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# Environmental Impact of Flooding in the Main (Smallwood) Reservoir of the Churchill Falls Power Plant, Labrador, Canada. II. Chemical and Mechanical Analysis of Flooded Trees and Shoreline Changes.

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## Abstract

The Churchill Falls Hydro Project (called the "Upper Churchill Development") in Labrador, Canada, was initiated in the late 1960s. At that time, in general, not much attention was paid to the impact of such development on the flooding of vegetation especially forest stands. Both forested and un-forested terrestrial vegetation types were flooded (244 915 ha). Some islands were created and in addition portions of existing areas were flooded to form islands (74 075 ha) in the Main (Smallwood) Reservoir area. This paper, the second in a series provides the rate of bio-chemical and physical deterioration of flooded trees in typical forest stands. The analysis of samples taken from selected trees indicated that their lignin content slightly increased and their elastic module decreased on the short term (three years after flooded). A model for the new shore line development was developed and illustrated with graphics and with an aerial photographic sterogramm in a typical flooded forest stand. Major changes were taking place within three years after the flooding. The most significant changes had occurred near the edge of the reservoir due to the continuous variation of water level caused by the amount of seasonal precipitation and by the required drawdown of water to operate the power plant. In general the water in the Main Reservoir reaches its maximum elevation in August, after this (from October to May) the water level slowly decreases during the ice cover. Ice forms first, when the water level is high, then the water level drops resulting in large vertical forces on the trees trapped in the ice. When the water in the reservoir is at its lowest point (at the spring) the ice cruses the trees, and when the water rises (in July) the ice up-roots the captured trees.

**Keywords:** New Reservoirs, Flooding, Boreal, Shoreline Development, Wood Properties

## 1. Introduction

To facilitate an orderly development of any large scale project the effect of consequential changes in the environment must be evaluated. Presently this is required by law in Canada. However, in the 1960s, when the Churchill Falls Power Development took place, no such law was in existence. In spite of this the Churchill Falls (Labrador) Company [CF(L)Co], the developer of the project, did fund some environmental studies concerning the flooding of large areas and dewatering several waterways ( Bajzak and Roberts [1] ). Two of these studies were contracted to the Faculty of Engineering and Applied Science, Memorial University of Newfoundland. The subject of the first study was the development of a vegetation classification and mapping in and at the vicinity of the Main Reservoir (Bajzak [2]). The second study, the subject of this publication, was designed to gather information on the effect of flooding in the same reservoir on major forest stands, especially on individual trees, and on various vegetation covers (Bruneau and Bajzak [3]). It was assumed that the fully submerged trees will be preserved for a long period of time and their presence will be a significant feature of the reservoir. However, the near shore should be cleared of trees. To remove these trees mechanically would be very expensive and time consuming. It was believed that the partially and occasionally flooded trees would die and deteriorate rapidly, therefore, they could be removed primarily by natural processes with minimum human intervention. In order to gather information in exercising this judgment it was necessary to monitor the changes in vegetation (mainly trees) due to flooding and to investigate the rate of deterioration of fully, partially, or occasionally submerged trees. It was hypothesized that the fully flooded dead trees will deteriorate slowly in the water, while the partially flooded ones, and those located near to the shore will be removed more quickly by currents, wave action, ice movement and erosion. The following three objectives were set:

1) To establish the rate of bio-chemical and physical deterioration of flooded trees in typical forest stands.

2) To relate the rate of deterioration to tree characteristics and to water level fluctuation in the Main Reservoir.

3) To investigate the water level fluctuation and of drainage system changes on various vegetation types.

