this study, hummocks were defined as elevated, convex shaped areas above the observed normal high water line. The observed normal high water line is the level where high water occurs often enough to cause a distinct difference in the topography and vegetation. The high water line was found by looking for significant topographic breaks which consistently occurred between the microtopographical types.

Pools are depression areas below the observed high water line. Pools are normally filled with water, but can dry out during dry summers. Pools were easily delineated by their concave shape and presence of black decomposing litter within them. Intermediate areas were defined as flat areas very near the normal high water level.

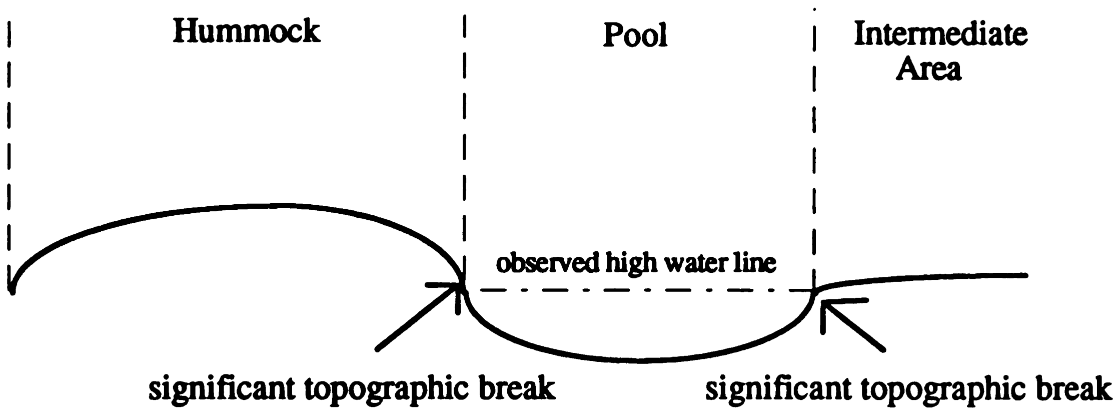

Figure 4. Microtopography types.

Microtopography for each plot was determined by two line transects 6 meters (20') long by 41 cm (16") wide in each cut plot, one oriented north-south and the other east-west through the center of each plot. Using the criteria above, the microtopographic types were delineated and their lengths recorded for each transect. Along with micotopography type, number and type of trees and shrubs were recorded. The two transects in each plot were than combined to calculate the percent of the area covered by each microtopography type.

Data analysis

Exploratory analysis of hydrology, microtopography, water chemistry, soil and stem density data included examinations of Pearson's product-moment correlation coefficients, graphs, means, minimums, maximums and standard deviations. Significance was determined by testing Pearson correlation coefficients at alpha=.05 (*). High significance was tested at alpha=.01 (**)

To achieve predictability, least-squared regressions were used. Predictions were done for density of cedar and shrubs regeneration using various hydrological, chemical, soil and microtopographical factors. Predictions were also done for water table fluctuations, dissolved oxygen and calcium levels.

Graphs are used to present untransformed data. Graphs also include the form of regression model, R^2 results and significance. Equations are discussed in the text. Curvilinear data were linearly transformed when needed to find the line of best fit. Regression models normally took one of the following forms:

Regression form	Regression model	Equation
Linear	Y=b+mX	Y=b+mX
Exponential function	lnY=lnb+mX	$Y=be^{mX}$
Power function	lnY=lnb+m(lnX)	$Y=bX^{m}$
Logarithmic function	Y=b+m(lnX)	Y=b+mln(X)

A constant of 1 was added to linearize cedar and shrub density (some plots had zero trees), to allow natural log transformations. Equations where this was done are listed as #cedar/plot-1 and #shrubs/plot-1.

CHAPTER 3

RESULTS AND DISCUSSION

Stand composition

The eastern half of the study site regenerated naturally after clearcutting in the mid-sixties, while the uncut western half was an older mature stand. There is a major shift in the forest composition from north to south in the regenerating area (Table 3, Appendix A). The northern portion of the study site is comprised mainly of northern white-cedar and balsam fir with black spruce in lesser numbers. Concurrently, the southern portion is dominated by tag alder, willows, dogwood, and balsam fir. Deer browsing was observed to be minimal and not a significant factor precluding cedar regeneration at this site.

Plot #530 was different from all the rest of the plots in composition. It was composed of mostly grasses with shrubs being the overstory. A dense layer of sticks and small logs where found under the grass composing the top most layer of the peat profile. The area is also the topographical lowest spot in the study site with very wet conditions for most of the year (Table 6). The reason for this isolated low grassy area is unknown, but is hypothesized to be caused by a harvesting process (i.e. old slash pile burn area).

Table 3. Summary of stand composition of study site (trees per plot)(for complete listing see Appendix A).

Plot #[1]	Cedar	Other Conifers[2]	Hardwoods[3]	Shrubs[4]
510 (C)	33	30	1	10
511 (C)	27	35	0	0
512 (N)	5	28	1	5
513 (N)	6	23	2	1
520 (C)	62	38	10	15
521 (C)	37	42	4	2
522 (N)	8	76	0	5
523 (N)	7	39	1	4
530 (C)	2	18	15	46
531 (C)	38	30	3	10
532 (N)	5	80	0	6
533 (N)	9	88	0	6
540 (C)	11	21	4	23
541 (C)	22	20	1	9
542 (N)	15	32	1	12
543 (N)	6	23	1	12
550 (C)	2	24	2	30
551 (C)	3	43	2	18
552 (N)	10	16	0	15
553 (N)	2	9	0	47
560 (C)	2	11	6	44
561 (C)	5	10	3	36
562 (C)	0	17	3	52
563 (N)	3	12	5	24

[1](C)= cut area, (N) = Uncut area (grouped by row from north to south).
[2]mostly balsam fir with some black spruce, tamarack and white spruce.
[3]red maple, quaking aspen, balsam popular, white birch, ash and cherry.
[4]mostly tag alder with some alternate leafed dogwood and willow.

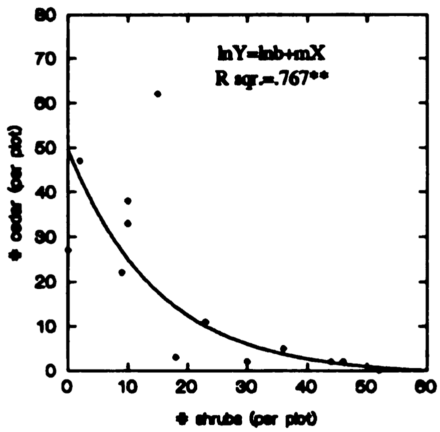

Figure 5. Graph of data with line of best fit, form of linear transformation and results of regression between density of cedar(# per plot) and density of shrubs (# per plot).

A highly significant negative correlation (Figure 5) was found between the density of regenerating shrubs (tag alder, dogwood & willows) and cedar found within a plot according to the equation: # cedar/plot-1 $=50.4\ e^{-0.0668*(\#\ \mathrm{shrubs/plot}-1)}$. This incompatibility has been stated in earlier studies and explained as suppression of cedar by either litterfall or competition from alder and shrubs (Curtis, 1946; Nelson, 1951). Another possibility is that cedar and shrubs require slightly different habitats. Cedar may not be growing where there are numerous shrubs not because they are being suppressed, but because they cannot grow there.

Soils

The north end of the study site borders railroad tracks and an accompanying ditch. The southern end of the site extends into a larger swamp with a small ridge to the west and south-west. The organic soils are mostly Tawas muck with small inclusions of Carbondale muck and Brevort mucky loamy sand. The soil interpretation for Tawas muck describes it as a surface layer of sapric peat with a substratum of sapric peat which developed from woody organic deposits within outwashes, lakes and till plains overlying sand. The hydraulic conductivities where not measured but are estimated to be very low (<0.01 meters/day).

The surface of the wetland is extremely flat with an average slope about one foot over the entire study site (Figure 6, Appendix D). The majority of the area is overlain with approximately 1 meter of organic soil which varies from under a third of a meter to a deep spot of almost 2 meters (Figure 6, Appendix D). The depth of organic soil was found to have no significant correlation with the number of cedar regenerating, water levels or water chemistry (Appendix C).

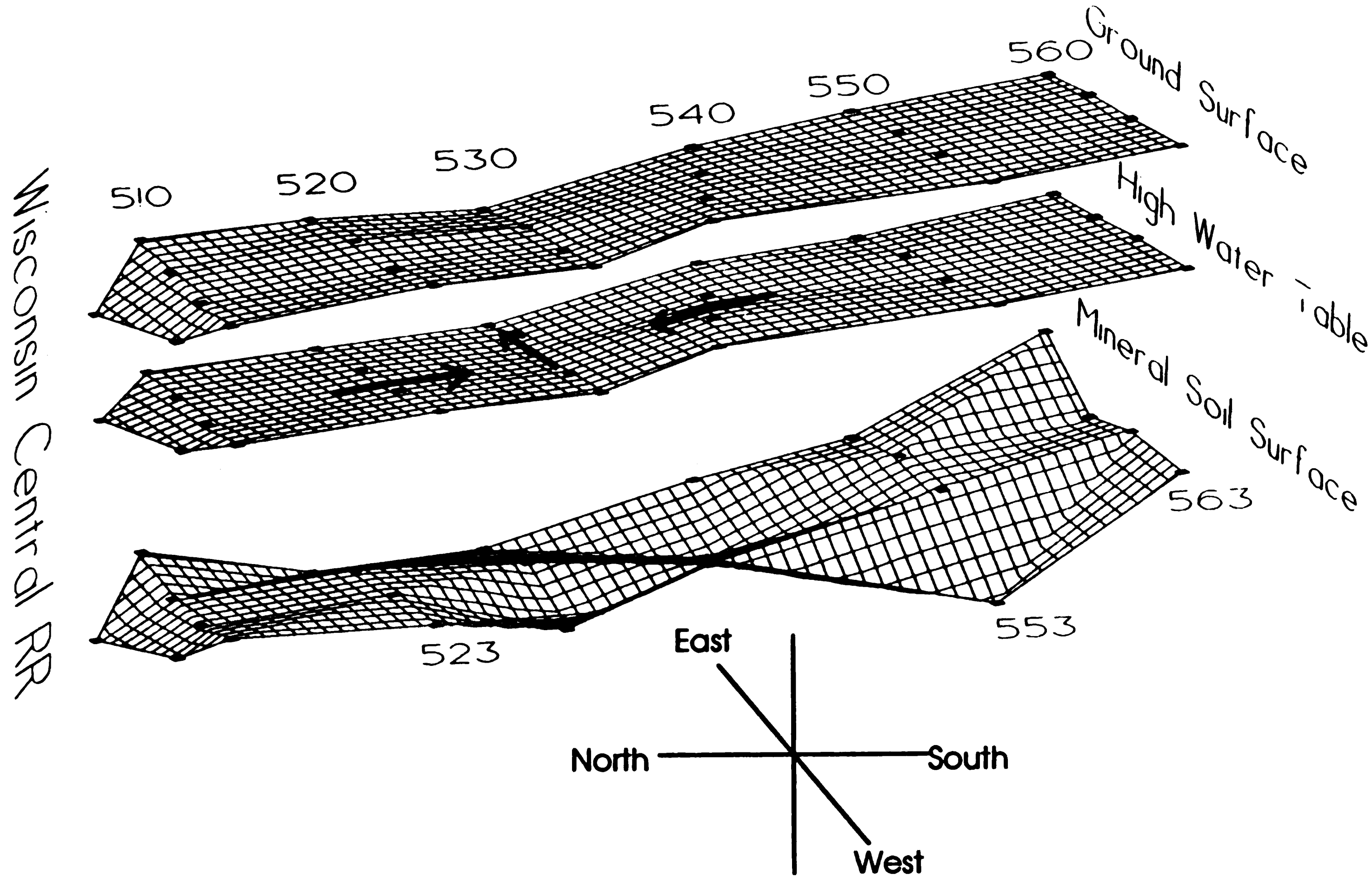

Figure 6. Ground, high water with flow lines and mineral soil surfaces.