As the area of the Smallwood Reservoir is extremely large, 6527 km$^2$ (MacCallum [4]), approximately one-third the size of Lake Ontario, the global changes in it was to be interpreted on remotely sensed imagery, supplemented by spot observations from a helicopter and on the ground. Although many aspects of the results regarding the effects of flooding on forest and other vegetation types were compiled in report form, formal publication of these data were delayed for several reasons, but chiefly it was the longer term results from the base line that interested the authors. The current interest in the effects of flooding as a result of renewed calls for the development of the Lower Churchill has stimulated our desire to compile this historical research data in a numbered publication series. The first two papers cover the immediate initial inventory and the short term effects of flooding in 'boreal' vegetation. Future papers will summarize some of the lasting effects from de-watering, excavations and re-vegetation to the long term changes.

Our main intention was and is to monitor the long term effects of flooding and to provide information on it in a deliberate and organized manner to assure that a reasonably complete and well documented case study for the project will be maintained and the value of the work already done in the pre- and post-flooded conditions would be enhanced rather than lost. Very detailed information on the project can be found in reports submitted to [CF(L)Co] (Bruneau and Bajzak [3,5] and Bajzak [6]).

## 2. Methods

In order to acquire accurate information on the tree deterioration extensive field investigations were conducted in the following three major forest stands: almost pure black spruce (*Picea mariana*, Mill.); white birch (*Betula papyrifera*, Marsh.) mixed with other coniferous species such as balsam fir (*Abies balsamea* (L) Mill.) and black spruce, and a recently burnt stand (composed mainly of dead black spruce trees). A line was established in each of the above listed forest stands in July of 1972 prior to complete flooding. Along both sides of these lines, in a strip of approximately 6 m wide, individual trees were marked with a numbered tag, tree characteristics were observed and recorded, a core sample was taken mostly at stump (and/or at breast height) of selected trees for chemical (cellulose and lignin content) and physical (compressive strength) analyses. The following characteristics were obtained from each marked tree: species, dominance, diameter at breast height, total height, and age.

It was anticipated that the most changes would occur within a few years after the flooding, therefore, the trees along each line were re-sampled at the spring (July) and fall (October) of 1973, and at the fall (September) of 1974. The status and location of each tree was recorded. Slower changes to be observed were intervals of first five (this was done in 1977), then ten year intervals. The underwater observations were conducted by a scuba diving team from an open boat consisting of a student, a technologist (who obtained the under water core samples and photography), and an engineer.

To observe general changes the whole development area was covered by 1:110 000 scale color infrared vertical aerial photography and by Side Looking Airborne RADAR (SLAR) during the summer of 1972. Large scale 70 mm stereo aerial photographs were obtained of the three test lines from a helicopter. Numerous oblique photos were also taken from the air at different points in the reservoir. In addition general descriptions were made and supplemented with ground photos in selected places at the rim just below and above of the main dykes. The small scale color infrared aerial photographic coverage of the experimental area was to be repeated in 1977, then every ten years. Our field investigations were concentrated mainly on accessible areas by a motor vehicle (on roads and dykes) and by an open boat.

### 2.1. Data Collection and Analysis

Because of some flooding already took place in 1972, when the lines were established, each line was started near the shore (perpendicular to it) and extended beyond the approximate full reservoir elevation. All together 194 trees were numbered from which 38 trees were selected initially for the chemical and mechanical analyses. Almost all of the trees of each line were flooded eventually with the exception of the burnt area where many of the trees were never flooded. At each follow up field visit all previously marked trees, that could be found, were identified, their status noted, and core samples were taken from few of them.

An attempt was made to repeat the small scale color infrared aerial photography in 1977. However, because of the restricted availability of an appropriate aircraft, and bad weather conditions when the plane was available, only one short line was flown. Some of the remaining flight lines were photographed in 1978. However, these photos were considered not adequate for interpretation as a wrong filter was used during the photographic mission.

Following each field investigations the collected data were analyzed, and a report on the results were submitted to [CF(L)Co] periodically (Bruneau and Bajzak [3,5] and Bajzak [6]). The core samples were tested in the laboratories of Memorial University of Newfoundland. In support of our studies a large portion of the Smallwood Reservoir was mapped providing information on the surficial and glacial geology (Vanderveer [7]).

## 3. Results

This paper gives information on the initial effect of flooding in accordance with the stated objectives. Results of individual tree analyses are presented first then a general model of new shore line development is proposed.

### 3.1. Surveillance of Individual Trees

Observations made on individual trees in 1973 indicated that only minimal changes occurred in tree status after the first year of flooding (**Table 1**). Trees, standing in the water discolored rapidly (especially the birch). Many of the trees had been washed out and floated away, but some were hidden in a conglomerate mass of accumulated trees and branches by 1974, (**Table 1**). In 1977 the following number of washed out and under water trees were found: 31 of the black spruce line; 32 of the birch line; and 4 at the burnt area.

The 1974 underwater observations of flooded trees revealed three types of damage: considerable lean, few uprooted trees lying on the bottom, and some snapped tree trunks. The extent of trees affected by the flooding varied in the various stand types with the least changes occurring in the burnt area.

### 3.2. Chemical and Mechanical Analyses

Since the chemical analysis was very expensive and significant changes in cellulose-lignin ratio were not anticipated within a few years of flooding, only a few specimens were obtained in 1973, 1974, and in 1977. Results of the chemical analysis of some of these trees are presented in **Table 2**.

On the basis of preliminary testing for physical strength it was decided that the most useful procedure would be to perform simple compression tests on the core specimens. The values of Young's Modulus and of Elastic Limit were determined for each sample (some typical values of the Young's Modulus are presented in **Table 3**).

### 3.3. New Shoreline Development

The fluctuation of water level is a very important factor-relating to the removal of trees located at the edge of the reservoir and in new shoreline development. It fluctuates seasonally as illustrated by **Figure 1** (for a typical year). The supply level of water in the Main Reservoir reached its design maximum at the end of summer 1973. As more and more generators became operational at the plant the drawdown increased significantly (**Table 4**).

**Table 1. Status of trees (by field visits).**

| Stand Type → | Black spruce | | | | | | Mixed birch and Coniferous | | | | | | Recently burnt (all dead) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Status → | D | U | N | + | – | O | D | U | N | + | – | O | D | U | N | + | – | O |
| Field visit | Number of trees | | | | | | | | | | | | | | | | | |
| 1972 | 5 | n | n | n | n | 60 | 10 | n | n | n | n | 63 | 54 | n | n | n | n | n |
| July, 1973 | 0 | 0 | 16 | 45 | 2 | 2 | 0 | 0 | 1 | 72 | 0 | 0 | n | n | n | 54 | n | n |
| Oct. 1973 | 0 | 0 | 2 | 38 | 2 | 23 | 0 | 3 | 0 | 63 | 1 | 6 | n | 0 | 0 | 54 | 0 | n |
| Sept. 1974 | 9 | 4 | 7 | 26 | 1 | 18 | 20 | 9 | 4 | 18 | 2 | 20 | n | 4 | 1 | 39 | 2 | 8 |

NOTE: 1) The codes relate to changes between consecutive field observations, with the exception at the establishment of lines in 1972: D = dead trees; O = healthy and trees with some physical damage; n = not applicable. 2) Status codes for 1973 and 1974: D = died between observations; N = could not be found; U = up-rooted and floated away; + = no change from previous observation; – = trees removed from their original positions (but found); O = other physical damage (like dead top, tree trunk with some bark off; broken trunk of trees under the water, etc.); n = not applicable. 3) Tree number 10 (of black spruce line) is excluded as no data is available for this tree. No complete underwater data could be obtained in 1977, therefore they are not included in the table, however, at this time some core samples were taken from trees standing in deep water and of washed out trees.