Water levels

The piezometric surface converges towards transect line #530 from the north and from the south (Figure 6). Transect line #530 slopes east towards portage creek. This is locally different from the regional flow of groundwater which flows south towards the Ford river, which drains out to Lake Michigan. An explanation for this could be that the area of higher ground to the south and west, along with the ditch and Portage Creek to the north and east have caused the local piezometric surface to slope in different directions.

No significant effect of ditching was evident from the piezometic surface elevations (Figures 7, 8 & Appendix E). The ditch influence on the water table profile does not extend to the first line of Piezometer wells (3 to 7 m). This agrees with Boelter (1972) who reported a 5 meter ditch influence in a hemic peat. The sapric peat encountered in this study, with its very low hydraulic conductivity, should result in even less of a drainage influence than the 5 meters Boelter measured. It may be possible that the ditch may actually drain a large area and influence vegetation at some distance if the ditch is effective in rapidly draining the acrotelm but not effective in draining the catotelm. The draining of the acrotelm could drop water levels just enough to permit

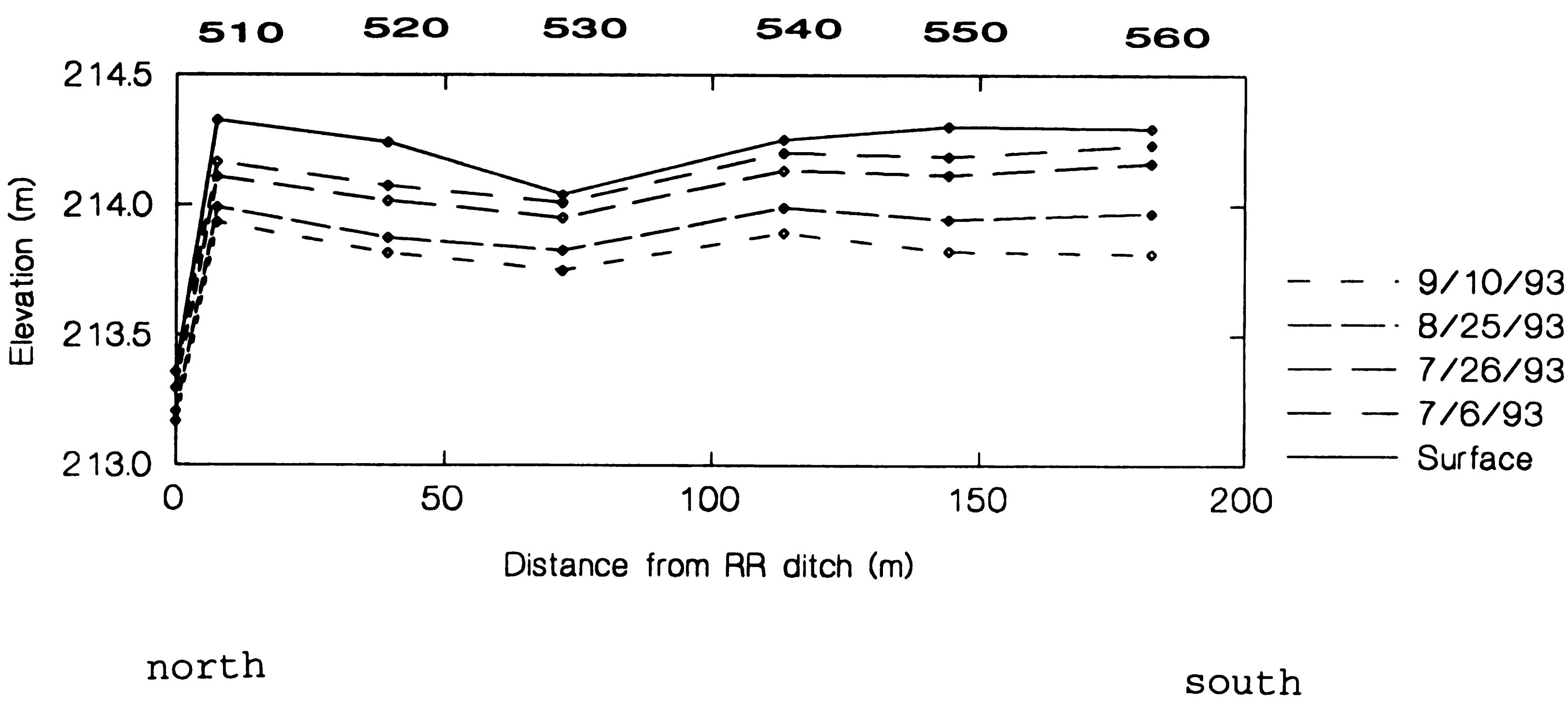

Figure 7. Water table profile (N-S) of wells 510-560 for 7/6/93 through 9/10/93.

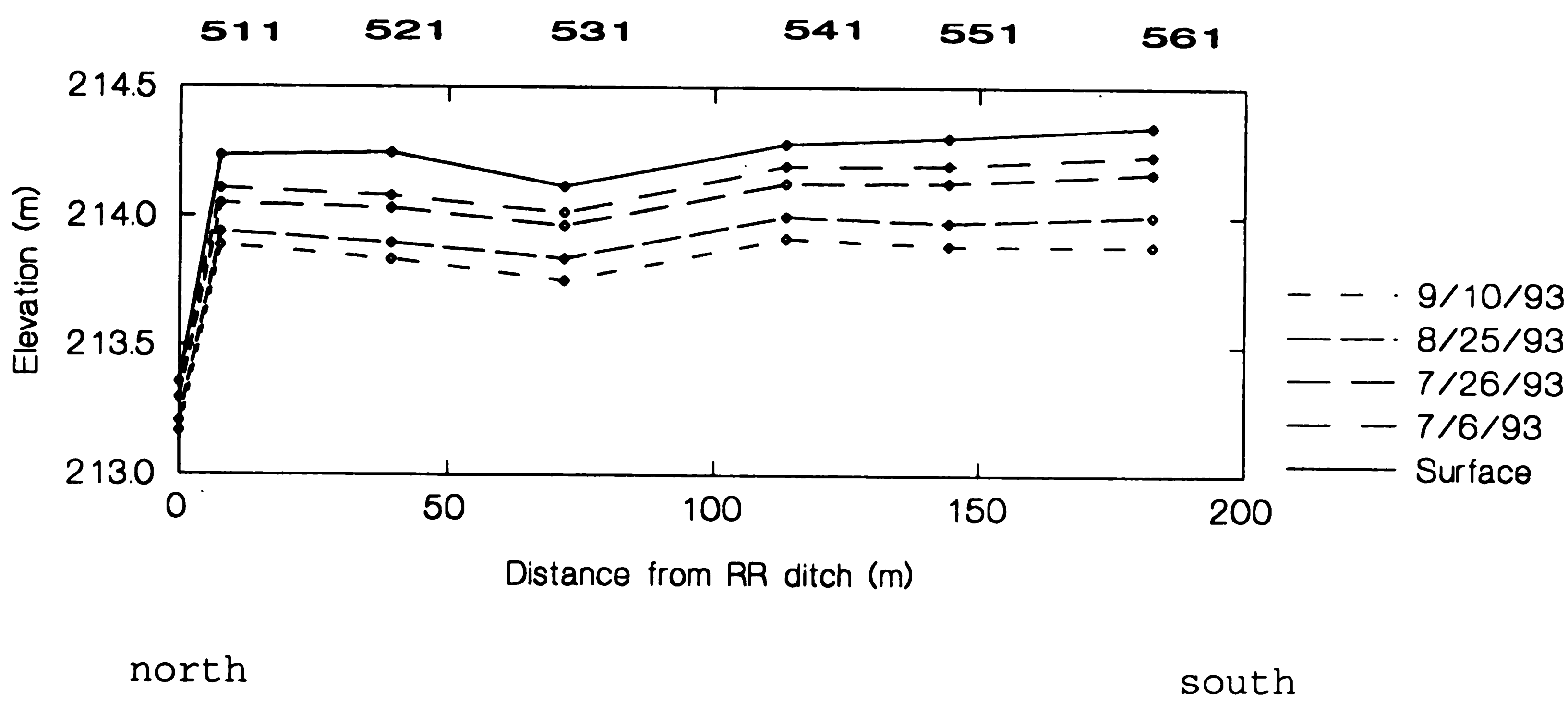

Figure 8. Water table profile (N-S) of wells 511-561 for 7/6/93 through 9/10/93.

higher establishment and growth of cedar, but this would go unnoticed unless water levels were recorded at least daily.

There is a significant relationship between the magnitude of the water table fluctuation during the growing season and distance from the railroad ditch according to the equation: cm fluctuation = $22*e^{0.0028*(\text{m from ditch})}$ (Figure 9). The fluctuation of the water table was calculated by subtracting the highest water table elevation by the lowest. The water table was found to fluctuate least near the ditch and increase at an increasing distance from the ditch (Appendix D). The fluctuation of the water table showed a highly significant relationship with cedar regeneration according to the equation: # cedar/plot-1 =210.1 x 10^{6} *(cm fluctuation)$^{\wedge-4.99}$ (Figure 10).

Satterlund (1960) reported that high water table levels in the growing season limit root growth for northern white-cedar. The high water table levels in the growing season also appear to play a role in cedar regeneration. The July 6th water table elevation (highest level measured in growing season) was significantly and linearly related with the number of cedar regenerating according to the equation: # cedar/plot =30,009.4-140(water table elevation in m) (Figure 11). There were no significant relationships between water

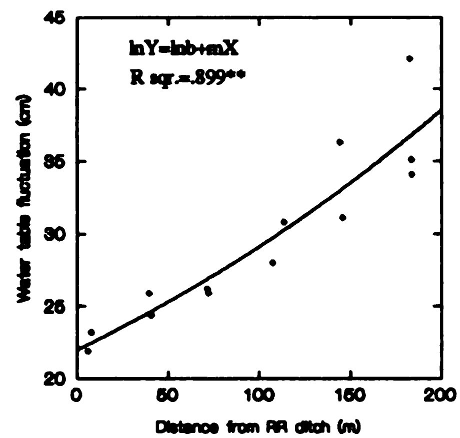

Figure 9. Graph of data with line of best fit, form of linear transformation and results of regression between the fluctuation of the water table (cm) and the distance from the railroad ditch (m).

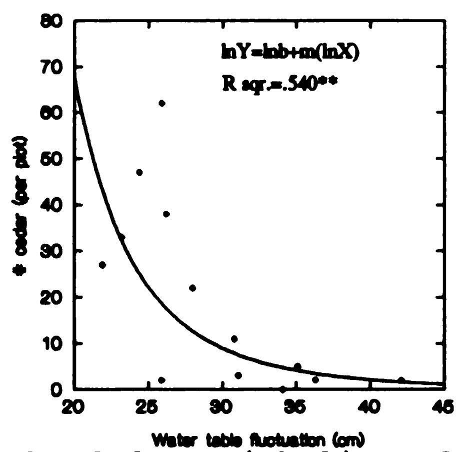

Figure 10. Graph of data with line of best fit, form of linear transformation and results of regression between the density of cedar regeneration (per plot) and water table fluctuation (cm).