**Table 2. Lignin and cellulose content of some individual trees (% of dry weight).**

| Year: | | 1972 | | 1973 | | 1974 | | 1977 | |
|---|---|---|---|---|---|---|---|---|---|
| Content: | | Lignin | Cellulose | Lignin | Cellulose | Lignin | Cellulose | Lignin | Cellulose |
| Line | Tree # | | | (%) | | | | | |
| Spruce | 5(bS) | 10.9 | 89.1* | --- | ---- | 45.9 | 42.3 | 23.7 | 61.4 |
| | 23(bF) | 26.0 | 62.1 | 33.2 | 73.8 | --- | ---- | 27.0 | 52.0 |
| | 24(bS) | 25.1 | 80.2* | 22.4 | 74.9* | 18.8 | 67.0 | 20.4 | 61.9 |
| | 37(L) | 29.7 | 65.5 | --- | ---- | --- | ---- | 25.9 | 54.6 |
| Birch | 101(wB) | 13.7 | 59.9 | 24.7 | 78.2 | --- | ---- | 17.2 | 68.8 |
| | 108(bF) | 17.3 | 59.9 | 24.7 | 78.2* | --- | ---- | 26.6 | 59.8 |
| | 109(bS) | 33.6 | 57.8 | 27.2 | 83.8* | 59.7 | 28.7 | 27.4 | 66.0 |
| Burnt | 206(bS) | 32.9 | 60.0 | --- | ---- | 56.5 | 35.5 | 25.5 | 65.8 |
| | 221(bS) | 24.3 | 83.6* | 27.976.2 | | --- | ---- | 22.8 | 61.4 |
| | 234(L) | 29.1 | 48.8 | 28.4 | 72.6* | 49.1 | 29.2 | 24.0 | 62.5 |
| | 246(bF) | 29.2 | 70.4* | 28.2 | 77.8* | --- | ---- | 25.6 | 66.5 |

NOTE: 1) Species designation codes (in parentheses after tree number): Black spruce (bS); Balsam fir (bF); White birch (wB); Larch, (L). (*Larix laricina* Du Roi K. Koch. 2) Tree # 206 and # 234 was not flooded. 3)* Ten to 30% higher than normal values. 4) Not every collected sample was analyzed. 5) During the analysis process numerous difficulties arose due to the small core sample size and limitations imposed by the available equipment.

**Table 3. Young's Modulus for some samples (units are 10 gm/cm$^2$).**

| Stand Type | Tree number and species | 1972 | 1973 | 1974 | 1977 |
|---|---|---|---|---|---|
| Black spruce | 5(bS) | 4.11 | 3.19 | 0.50 | 1.84 |
| | 24(bS) | 1.71 | -- | 0.04 | 0.11 |
| | 36(bS) | 3.95 | 2.55 | -- | -- |
| | 44(bS) | 3.84 | 1.85 | -- | -- |
| Birch and | 101(wB) | 4.76 | 2.98 | -- | 4.29 |
| mixed | 108(bF) | 1.72 | 2.58 | -- | 1.03 |
| coniferous | 109(bS) | 6.19 | 4.56 | 0.63 | 3.90 |
| Burnt | 206(bS) | 3.65 | 2.61 | 0.88 | 0.41 |
| | 234(L) | 4.89 | 2.26 | 0.91 | 3.53 |
| | 245(bS) | 2.99 | 1.73 | 1.52 | 2.62 |
| | 246(bF) | 1.61 | 0.81 | -- | 0.77 |

NOTE: The Elastic Limits for the same specimens were also determined. They showed similar trend as the Young's Modulus.

The effect of flooding in the reservoir was observed in the following three distinct areas: shore line just above and slightly below the maximum water level mark, fluctuating water level area, and permanently flooded areas: below the minimum water level mark ( **Figure 2**).

Actually the flooding created four zones near the edge of the reservoir (**Figure 2**).

## 4. Discussion and Conclusions

In the late 1960s and early 1970s, just before and shortly after the establishment of our project, most research, concerning the effect of hydroelectric power developments (man made lakes, was directed towards the study of the aquatic ecosystems, the limnology, and the thermal characteristics of reservoirs, Oberg [8] and Scientific Committee on Water Resources) [9].