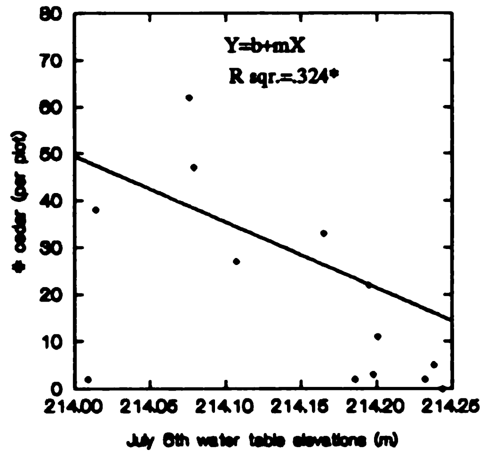

Figure 11. Graph of data with line of best fit, form of linear transformation and results of regression of July 6th water table elevations (m) vs. density of cedar regenerating (per plot).

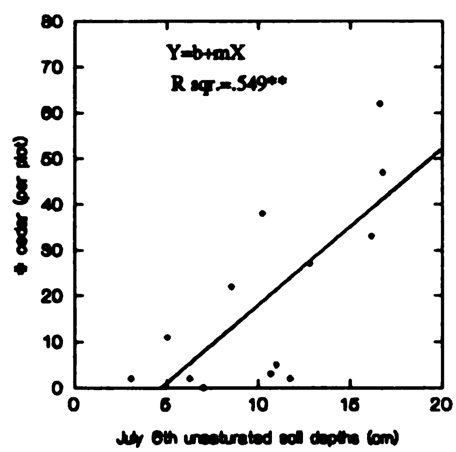

Figure 12. Graph of data with line of best fit, form of linear transformation and results of regression between unsaturated soil depth (cm) for the July 6th water table and density of cedar regenerating (per plot).

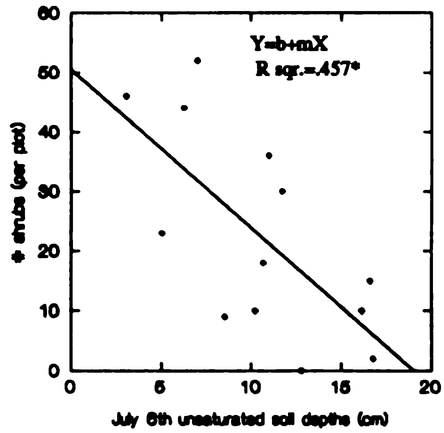

Figure 13. Graph of data with line of best fit, form of linear transformation and results of regression between unsaturated soil depth on July 6th and density of shrubs regenerating (per plot).

table elevations at other times of the year and the density of regenerating cedar (Appendix C).

The depth of unsaturated soil above the water table is determined by the water table level and average surface elevation (Table 4). The depth of unsaturated soil was calculated by subtracting the water table elevations from average surface elevations (Appendix D). The unsaturated soil depth was found to be a better measurement for predicting cedar regeneration than water table elevations and fluctuations, probably because it takes into account surface topography as well as the level of the water. The

Table 4. Depth of unsaturated soil (cm).

Well #	6/27 1993	7/2 1993	7/6 1993	7/26 1993	8/25 1993	9/10 1993	Avg.
510	19.81	20.42	16.15	21.64	33.53	39.32	25.15
511	17.07	17.37	12.80	18.59	29.57	34.75	21.69
512	12.34	13.26	8.69	14.78	25.15	30.02	17.37
513	10.67	13.41	8.53	15.54	24.69	29.57	17.07
520	19.05	20.57	16.61	22.40	36.73	42.52	26.31
521	18.29	20.42	16.76	21.64	35.05	41.15	25.55
522	10.67	13.11	8.53	14.94	27.43	33.53	18.03
523	12.19	13.72	9.75	16.46	28.65	33.83	19.10
530	4.57	6.40	3.05	8.84	21.34	28.96	12.19
531	11.43	12.95	10.21	15.09	27.89	36.42	19.00
532	12.19	14.02	10.67	17.37	29.26	36.58	20.02
533	12.04	15.09	11.13	17.83	28.80	35.81	20.12
540	5.64	8.08	5.03	11.73	26.06	35.81	15.39
541	10.06	11.58	8.53	15.24	28.04	36.58	18.34
542	9.91	11.43	8.38	15.09	26.67	34.29	17.63
543	16.76	15.24	11.58	18.29	30.18	37.80	21.64
550	12.95	15.39	11.73	18.75	35.81	48.01	23.77
551	11.58	14.02	10.67	17.37	32.92	41.76	21.39
552	10.67	14.63	10.67	17.68	30.48	40.84	20.83
553	9.30	11.89	8.69	14.78	28.19	37.95	18.47
560	5.94	9.30	6.25	13.26	32.46	48.01	19.20
561	10.97	14.33	10.97	17.98	34.44	46.02	22.45
562	7.32	10.67	7.01	13.72	29.26	41.15	18.19
563	8.23	11.58	8.53	15.24	29.57	41.15	19.05

unsaturated soil depths for July 6th (highest level measured in growing season) was highly significant and linearly related to the density of cedar and shrubs. The equations are: # cedar/plot =-16.146+3.417(cm of unsaturated soil) (Figure 12), and # shrubs/plot =50.39-2.65(cm of unsaturated soil) (Figure 13). As water levels dropped, the relationships became less significant and non-significant (Appendix C). It appears that the high water table during the growing season is the most important water table relationship for determining cedar.

Using the regression equations, the depth of unsaturated soil required for cedar to regenerate on this site was calculated. Apparently cedar need around 12 cm of unsaturated soil (measured from the average plot elevation) to regenerate. If unsaturated soil depths become less than 12 cm, than it becomes to wet for cedar.

Microtopography

Only small hummocks, averaged about .5 to 3 meters in length, where encountered in the study site, no large hummocks where found. Since small hummocks are favorable for tree growth, all hummocks on this site where assumed suitable for regenerating trees. The heights of hummocks were not measured but are estimated as 15-30 cm. The pools were also small in size averaging around 1 meter or less in length.

Microtopography transect data (Appendix B) for the entire cut area were analyzed for occurrence of different tree species on microtopographical features (Table 5). The majority of trees and shrubs, especially conifers, were found growing only on hummocks. This was true of trees growing in the wetter southern area and in the drier northern area. These results agree with other reports citing that the majority of trees occur on hummocks (Curtis, 1946; Satterlund, 1960; Vompersky, 1968; Pregitzer, 1990). While conifers are confined to hummocks, alder, shrubs and hardwoods are found growing in pools and intermediate areas as well as hummocks.

Table 5. The percent of trees and shrubs growing on different microtopography types.

Tree species	Number of Trees	Hummocks %	Intermed. areas %	Pools %
Cedar	56	95	2	3
Balsam Fir	87	91	3	6
Alder	54	69	11	20
Shrubs[1]	51	73	17	10
B. Spruce	7	100	0	0
Hardwoods[2]	9	89	0	11

[1]alternate leafed dogwood and willow.
[2]red maple, quaking aspen, balsam popular, white birch, ash and cherry.

Table 6. Microtopography percentages in regenerating area.

Plot Site	% Hummocks			% Intermediate Areas			% Pools		
	N-S	E-W	Avg.	N-S	E-W	Avg.	N-S	E-W	Avg.
	Transects			Transects			Transects		
510	87.5	73.5	80.5	0	8.5	4.25	12.5	18	15.25
511	86.5	76.5	81.5	0	15	7.5	11.5	8.5	10
520	92.5	83	87.75	0	4.5	2.25	7.5	12.5	10
521	78.5	70	74.25	8.5	9.5	9	13	20.5	16.75
530	14	40.5	27.25	62.5	43	52.75	23.5	16.5	20
531	80.5	77	78.75	0	17.5	8.75	19.5	5.5	12.5
540	45.5	49	47.25	12.5	27.5	20	42	23.5	32.75
541	71	69	70	9	7.5	8.25	20	23.5	21.75
550	55	39	47	0	20	10	45	41	43
551	42.5	60	51.25	0	6.5	3.25	57.5	33.5	45.5
560	30	31.5	30.75	45.5	23.5	34.5	24.5	45	34.75
561	58	54.5	56.25	11.5	13	12.25	30.5	32.5	31.5
562	41	36	38.5	13	4.5	8.75	46	59.5	52.75

The average plot microtopograpy (Table 6) was found to be the best indicator of cedar regeneration success in this study. The percent of the plot area consisting of hummocks exhibits a very significant relationship with the number of cedar and shrubs regenerating in that area according to the equations: # cedar/plot =0.109+93.967(%hummocks^4) (Figure 14) and shrubs-1 =-0.449-39.44*ln(%hummocks) (Figure 15). The greater the percentage of hummocks, the more numerous the regenerating cedar. Pools and intermediate areas have limited cedar regeneration but increased shrub and alder numbers. The percent of the plot that is hummocks predicts stand composition. Shrubs are most numerous at low hummock percentages while cedar are found at high hummock percentages. For this site, it appears that there should be at least 70 percent of the area covered by hummocks for good cedar regeneration.

Combining the 12 cm of unsaturated soil with the average height of hummocks (15-30 cm), it appears that cedar need an average of around 27-42 cm of unsaturated soil (as measured from the top of a hummock) to successfully regenerate.

It appears that the slight difference in habits between shrubs and cedar are due to their different tolerances for water levels. The greatest density of shrubs are found in the wetter areas (low unsaturated soil depths and low percentage of hummocks) while cedar are found in relatively drier areas (high unsaturated soil depths and high percentage of hummocks).

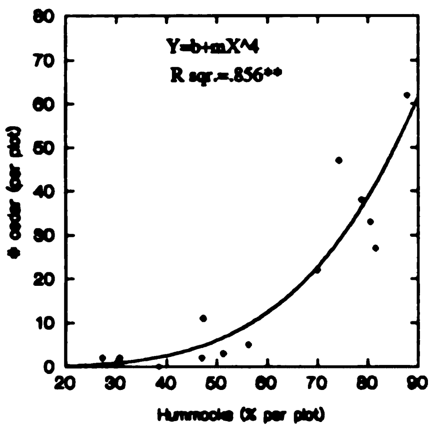

Figure 14. Graph of data with line of best fit, form of linear transformation and results of regression between percent hummocks of plots and density of cedar regenerating (per plot).

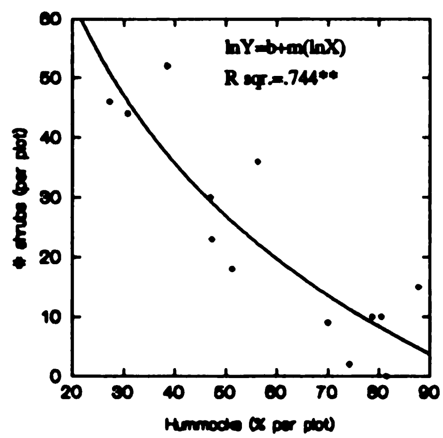

Figure 15. Graph of data with line of best fit, form of linear transformation and results of regression between percent hummocks of plots and density of shrubs regenerating (per plot).

Water chemistry

All water samples on June 26th were collected out of pools. Due to the late summer dry conditions, some of the September 10th samples had to be collected from piezometer wells. A water sample was not collected or analyzed on September 10th for plot #560, because the water table had dropped below the bottom of the piezometer well.
Water chemistry has been cited as a major determining factor in northern white cedar establishment (Curtis, 1946; Nelson, 1951; Pregitzer, 1990; Miller et. al, 1990). The four most important chemical components cited are: pH, specific conductivity, calcium and dissolved oxygen levels. Water pH levels ranged from 6.6 to 7.16 on June 26th (Table 7), and increased to 7.3 to 7.73 on September 10th (Table 8). Specific conductivity levels on June 26th ranged from 171 uS cm-1 to 342 uS cm-1 (Table 7), and increased by the end of the summer to 232 uS cm-1 to 487 uS cm-1 (Table 8). Regression analysis determined that cedar regeneration is not significantly related to pH or specific conductivity levels (Appendix C).

This can most likely be explained by comparing results with Glaser's et al. (1981, 1990) data (Table 9). Specific conductivity and pH levels are likely not showing major impacts on cedar because the entire study area would be classified as an extremely rich fen. Since, northern white-

Table 7. Specific conductivity, pH, dissolved oxygen and calcium levels for 6/26/93.

Plot Number	pH	Specific Conductivity (uS cm-1)	Dissolved Oxygen (ppm)	Calcium (mg/l)
501	7.15	305	3.8	46.6
503	6.91	342	6.9	61.3
510	6.65	342	6.9	38.5
511	6.61	189	6.3	38.5
512	6.65	190	6.3	42.6
513	6.85	188	6.0	49.0
520	6.85	219	5.7	41.7
521	6.82	234	5.6	42.0
522	6.88	233	5.5	43.3
523	7.12	283	3.7	48.6
530	6.84	203	2.6	37.6
531	6.83	239	2.6	42.4
532	7.13	314	3.2	50.0
533	7.16	315	3.0	53.2
540	6.86	213	2.8	35.9
541	6.89	234	2.8	37.9
542	6.96	241	2.9	39.1
543	7.02	277	3.7	44.3
550	6.88	221	3.1	34.2
551	6.92	240	3.5	36.5
552	6.91	253	2.9	36.4
553	6.89	250	2.7	35.9
560	6.60	171	1.8	23.2
661	6.75	207	2.3	31.2
562	6.73	233	2.3	33.5
563	6.87	252	2.5	37.4

Avg.	6.87	245.7	3.9	40.8
Sd	0.156	47.2	1.62	7.68
Max	7.16	342	6.9	61.3
Min	6.6	171	1.8	23.2

Table 8. Specific conductivity, pH, dissolved oxygen and calcium levels for 9/10/93.

Plot Number	pH	Specific Conductivity (uS cm-1)	Dissolved Oxygen (ppm)	Calcium (mg/l)
501	7.54	406	9.9	60.5
503	7.59	472	9.0	67.3
510	7.73	276	8.7	47.0
511	7.68	320	8.7	49.0
512	7.58	376	6.7	53.8
513	7.6	320	7.0	51.7
520	7.41	297	7.0	45.7
521	7.46	357	6.9	57.4
522	7.60	415	7.5	60.4
523	7.62	332	7.2	50.0
530	7.44	348	7.3	58.0
531	7.61	354	6.6	50.0
532	7.55	346	7.1	44.2
533	7.51	456	7.1	55.7
540	7.43	232	7.4	35.5
541	7.53	273	7.4	38.2
542	7.59	288	8.5	41.4
543	7.47	324	7.3	46.0
550	7.61	487	7.2	55.8
551	7.64	326	8.1	46.0
552	7.42	330	6.0	27.7
553	7.45	310	7.3	41.0
560	N/A	N/A	N/A	N/A
661	7.44	318	6.6	37.4
562	7.41	301	6.5	36.5
563	7.41	344	4.9	44.5
Avg.	7.53	344.32	7.36	48.03
Sd	0.092	70.0	1.01	9.14
Max	7.73	487	9.9	67.3
Min	7.41	232	4.9	27.7

Table 9. Average calcium, specific conductivity and pH levels of the study site compared to Glaser et al. (1981, 1990) levels.

Peatland type	pH	Specific Cond (uS cm-1)	Calcium (mg/l)
Extremely Rich Fen	>6.8	>82	>20
Rich Fen	6.0-6.8	23-82	10-20
Poor Fen	4.3-6.0		3-10
Bog	<4.3	12-27	<3
Avg. for study site	7.31	295	44.4

cedar is an indicator species of extremely rich fens and rarely found in the other peatland types, the entire study site is excellent habitat for cedar. The variations seen in water pH and specific conductivity are small compared with the changes needed to alter peatland types (cedar habitat). If pH or specific conductivity levels had dropped below acceptable levels of cedar habitat, cedar may have then been adversely effected.

Calcium levels ranged from 23.2 mg/l to 61.3 mg/l (Table 7) and 27.7 mg/l to 67.3 mg/l (Table 8). Dissolved oxygen levels for June 26th, ranged from 1.8 ppm to 6.9 ppm (Table 7), and increased to 4.9 ppm to 9.9 ppm on September 10th levels (Table 8). The highest calcium and oxygen levels were found in the ditch and the lowest were found farthest from the ditch. Calcium and dissolved oxygen levels for June 26th are significant related to the distance from the ditch. The equations are: oxygen(ppm) =9.43-1.359*ln(m from ditch) (Figure 16) and calcium(mg/l) =42.434-0.061*(m from ditch) (Figure 17).

June 26th dissolved oxygen levels show a highly significant relationship with cedar density: # cedar/plot-1 =0.833*(ppm oxygen)$^{2.01}$ (Figure 18). June 26th calcium levels also showed a highly significant relationship with cedar density: #cedar/plot-1 =0.0156 * exp$^{(.1786*mg/l\ Ca)}$ (Figure 19). Neither oxygen or calcium levels, for September 10th, showed any significant relationship with cedar density.

Dissolved oxygen and calcium levels were more significantly related with distance from the ditch than cedar density. It is not known therefore if oxygen and calcium levels directly affected cedar regenerating, or if the cedar were resulted from other factors related to the ditch.

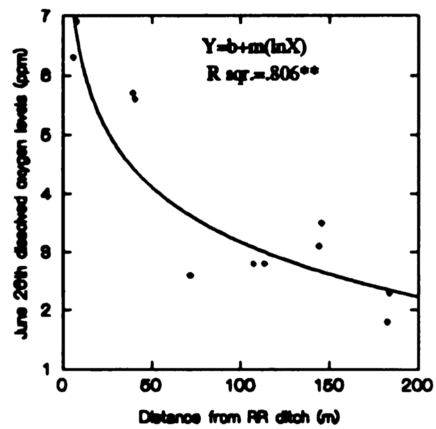

Figure 16. Graph of data with line of best fit, form of linear transformation and results of regression between June 26th dissolved oxygen levels (ppm) and distance from the railroad ditch (m).

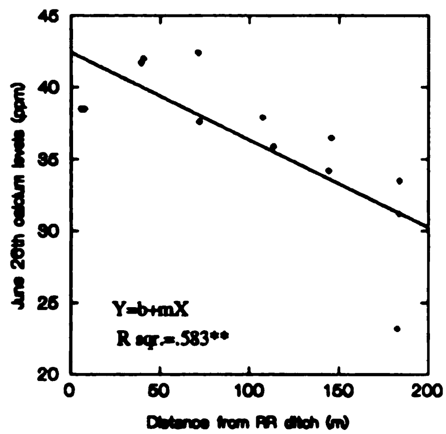

Figure 17. Graph of data with line of best fit, form of linear transformation and results of regression between June 26th calcium levels (mg/l) and distance from the ditch (m).

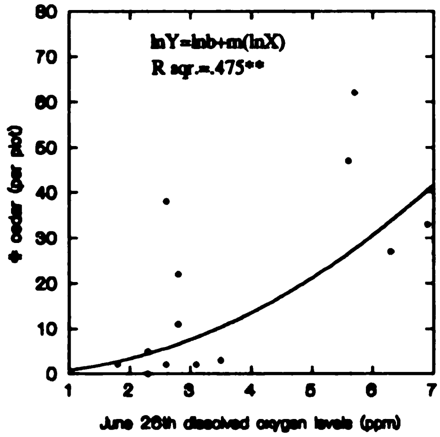

Figure 18. Graph of data with line of best fit, form of linear transformation and results of regression between June 26th dissolved oxygen levels (ppm) and density of cedar regenerating (per plot).

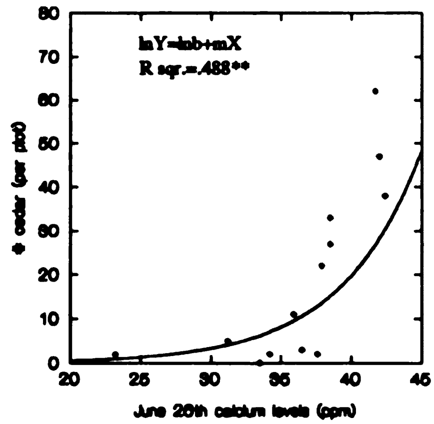

Figure 19. Graph of data with line of best fit, form of linear transformation and results of regression between June 26th calcium levels (mg/l) and density of cedar regenerating (per plot).

CHAPTER 4

SUMMARY AND RECOMMENDATIONS

Summary

The main objectives of this study were to determine factors related to successful cedar regeneration at this study site and suggest methods to successfully regenerate northern white-cedar. This was accomplished by looking at wetland hydrology, water chemistry and microtopography and their relationships to northern white-cedar regeneration. The hypotheses were:

1) The ditch will lower the water table to a measurable distance away from the tracks.

2) The density of northern white-cedar regeneration is related to the depth to the water table.

3) Increased density of hummocks is associated with areas of higher northern white-cedar regeneration.

4) Calcium, pH, specific conductivity and dissolved oxygen levels are related to higher levels of northern white-cedar regeneration.

The railroad ditch was not effective in lowering the water table at distances needed to explain an increase in cedar regeneration. Instead, it appears that the density of hummocks and hydrology of the site explained most of the variance found in the density of cedar regeneration.

The water table was found to fluctuate least near the ditch and increase at an increasing distance from the ditch. The fluctuation of the water table showed a highly significant relationship with cedar regeneration according to the equation: # cedar/plot-1 =210.1 x 10^6 *(cm fluctuation)$^\wedge{}^{-4.99}$ (R^2=.540**). The high water table level in the growing season was measured on July 6th. The high water table level in the growing season was significantly and linearly related with the number of cedar regenerating according to the equation: # cedar/plot =30,009.4-140(water table elevation in m)(R^2=.324*).

The unsaturated soil depth was found to be a better measurement for predicting cedar regeneration than water table elevations and fluctuations, probably because it takes into account surface topography as well as the level of the water. Unsaturated soil depths for July 6th (highest level measured in growing season) was highly significant and linearly related to the density of cedar and shrubs. The equations are: # cedar/plot =-16.146+3.417(cm of unsaturated soil) (R^2=.549**), and # shrubs/plot =50.39-2.65(R^2=.457**). As water levels dropped, the relationships became less significant and non-significant. It appears that the high water table during the growing season is the most important water table relationship for determining cedar regeneration.

Using regression equations, the depth of unsaturated soil required for cedar to regenerate on this site was calculated. Apparently cedar require approximately 12 cm of unsaturated soil during high water in the growing season (measured from the average plot elevation) to regenerate at this site.