After the Churchill Falls power establishment was completed, to generate electricity extensive flooding took place in Quebec (one of the Canadian provinces) at James Bay. In connection with this development a very-

**Table 4. Elevation changes (minimum, maximum) and drawdown values in the Main Reservoir.**

| YEAR | MINIMUM | MAXIMUM | DRAWDOWN |
|---|---|---|---|
| | (meters above mean sea level) | | (meters) |
| 1974 | 471.14 | 472.73 | 1.59 |
| 1975 | 470.87 | 472.76 | 1.86 |
| 1976 | 470.63 | 472.76 | 2.1 |
| 1977 | 470.38 | 472.76 | 2.35 |
| 1978 | 469.96 | 472.76 | 2.77 |
| 1979 | 469.1 | 472.76 | 3.63 |
| 1980 | 470.41 | 472.76 | 2.32 |
| 1981 | 469.77 | 472.76 | 2.96 |
| 1982 | 467.61 | 471 | 5.12 |
| 1983 | 468.4 | 472.73 | 4.33 |
| 1984 | 470.2 | 472.58 | 2.53 |
| 1985 | 469.04 | 472.73 | 3.69 |
| 1986 | 466.71 | 470.61 | 6.02 |
| 1987 | 466.59 | no data | 6.14 |

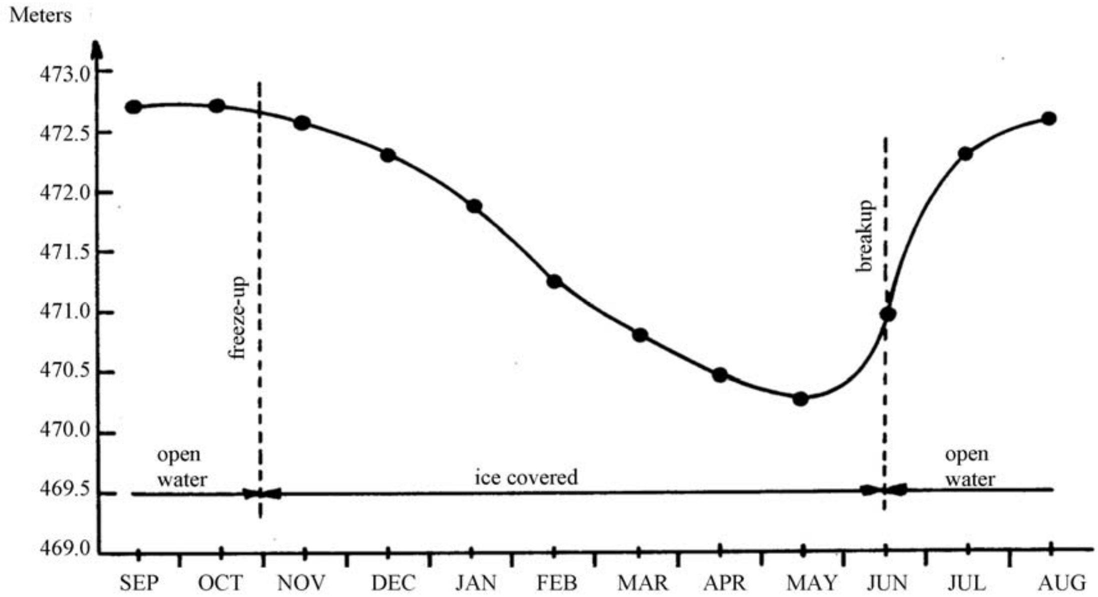
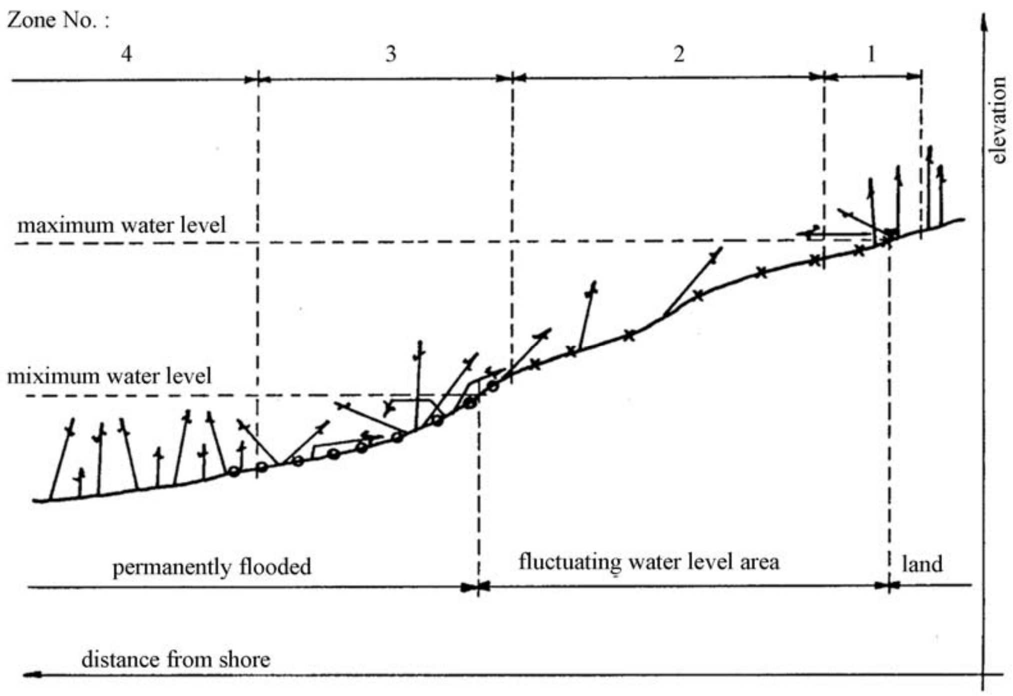