The average plot microtopograpy was found to be the best indicator of cedar regeneration success in this study. The percent of the plot area consisting of hummocks exhibits a very significant relationship with the number of cedar and shrubs regenerating in that area according to the equations: # cedar/plot =0.109+93.967(%hummocks^4) (R^2=.856**) and shrubs-1 =-0.449-39.44*ln(%hummocks) (R^2=.744**). The greater the percentage of hummocks, the more numerous the regenerating cedar. For the study site, 95% of cedar were found on hummocks. Pools and intermediate areas have limited cedar regeneration but increased shrub and alder numbers. The greatest density of shrubs are found in the wetter areas (low unsaturated soil depths and low percentage of hummocks) while cedar are found in relatively drier areas (high unsaturated soil depths and high percentage of hummocks). For this site, it appears that there should be at least 70 percent of the area covered by hummocks for good cedar regeneration.

Combining the 12 cm of unsaturated soil with the average height of hummocks (15-30 cm), it appears that cedar require an average of approximately 27-42 cm thickness of unsaturated soil during high water in the growing season (as measured from the top of a hummock) to successfully regenerate. If unsaturated soil depths become less than 27-42 cm, than it becomes to wet for cedar. The hummocks are important at this site because they are the only places where 27-42 cm of unsaturated soil (as measured at high water for the growing season) can be found.

Throughout the wide spectrum of peatland ecotypes, water chemistry is very important for determining northern white-cedar distribution. But the role of water chemistry in cedar regeneration at this site is inconclusive. Specific conductivity and pH levels where not significantly related with the density of cedar. However, June 26th calcium and dissolved oxygen levels were significantly related to density of cedar regeneration while September 10th levels were not. Both calcium and dissolved oxygen levels were better correlated with distance from the ditch than with cedar regeneration. I conclude that while water chemistry is important, hydrology and microtopography are the dominant factors controlling differences in cedar regeneration at this site.

This study reveals that it may be possible to predict potential cedar regeneration in extremely rich fen wetlands by knowing how much of an area will be suitable cedar habitat after harvesting. The microtopography of an area can give an estimate of suitable cedar habitat. Small hummocks are suitable cedar habitat if there is at least 27-42 cm of unsaturated soil during high water during the growing season. If there is less than 27-42 cm than cedar may not be able to regenerate on the hummocks. Large hummocks can usually be delineated from small hummocks by the absence of moss growing on the upper regions of large hummocks, and are not generally suitable for cedar regeneration. Large hummocks will dry out in the mid-summer creating unfavorable conditions for cedar. Cedar might be able to regenerate on the edges of large hummocks, but this needs to researched further. Pools are not suitable for cedar under any conditions. Intermediate areas are not suitable for cedar regeneration unless the high water table during the growing season is greater than 46 cm (Satterlund, 1960).

Groundwater tables may be measured by using piezometer wells. Using the high water table during the growing season, which seems to be the most influential for cedar establishment, the thickness of unsaturated soil above the water table can be calculated. If significant water table changes after harvesting are predicted, than the amount of potential cedar habitat after harvesting can also be calculated. All small hummocks with at least 27-42 cm of unsaturated soil, after adding the water table changes due to harvesting, will be potential cedar habitat. Any intermediate areas with at least 46 cm of unsaturated soil, after harvesting, will also be potential cedar habitat. All other microtopography types will not be beneficial to cedar regeneration. This study reveals that cedar need at least 70% of the area composed of suitable cedar habitat to successfully regenerate on this site. If there is less than 70%, than the site will most likely become dominated by alder, shrubs and other trees species better adapted for wetter sites.

This study reports important relationships and increases our understanding of the hydrological and microtopographical effects on northern white-cedar regeneration. The values obtained in this study are notable, however, some of the values may change with additional research.

Future research recommendations

Research is needed to determine the hydroperiods (the upper and lower limits of water levels that a species can live in) for northern white-cedar and other peatland tree and shrubs species. Knowing the hydroperiods of different species is important when dealing with activities which can alter water table levels in peatlands (e.g., draining, harvesting or road building). If water tables are altered, different species can take advantage depending on where the water table levels are and the microtopography of the site.

Research needs to be conducted to further define the relationship between cedar regeneration to the water chemistry. Research also needs to consider the effect of deer browsing on cedar seedlings. There seem to be many reports on the negative effects of deer browsing pressure, but few research studies that actually address this area. Methods must be devised to keep deer out of regenerating areas until seedlings are above the browse height.

More research needs to be done on harvesting effects on peatlands. The effects of harvesting should be quantified for different sites and treatments. The hydrology, microtopography, light, temperature and browsing pressure can all be altered by harvesting. Methods should be devised to maintain the microtopography when harvesting in peatlands. Hummocks can be easily destroyed by harvesting methods. Harvesting effects need to be better understood if we are to successfully harvest and regenerate cedar in peatlands.

APPENDICES

APPENDIX A. Number of trees and shrubs per plot.

Table A.1. Number of trees and shrubs in plots 510, 511, 512 and 513.

Species	Plot number				
	510	511	512	513	Total
Northern white cedar	33	27	5	6	71
Balsam fir	27	26	28	21	102
Black spruce	3	9		2	14
White birch			1		1
Balsam popular					0
White pine					0
Alt. leafed dogwood	8		2		10
Tag alder	1		3	1	5
Quaking aspen					0
Ash					0
Willow species	1				1
Red maple	1			2	3
Cherry					0
Tamarack					0
White spruce					0
Totals	74	62	39	32	207

Table A.2. Number of trees and shrubs in plots 520, 521, 522 and 523.

Species	Plot number				
	520	521	522	523	Total
Northern white cedar	62	47	8	7	124
Balsam fir	31	37	75	39	182
Black spruce	7	2	1		10
White birch					0
Balsam popular					0
White pine					0
Alt. leafed dogwood					0
Tag alder	3	2	5	4	14
Quaking aspen	3	1			4
Ash				1	1
Willow species	12				12
Red maple					0
Cherry	7	3			10
Tamarack		2			2
White spruce		1			1
Totals	125	95	89	51	360

Table A.3. Number of trees and shrubs in plots 530, 531, 532 and 533.

Species		Plot number				
		530	531	532	533	Total
Northern white cedar		2	38	5	9	54
Balsam fir		18	23	80	88	209
Black spruce			7			7
White birch		12	2			14
Balsam popular			1			1
White pine						0
Alt. leafed dogwood		3	3	6	5	17
Tag alder		40	5			45
Quaking aspen		1				1
Ash		2				2
Willow species		3	2		1	6
Red maple						0
Cherry						0
Tamarack						0
White spruce						0
Totals	81	81	91	103	356	

Table A.4. Number of trees and shrubs in plots 540, 541, 542 and 543.

Species		Plot number				
		540	541	542	543	Total
Northern white cedar		11	22	15	6	54
Balsam fir		19	18	32	23	92
Black spruce		1	2			3
White birch		1	1	1		3
Balsam popular		3				3
White pine		1				1
Alt. leafed dogwood		21	6	4	4	35
Tag alder			1	6	8	15
Quaking aspen						0
Ash					1	1
Willow species		2	2			4
Red maple						0
Cherry						0
Tamarack						0
White spruce						0
Totals	59	52	58	42	211	

Table A.5. Number of trees and shrubs in plots 550, 551, 552 and 553.

Species	Plot number				
	550	551	552	553	Total
Northern white cedar	2	3	10	2	17
Balsam fir	23	42	16	9	90
Black spruce		1			1
White birch	1	2			3
Balsam popular	1				1
White pine					0
Alt. leafed dogwood			11	38	49
Tag alder	24	12	4	9	49
Quaking aspen					0
Ash					0
Willow species	6	6			12
Red maple					0
Cherry					0
Tamarack	1				1
White spruce					0
Totals	58	66	41	58	223

Table A.6. Number of trees and shrubs in plots 560, 561, 562 and 563.

Species	Plot number				
	560	561	562	563	Total
Northern white cedar	2	5		3	10
Balsam fir	11	10	17	12	50
Black spruce					0
White birch	4	3	2	5	14
Balsam popular					0
White pine					0
Alt. leafed dogwood					0
Tag alder	44	36	52	24	156
Quaking aspen					0
Ash	2		1		3
Willow species					0
Red maple					0
Cherry					0
Tamarack					0
White spruce					0
Totals	63	54	72	44	233

APPENDIX B. Data from microtopography transects.

Table B.1 Data from microtopography transects. (Trans=trancest number), (Seg=segment number), (Topo type=topography type{2=hummock, 3=intermediate area, 4=pool}), (NWC=northern white-cedar), (ALD=tag alder), (BF=balsam fir), (SH=shrubs;dogwood,willows), (BS=black spruce), (HW=hardwoods;red maple,aspen, balsam popular)

Plot #	Trans #	Seg #	Topo type	Length ft	NWC #	ALD #	BF #	SH #	BS #	Hw #
510	1	1	2	3.1	1	0	0	0	0	0
510	1	2	4	0.8	0	0	0	0	0	0
510	1	3	2	0.5	2	0	0	0	0	0
510	1	4	2	2.9	0	1	0	0	0	0
510	1	5	4	1.2	0	0	0	0	0	0
510	1	6	2	2.1	2	0	0	0	0	0
510	1	7	2	3.0	3	0	0	0	0	0
510	1	8	2	3.0	1	1	0	0	0	0
510	1	9	2	2.9	2	1	0	0	0	0
510	1	10	4	0.5	0	0	0	0	0	0
510	2	1	2	5.4	0	1	0	0	0	0
510	2	2	4	0.8	0	0	0	0	0	0
510	2	3	2	2.2	0	0	0	2	0	0
510	2	4	2	2.0	2	0	0	0	0	0
510	2	5	2	2.9	1	1	0	0	0	0
510	2	6	2	2.2	1	2	0	0	1	0
510	2	7	4	2.8	0	0	0	0	0	0
510	2	8	3	1.7	0	0	0	0	0	0
511	1	1	2	2.1	2	1	0	0	0	0
511	1	2	2	2.0	0	0	0	0	0	0
511	1	3	4	0.8	0	0	0	0	0	0
511	1	4	2	1.6	0	0	0	0	0	0
511	1	5	2	2.7	0	0	0	0	0	0
511	1	6	2	4.2	1	2	0	0	0	0
511	1	7	4	1.1	0	0	0	0	0	0
511	1	8	2	1.7	1	0	0	0	0	0
511	1	9	4	0.8	1	0	0	0	0	0
511	1	10	2	3.0	0	0	0	0	0	0
511	2	1	2	3.6	0	0	0	1	0	0
511	2	2	4	0.6	0	0	0	0	0	0
511	2	3	2	3.8	0	0	0	0	0	0
511	2	4	2	2.3	0	0	0	0	0	0
511	2	5	2	3.3	0	1	0	0	1	0
511	2	6	4	1.1	0	0	0	0	0	0

Table B.1 Cont.

511	2	7	2	1.8	0	1	0	0	0	0
511	2	8	3	3.0	0	0	0	0	0	0
511	2	9	2	0.5	0	0	0	0	0	0
520	1	1	2	2.0	0	1	0	0	0	0
520	1	2	4	0.6	0	0	0	0	0	0
520	1	3	2	1.1	0	2	0	0	0	0
520	1	4	2	2.4	1	1	0	0	0	0
520	1	5	2	2.0	1	0	0	0	0	1
520	1	6	2	1.6	0	3	0	0	0	0
520	1	7	2	0.8	0	0	0	0	0	0
520	1	8	2	3.4	3	2	0	0	0	3
520	1	9	2	2.8	0	5	0	0	0	2
520	1	10	4	0.9	1	3	0	0	0	1
520	1	11	2	2.4	0	0	0	0	0	0
520	2	1	2	4.6	0	1	0	0	0	0
520	2	2	4	0.7	0	0	0	0	0	0
520	2	3	2	2.0	2	0	0	0	0	0
520	2	4	2	2.1	2	3	0	0	0	0
520	2	5	4	1.8	0	0	0	0	0	0
520	2	6	2	1.8	1	0	0	0	0	0
520	2	7	3	0.9	0	0	0	0	0	0
520	2	8	2	3.1	1	1	0	0	0	0
520	2	9	2	3.0	0	1	0	0	0	0
521	1	1	3	0.4	0	0	0	0	0	0
521	1	2	2	2.1	0	0	0	0	0	0
521	1	3	2	1.0	2	0	0	0	0	0
521	1	4	2	0.7	0	0	0	0	0	0
521	1	5	4	0.8	0	0	0	0	0	0
521	1	6	2	2.2	1	0	0	0	0	0
521	1	7	4	0.5	0	0	0	0	0	0
521	1	8	3	1.0	1	2	0	0	0	0
521	1	9	4	0.5	0	0	0	0	0	0
521	1	10	2	0.5	0	0	0	0	0	0
521	1	11	2	0.6	0	0	0	0	0	0
521	1	12	2	1.0	0	1	0	0	0	0
521	1	13	2	0.8	1	1	0	0	0	0
521	1	14	2	2.1	0	1	0	0	0	0
521	1	15	4	0.8	0	0	0	0	0	0
521	1	16	2	0.5	0	0	0	0	0	0
521	1	17	2	0.7	0	2	0	0	0	0
521	1	18	3	0.3	0	0	0	0	0	0
521	1	19	2	3.5	0	4	0	0	0	1
521	2	1	2	3.4	0	3	0	0	0	0
521	2	2	2	2.9	0	0	0	0	0	0
521	2	3	4	0.7	0	0	0	0	0	0
521	2	4	2	3.8	1	0	0	0	0	0
521	2	5	2	1.0	0	1	0	0	0	0
521	2	6	4	1.4	0	0	0	0	0	0

Table B.1 Cont.

521	2	7	2	2.0	0	0	0	0	0	0
521	2	8	3	1.4	0	0	0	0	0	0
521	2	9	2	0.9	0	0	0	0	0	0
521	2	10	3	0.5	0	0	0	0	0	0
521	2	11	4	2.0	0	0	0	0	0	0
530	1	1	3	2.4	0	0	0	0	0	0
530	1	2	4	1.1	0	0	0	0	0	0
530	1	3	2	1.3	0	0	0	1	0	0
530	1	4	3	3.4	0	0	0	1	0	0
530	1	5	3	2.7	0	0	1	0	0	0
530	1	6	3	0.6	0	0	0	0	0	0
530	1	7	2	1.5	0	0	0	2	0	0
530	1	8	4	2.6	0	0	0	0	0	0
530	1	9	3	1.3	0	0	0	0	0	0
530	1	10	4	0.5	0	0	0	0	0	0
530	1	11	3	1.6	0	0	1	2	0	0
530	1	12	4	0.5	0	0	0	0	0	0
530	1	13	3	0.5	0	0	0	1	0	0
530	2	1	4	1.7	0	0	0	0	0	0
530	2	2	2	2.2	0	0	0	0	0	0
530	2	3	3	2.3	0	0	0	0	0	0
530	2	4	2	1.3	0	0	0	0	0	0
530	2	5	3	3.5	0	0	0	0	0	0
530	2	6	3	1.5	0	0	0	0	0	0
530	2	7	2	1.4	0	0	0	0	0	0
530	2	8	4	1.1	0	0	0	0	0	0
530	2	9	2	1.8	0	0	0	0	0	0
530	2	10	3	1.3	0	0	0	0	0	0
530	2	11	2	1.4	0	0	0	0	0	0
530	2	12	4	0.5	0	0	0	0	0	0
531	1	1	2	2.9	0	2	0	0	0	1
531	1	2	2	3.4	1	1	0	0	1	0
531	1	3	4	0.7	0	0	0	0	0	0
531	1	4	2	1.1	2	0	0	0	0	0
531	1	5	4	0.8	0	0	0	0	0	0
531	1	6	2	0.8	0	1	0	0	0	0
531	1	7	4	0.6	0	0	0	0	0	0
531	1	8	2	1.3	1	3	0	0	0	0
531	1	9	4	0.4	0	0	0	0	0	0
531	1	10	2	3.6	3	4	0	0	0	0
531	1	11	2	3.0	0	0	0	0	1	0
531	1	12	4	1.4	0	2	0	0	0	0
531	2	1	2	4.0	2	2	0	0	1	0
531	2	2	4	1.1	0	0	0	0	0	0
531	2	3	2	2.1	0	2	0	0	0	0
531	2	4	3	0.5	0	0	0	0	0	0
531	2	5	2	0.7	0	0	0	0	0	0
531	2	6	3	1.0	0	0	0	0	0	0

Table B.1 Cont.

531	2	7	2	1.3	0	0	0	0	0	0
531	2	8	3	0.5	0	0	0	0	0	0
531	2	9	2	1.8	3	0	0	0	0	0
531	2	10	2	1.6	0	1	0	0	0	0
531	2	11	3	1.5	0	0	0	0	0	0
531	2	12	2	3.9	0	1	0	0	0	0
540	1	1	4	1.3	0	0	0	0	0	0
540	1	2	2	1.3	0	3	0	1	0	0
540	1	3	3	2.5	0	0	0	2	0	0
540	1	4	4	2.2	0	0	0	2	0	0
540	1	5	2	7.8	1	6	1	5	0	0
540	1	6	4	4.9	0	0	0	0	0	0
540	2	1	2	0.4	0	1	0	0	0	0
540	2	2	4	1.0	0	0	0	0	0	0
540	2	3	2	1.8	1	1	0	0	0	0
540	2	4	4	1.9	0	0	0	0	0	0
540	2	5	2	1.1	0	0	0	0	0	0
540	2	6	4	1.3	0	0	0	0	0	0
540	2	7	3	3.3	0	0	0	0	0	0
540	2	8	2	2.3	0	0	0	0	0	0
540	2	9	3	2.2	0	0	0	0	0	0
540	2	10	2	4.2	0	0	0	0	0	0
540	2	11	4	0.5	0	0	0	0	0	0
541	1	1	2	1.8	0	0	3	2	0	0
541	1	2	4	0.6	0	0	0	1	0	0
541	1	3	2	0.9	0	0	0	0	0	0
541	1	4	3	0.8	0	0	0	0	0	0
541	1	5	2	0.9	0	0	0	1	0	0
541	1	6	4	3.1	0	0	0	0	0	0
541	1	7	2	1.0	0	0	0	3	0	0
541	1	8	2	6.3	1	1	0	0	2	0
541	1	9	3	1.0	0	0	0	1	0	0
541	1	10	2	1.2	1	0	0	0	0	0
541	1	11	4	0.3	0	0	0	0	0	0
541	1	12	2	2.1	0	0	0	0	0	0
541	2	1	2	1.9	0	0	0	0	0	0
541	2	2	4	1.0	0	0	0	0	0	0
541	2	3	2	1.9	0	0	0	0	0	0
541	2	4	4	1.0	0	0	0	0	0	0
541	2	5	3	1.5	0	0	0	0	0	0
541	2	6	4	2.1	0	0	0	0	0	0
541	2	7	2	4.0	0	0	0	0	0	0
541	2	8	2	3.8	0	0	0	0	0	0
541	2	9	4	0.6	0	0	0	0	0	0
541	2	10	2	2.2	0	0	0	0	0	0
550	1	1	2	1.1	0	0	1	0	0	0
550	1	2	4	1.8	0	0	0	0	0	0
550	1	3	2	1.4	0	0	1	4	0	0

Table B.1 Cont.

550	1	4	4	2.0	0	0	0	1	0	0
550	1	5	2	1.5	0	0	4	0	0	0
550	1	6	4	0.8	0	0	0	0	0	0
550	1	7	2	0.4	0	0	6	0	0	0
550	1	8	4	1.1	0	0	0	0	0	0
550	1	9	2	1.3	0	0	1	0	0	0
550	1	10	4	1.4	0	0	0	0	0	0
550	1	11	2	1.3	0	1	0	0	0	0
550	1	12	4	1.9	0	0	0	0	0	0
550	1	13	2	4.0	0	1	0	3	0	0
550	2	1	4	0.7	0	0	0	0	0	0
550	2	2	2	0.7	0	0	0	0	0	0
550	2	3	4	3.4	0	0	0	0	0	0
550	2	4	2	1.3	0	0	0	0	0	0
550	2	5	4	0.8	0	0	0	0	0	0
550	2	6	2	1.0	0	0	0	0	0	0
550	2	7	4	2.1	0	0	0	0	0	0
550	2	8	2	1.8	0	0	0	0	0	0
550	2	9	4	1.2	0	0	0	0	0	0
550	2	10	2	1.0	0	0	0	0	0	0
550	2	11	3	4.0	0	0	0	0	0	0
550	2	12	2	2.0	0	0	0	0	0	0
551	1	1	4	7.7	0	0	3	0	0	0
551	1	2	2	2.2	0	0	0	0	0	0
551	1	3	4	0.8	0	0	0	0	0	0
551	1	4	2	1.2	0	0	0	2	0	0
551	1	5	4	0.8	0	0	0	0	0	0
551	1	6	2	1.4	0	0	0	0	0	0
551	1	7	2	1.5	0	0	0	0	0	0
551	1	8	4	1.1	0	0	0	0	0	0
551	1	9	2	2.2	0	0	0	0	0	0
551	1	10	4	1.1	0	0	0	0	0	0
551	2	1	2	2.0	0	0	0	0	0	0
551	2	2	4	1.0	0	0	0	0	0	0
551	2	3	4	3.0	0	0	0	0	0	0
551	2	4	2	4.1	0	0	0	0	0	0
551	2	5	4	2.7	0	0	0	0	0	0
551	2	6	2	1.9	0	0	0	0	0	0
551	2	7	3	1.3	0	0	0	0	0	0
551	2	8	2	4.0	0	0	0	0	0	0
560	1	1	4	1.8	0	0	1	0	0	0
560	1	2	2	1.1	0	1	1	0	0	0
560	1	3	4	2.1	0	0	0	0	0	0
560	1	4	3	0.8	0	0	1	0	0	0
560	1	5	2	4.2	0	0	5	0	0	0
560	1	6	2	0.7	0	0	2	0	0	0
560	1	7	3	1.4	0	0	1	0	0	0
560	1	8	3	6.2	0	0	1	0	0	0

Table B.1 Cont.