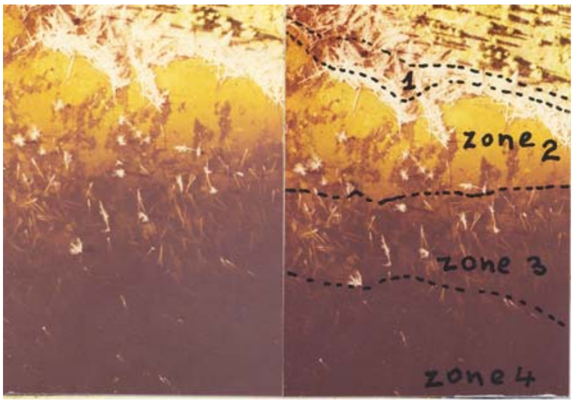

**Figure 1. Seasonal water level fluctuations for a typical year.**




LEGEND: Position of trees: Permanently flooded, fluctuating water level, near shore area. Zone number: 1 to 4. Zone 1 is a narrow strip of new shore line characterized by continuous erosion of soil. In this zone most of the trees were up-rooted, floated away, and eventually accumulated on the nearby new shores or on the dykes. However, some partially anchored trees were still standing in their original position (leaning or fallen on each other) for a few years. Later this zone was completely clear of trees. Zone 2 represents the approximate fluctuating water level area. Generally this zone is much wider than Zone 1.After a few years all of the trees were removed in this zone, exposing the bare lake bottom. Zone 3 is an area of partially flooded trees (also including those trees located below the minimum water level). Here organic material is accumulated forming a thick-unconsolidated layer with many particles suspended in the water. The edge of this zone, below the minimum water level mark, is also characterized by a conglomerate mass of fallen trees, most of which are affected by crashing action of ice during the winter and the spring and by wave action of the water in the summer. Zone 4 is an area below the minimum elevation of the water in the reservoir where the trees are completely submerged thus not affected by ice or wave action. **Figure 3(a)** is a stereogramm of the partially flooded birch-mixed stand when the line was established. **Figure 3(b)** illustrates the developed zones at the same place after few years of flooding. It is important to realize, however, that the above characterization of the near shore developments is just a model. The width of a zone and the status of trees in a particular zone are influenced by the following factors: exposure of a site to wind and wave actions; slope of the flooded land; the fluctuation of water level in the reservoir; and tree species.