560	1	9	2	0.7	0	0	7	0	0	0
560	1	10	4	1.0	0	0	0	0	0	0
560	2	1	4	0.9	0	0	0	0	0	0
560	2	2	2	2.6	0	0	0	0	0	0
560	2	3	4	3.5	0	0	0	0	0	0
560	2	4	3	3.4	0	0	0	0	0	0
560	2	5	4	2.4	0	0	0	0	0	0
560	2	6	2	1.5	0	0	0	0	0	0
560	2	7	4	2.2	0	0	0	0	0	0
560	2	8	3	1.3	0	0	0	0	0	0
560	2	9	2	2.2	0	0	0	0	0	0
561	1	1	4	2.0	0	0	6	0	0	0
561	1	1	3	1.9	0	1	0	0	0	0
561	1	2	4	1.3	0	0	1	0	0	0
561	1	2	2	1.8	0	0	5	0	0	0
561	1	3	3	0.4	0	0	0	0	0	0
561	1	4	2	2.1	0	0	0	0	0	0
561	1	5	4	1.1	0	0	0	0	0	0
561	1	6	2	5.2	0	0	0	0	0	0
561	1	7	4	2.8	0	0	0	0	0	0
561	1	8	2	1.7	1	0	0	0	0	0
561	1	9	4	0.9	0	0	0	0	0	0
561	1	10	2	1.3	0	1	0	0	0	0
561	1	11	2	1.3	1	1	0	0	0	0
561	2	3	4	1.2	0	0	0	0	0	0
561	2	4	2	3.7	0	0	0	0	0	0
561	2	5	3	0.8	0	0	0	0	0	0
561	2	6	2	2.5	0	0	0	0	0	0
561	2	7	3	1.8	0	0	0	0	0	0
561	2	8	2	1.9	0	0	0	0	0	0
561	2	9	4	3.3	0	0	0	0	0	0
561	2	10	2	1.0	0	0	0	0	0	0
562	1	1	3	1.6	0	0	1	0	0	0
562	1	2	2	1.4	0	0	0	5	0	0
562	1	3	3	1.0	0	0	0	2	0	0
562	1	4	4	3.5	0	0	0	1	0	0
562	1	5	2	3.5	0	0	0	5	0	0
562	1	6	4	0.8	0	0	0	0	0	0
562	1	7	2	1.2	0	0	0	0	0	0
562	1	8	2	0.6	0	0	0	0	0	0
562	1	9	2	1.5	0	0	0	0	0	0
562	1	10	4	4.9	0	0	0	0	0	0
562	2	1	4	3.6	0	0	0	0	0	0
562	2	2	2	1.8	0	0	0	0	0	0
562	2	3	4	5.2	0	0	0	0	0	0
562	2	4	2	1.9	0	0	0	0	0	0
562	2	5	3	0.9	0	0	0	0	0	0
562	2	6	2	0.6	0	0	0	0	0	0

Table B.1 Cont.

562	2	7	4	0.5	0	0	0	0	0	0
562	2	8	2	2.9	0	0	0	0	0	0
562	2	9	4	2.6	0	0	0	0	0	0

APPENDIX C. Regression results.

Table C.1. Regression results and equations for various factors (* =5% Significance, ** =1% Significance)

Equation	R square
Peat (m)=241.034-1.121*(7/6/93 water elevation(m))	R^2=.122
Peat (m)=213.839-0.061*(9/10/93 water elevation(m))	R^2=.016
#cedar(per plot)=-6.996+28.671*(m of peat)	R^2=.140
#cedar(per plot)=29,499-138*(6/26 water table(m))	R^2=.373*
#cedar(per plot)=30,689-143*(7/2 water table(m))	R^2=.341*
#cedar(per plot)=30,813-144*(7/26 water table(m))	R^2=.291
#cedar(per plot)=30,084-141*(8/25 water table(m))	R^2=.203
#cedar(per plot)=8,915-41.6*(9/10 water table(m))	R^2=.015
#cedar(per plot)=$1.27*e^{.18*(6/26\ \text{unsat. depth(cm)})}$	R^2=.498**
#cedar(per plot)=$.877*e^{.177*(7/2\ \text{unsat. depth(cm)})}$	R^2=.403*
#cedar(per plot)=$.479*e^{.185*(7/26\ \text{unsat. depth(cm)})}$	R^2=.329*
#cedar(per plot)=$1.55*e^{.061*(8/25\ \text{unsat. depth(cm)})}$	R^2=.042
#cedar(per plot)=$111.8*e^{-.059*(9/10\ \text{unsat. depth(cm)})}$	R^2=.062
#cedar(per plot)=-28.9+7.14*(6/26 pH levels)	R^2=.001
#cedar(per plot)=-177.5+26.2*(9/10 pH levels)	R^2=.027
#cedar(per plot)=-14.6+0.15*(6/26 S. cond (uS))	R^2=.001
#cedar(per plot)=35.9-0.051*(9/10 S. cond (uS))	R^2=.023
#cedar(per plot)=6.56×10^{-4}+10.62*ln(9/10 oxygen(ppm))	R^2=.297
#cedar(per plot)=-10.5+0.65*(9/10 calcium (ppm))	R^2=.064

APPENDIX D. Average surface elevations, depths of organic soil (peat), water table elevations and maximum water table fluctuations.

Table D.1. Average surface elevations, depth of organic soil (peat), water table elevations and maximum water table fluctuations.

Well	Peat	Surface	Water Table Elevations (m)							W. Table
#	Depth (m)	Elev (m)	6/27/93	7/2/93	7/6/93	7/26/93	8/25/93	9/10/93	Avg.	Flux (cm)
501	0.000	213.360	213.314	213.302	213.357	213.296	213.208	213.168	213.274	18.9
503	0.000	213.360	213.269	213.256	213.305	213.232	213.156	213.116	213.222	18.9
510	0.799	214.326	214.128	214.122	214.165	214.110	213.991	213.933	214.075	23.2
511	0.899	214.235	214.064	214.061	214.107	214.049	213.939	213.887	214.018	21.9
512	0.899	214.191	214.067	214.058	214.104	214.043	213.939	213.890	214.017	21.3
513	0.799	214.197	214.090	214.063	214.112	214.042	213.950	213.901	214.026	21.0
520	1.167	214.242	214.052	214.037	214.076	214.018	213.875	213.817	213.979	25.9
521	0.939	214.247	214.064	214.043	214.079	214.031	213.896	213.835	213.991	24.4
522	0.914	214.177	214.070	214.046	214.092	214.028	213.903	213.842	213.997	25.0
523	1.015	214.198	214.076	214.061	214.101	214.034	213.912	213.860	214.007	24.1
530	1.049	214.040	213.994	213.976	214.009	213.951	213.826	213.750	213.918	25.9
531	1.000	214.116	214.002	213.987	214.014	213.965	213.837	213.752	213.926	26.2
532	1.399	214.128	214.006	213.988	214.021	213.954	213.835	213.762	213.928	25.9
533	1.100	214.144	214.024	213.993	214.033	213.966	213.856	213.786	213.943	24.7
540	0.981	214.252	214.195	214.171	214.201	214.134	213.991	213.893	214.098	30.8
541	1.451	214.280	214.180	214.165	214.195	214.128	214.000	213.915	214.097	28.0
542	1.301	214.313	214.213	214.198	214.229	214.162	214.046	213.970	214.136	25.9
543	1.049	214.341	214.174	214.189	214.226	214.159	214.040	213.964	214.125	26.2
550	0.899	214.303	214.174	214.149	214.186	214.116	213.945	213.823	214.066	36.3
551	0.899	214.305	214.189	214.165	214.198	214.131	213.976	213.887	214.091	31.1
552	1.000	214.296	214.189	214.149	214.189	214.119	213.991	213.887	214.087	30.2
553	1.801	214.276	214.183	214.157	214.189	214.128	213.994	213.896	214.091	29.3
560	0.250	214.294	214.235	214.201	214.232	214.162	213.970	213.814	214.102	42.1
561	0.899	214.348	214.238	214.205	214.238	214.168	214.004	213.888	214.124	35.1
562	0.799	214.314	214.241	214.207	214.244	214.177	214.021	213.903	214.132	34.1
563	0.899	214.332	214.250	214.216	214.247	214.180	214.037	213.921	214.142	32.9

APPENDIX E. Water table profiles.

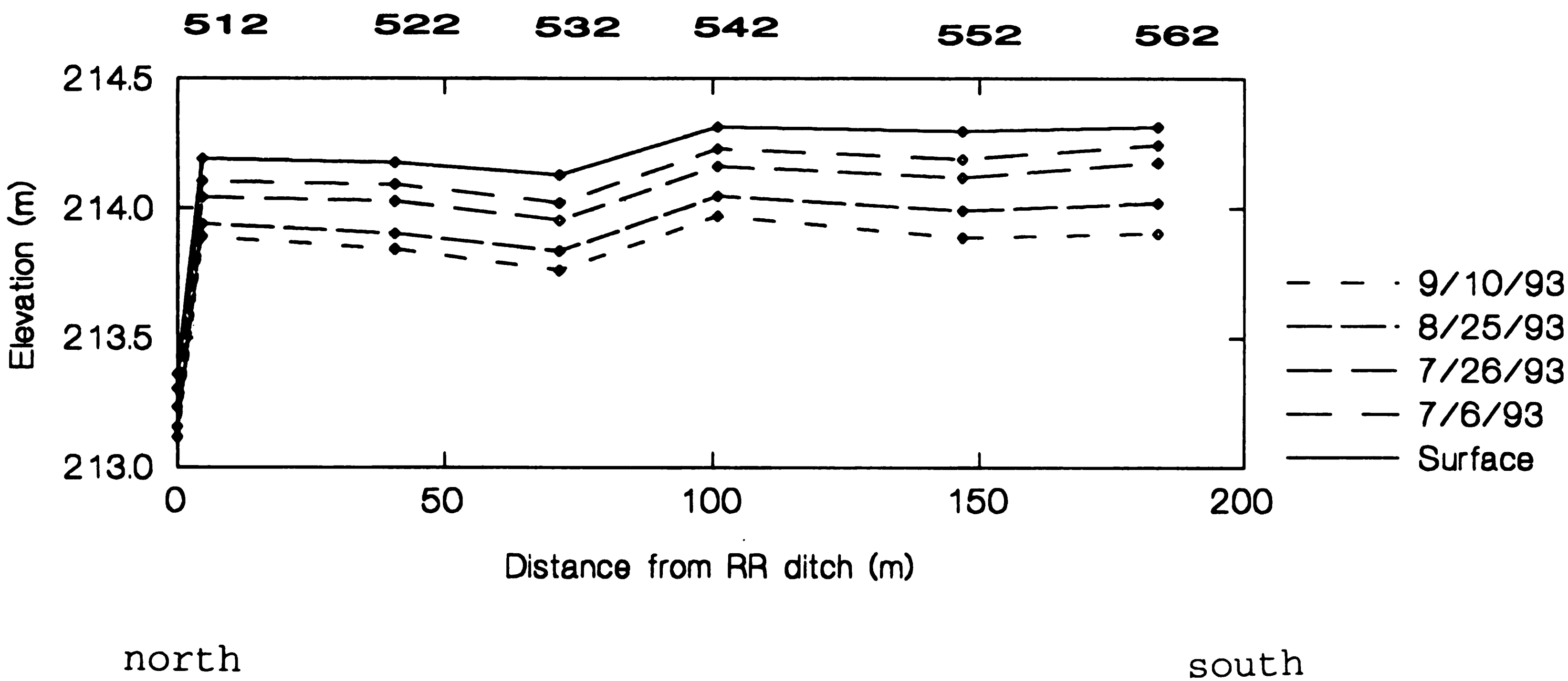

Figure E.1. Water table profile (N-S) of wells 512-562 for 7/6/93 through 9/10/93.