**Figure 2. New shoreline development.**

(a)




(b)

**Figure 3. Sterogramm of New Shoreline Development ((a) early stage of flooding; (b) three years after flooding).**

large scale study of the environment was conducted by several research teams (James Bay Development Corporation and Environment Canada [10] and Societe d'energie de la Baie James [11]). These studies were fully financed by the Canadian (federal) and Quebec (provincial) governments.

The results of many word wide investigations concerning the "environmental and social effects of methylmercury bioaccumulation in the food web, emission of greenhouse gases from reservoirs, down stream effects of altered flow, and impacts on biodiversity" (Rosenberg *et al.* [12]) of large scale hydroelectric power developments on spatial and temporal scales were reported by Rosenberg with co-authors [12]. These studies did deal with many aspects of the effect of flooding on the environment, but in them only minor attention was directed towards the forest. Contrast to these our work was and is concerned with the short and long term changes of vegetation types in a large reservoir and its immediate vicinity with special attention paid to forest stand and individual trees. In 1974 the previously mentioned Society from Quebec made contact with us about our work and reproduced two of our reports for distribution (Dumas [13]).

The results of our study indicated that major changes were taking place within three years after the flooding. The most significant changes had occurred near the edge of the reservoir due to the continuous variation of water level caused by the amount of seasonal precipitation and by the required drawdown of water to operate the power plant. In general the water in the main Reservoir reaches its maximum elevation in August, after this (from October to May) the water level slowly decreases during the ice cover. Ice forms first, when the water level is high, then the water level drops resulting in large vertical forces on the trees trapped in the ice. When the water in the reservoir is at its lowest point (at the spring) the ice cruses the trees, and when it rises (in July) the ice up-roots the captured trees. The wind causes significant waves affecting the development of new shore lines in exposed areas where the wave action removes the soil. This does not happen in sheltered places and in shallows. The trees in the completely submerged zone are subject to slow degradation. In the occasionally submerged zone the trees fall on each other first, causing a mass of tree trunks and branches. Eventually the trees here are completely up-rooted and float away creating a bare lake bottom. Most likely the root characteristics of the affected tree species influence the rapidity of tree removal. The geomorphic nature of soil surface is a determinant factor in the extent and rapidity of erosions.

Originally we anticipated that the combined effect of fungal and bacterial decay causes a reduction in the strength of tree stems. The normal wood is composed of about 60% cellulose and 30% lignin by dry weight. Any imbalance in their ratio would give some indication on changes in wood strength, therefore, we subjected the samples to chemical and mechanical analyses. The results of the cellulose content analysis were very erratic due to procedural errors. The physical strength analysis indicated that in most cases when comparisons were possible between years, the value of Young's Modulus and the Elastic Limit decreased from one year to the next. However, some of the 1977 values are higher than of the 1974. This could due to experimental and systematic errors (consecutive samples were taken at different location of tree trunk and they were very small). The results of chemical and mechanical analyses, description of laboratory procedures applied in the chemical and mechanical analyses, and detailed explanation of effect of ice movement and of wave actions can be found in the various reports submitted to the [CF(L)Co] (Bruneau and Bajzak [3,5] and Bajzak [6]). A copy of the 1975 report, Bruneau and Bajzak [5] is available on request.

The individual tree characteristics were not correlated with the rate of wood deterioration (first part of the second objective) as the natural forces removed most of the trees in the fluctuating water level area within a short period of time. Results concerning our third objective were partially covered in this paper, the rest will be reported in another publication (see this volume).

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