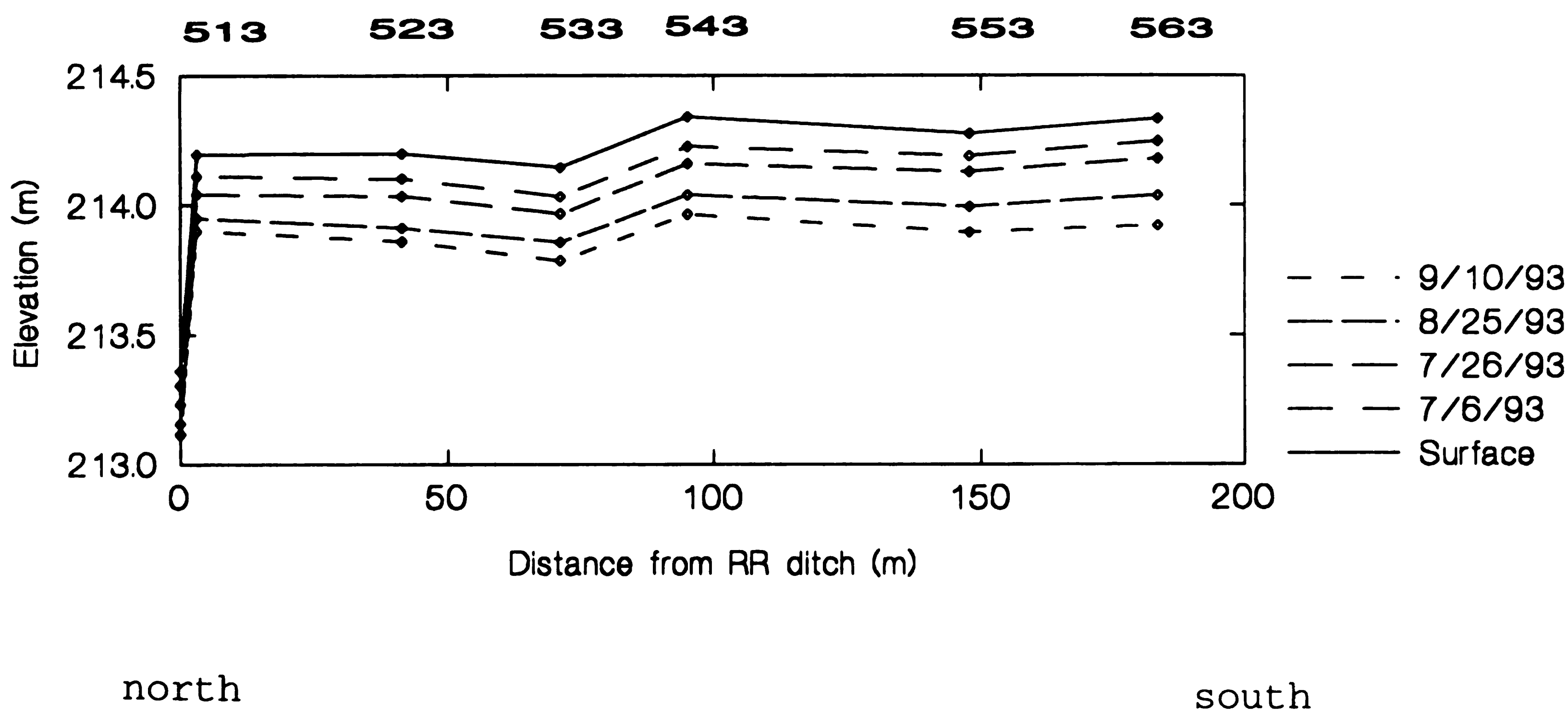

Figure E.2. Water table profile (N-S) of wells 513-563 for 7/6/93 through 9/10/93.

BIBLIOGRAPHY

BIBLIOGRAPHY

Boelter D.H., 1972. Water table drawdown around an open ditch in organic soils. J. of Hydrology 15, 329-340.

Boelter D.H., & E.S. Verry. 1977. Peatland and water in the northern lake states. USDA For. Serv. Gen. Tech. Rep. NC-31: North Cent. For. Exp. Stn., St. Paul, Minnesota pp. 22.

Boelter D.H., & E. S. Verry. 1978. Peatland hydrology. In: Wetlands functions and values: the state of our understanding. American Water Resources Association.

Boggie, R. 1972. Effect of water-table height on root development of Pinus contorta on deep peat in Scotland. OIKOS 23: 304-312. Copenhagen.

Brown, S.B. 1988. Wetland Protection Guidebook. Michigan Dept. of Nat. Res. Division of Land and Water. State of Michigan. Lansing.

Burke, W. 1967. Principles of drainage with special reference to peat. Irish Forestry. Vol. 24.1

Carter, V., M.S. Bedinger, R.P. Novitzki & W.O. Wilen. 1978. Water resources and wetlands (Theme Paper). In: Wetland Functions and Values: The State of our Understanding. Greeson, P.E., J.R. Clark, J.E. Clark. eds. National Symposium on Wetlands; Falls Hydraulic Laboratory. American Water Resources Association. November. pp. 344-376.

Crum, H. 1988. A focus on peatlands and peat mosses. University of Michigan Press.

Curtis, J.D. 1946. Preliminary observations on northern white-cedar in Maine. Ecology 27, No. 1;23-36.

Cwikiel, W. 1992. Michigan Wetlands, Yours to Protect A Citizen's Guide to Local Involvement in Wetland Protection. Tip of the Mitt Watershed Council. Conway Mi.

Glaser, P.H., G.A. Wheeler, E. Gorham & H.E. Wright Jr. 1981. The patterned mires of the Red Lake peatland, northern Minnesota: Vegetation, water chemistry and landforms. J. of Ecology. 69:575-599.

Glaser, P.H., J.A. Janssens & D.I. Siegel. 1990. The response of vegetation to chemical and hydrological gradients in the lost river peatland, northern Minnesota. J. of Ecology.

Heikurainen, L. 1968. On the influence of cutting on the water economy of drained peat lands. Acta Forestalia Fennica. Vol:82.

Heikurainen, L. & J. Paivanen. 1970. The effect of thinning, clear cutting, and fertilization on the hydrology of peatland drained for forestry. Acta Forestalia Fennica. Vol. 104

Ivanov, K.E. 1981. Water Movement in Mirelands. Academic Press Inc. New York, NY. 276 p.

Johnston, W.F. 1977. Manager's handbook for northern white-cedar in the north central States. USDA For. Serv. Gen. Tech. Rep. NC-35, 18 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Johnston, W.F. 1990. Northern White-Cedar. In: Silvics of North America: 1. Conifers. Burns, Russell M., & Barbara H. Honkala, tech. coords. Agriculture Handbook 654. USDA For.serv. Washington, DC. 675 p.

LeBarron R.K. & J.R. Neetzel. 1942. Drainage of forested swamps. Ecology, Vol. 23, No.4:457-465

Lieffers, V.J. 1989. Growth and foliar nutrient of black spruce and tamarck in relation to depth of water table in some Alberta peatlands. Can. J. For. Res. Vol. 20. 805-809.

McKee, W.H. Jr. & E. Shoulders. 1970. Depth of water table and redox potential of soil affect slash pine growth. Forest Science, Vol. 16:4

Miller, R.O. 1992. Ecology and management of northern white-cedar. In: Proceedings of a workshop held in North Bay on December 4th and 5th 1990. Central Ontario Forst Technology Development Unit. Tech. Report No. 28

Miller, R.O., D. Elsing, M. Lanasa & M. Zuidema. 1990. Northern white-cedar: Stand assessment and management options. In: Proc. of Northern White-Cedar in Michigan workshop. Sault Ste. Marie, Mi Feb. 1990.

Miller, R.O., R. Chimner & M. Zuidema. 1994. Bob's Lake Study. Mich. Dept. Nat. Res., Escanaba office. In preperation.

Mitch, W.J. & J.G. Gosselink. 1986. Wetlands. New York: Van Nostrand Reinhold Company.

Nelson, T.C. 1951. A reproduction study on northern white-cedar. Res. Rep. for the Game Division of the Michigan Department of Conservation. Lansing, MI. p. 99

Patrick, W.H., Jr. 1978. Chemistry of flooded soil and effects on mineral nutrition. In: Proc. Soil Moisture, Site Productivity Symposium. ed. William E. Balmer. Myrtle Beach, S.C. Nov 1-3, 1977. pp. 40-48.

Patrick, W.H., Jr. & A. Jugsujinda. 1992. Sequential reduction of inorganic nitrogen, manganese, and iron in flooded soils. Soil. Sci. Soc. Am. J. 56:1071-1073.

Pregitzer, K.S. 1990. Northern white-cedar: Stand assessment and management options. In: Proc. of Northern White-Cedar in Michigan workshop. Sault Ste. Marie, MI. Feb. 1990.

Romanov, V.V. 1961. Hydrophysics of bogs. Israel program for scientific translations. Jerusalem.

Satterlund, D.R. 1960. Some interrelationships between groundwater and swamp forest in the western Upper Peninsula of Michigan. Dissertation. University of Michigan.

Shotyk, W. 1984. An overview of the geochemistry of peatland waters. In: Proc. Advances in Peatland Engineering. Carleton University, Ottawa, Canada. National research Council of Canada. pp. 159-171.

Sikora, L.J. & D.R. Keeney. 1983. Further aspects of soil chemistry under anaerobic conditions. In: Ecosystems of the World. Vol 4A. Mires:Swamps, Bog, Fen and Moor. New York, NY. Elsevier Science Pub. Co. pp. 247-255.

Smith, D.A. 1986. The Practice of Silviculture. 8th Edition. John Wiley & Sons, Inc.

Soil Survey Manual. 1993. USDA Handbook No. 18. Washington D.C.

Stanek W. & I.A. Worley. 1984. A terminology of virgin peat and peatlands. In: International Symposium on Peat

Utilization. C.H. Fuchsman and S.A. Spigarelli, eds. Bemidji State University Center for Environmental Studies.

Thornton, P.L. 1957. Problems of managing upper Michigan's coniferous swamps. J. For. 5:192-197.

Verry, E.S. 1975. Streamflow chemistry and nutrient yields from upland-peatland watersheds in Minnnesota. Ecology. 56:1149-1157.

Verry, E.S. 1980. Water table and streamflow chanes after stripcutting and clearcutting an undrained black spruce bog. In: Proc. of the 6th International Peat Congress. Internation Peat Society.

Verme, L.J. 1965. Swamp conifer deeryards in northern Michigan: their ecology and management. J. For. 63:523-529.

Vompersky, S.E. 1968. Biological foundations of forest drainage efficiency. U.S. Dept. of Commerce. Natl. Tech. Info. Service, Springfield, Va.

Winter, T.C. 1988. A conceptual framework for assessing cumulative impacts on hydrology of nontidal wetlands. Environmental Management. 12:605-620.

Winter, T.C. & Woo, M-K. 1990. Hydrology of lakes and wetlands. In: Surface Water Hydrology. M.G. Wolman & H.C. Riggs,eds. Boulder, Colorado. Geological Society of America, The Geology of North America.

Yoshida, T. 1975. Microbial metabolism of flooded soils. In: Soil Biogeochemistry. Vol 3., eds. E.A. Paul and A.D. McLaren. New York. Marcel Dekker, Inc.

Zasada, Z.A. 1952. Reproduction on cut-over swamplands in the Upper Peninsula of Michigan. U.S.D.A. Forest Service, Lake State Forest Experiment Station. Station Paper No. 27.

Zon, R. & J.L. Averell. 1930. Growth in swamps before and after drainage. J. Foresrty 28:100-101.