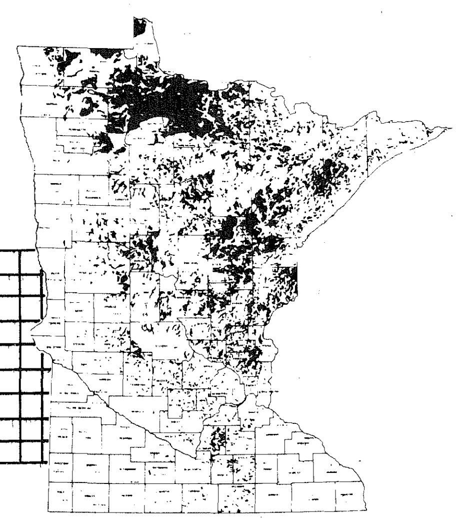
MINNESOTA PEAT PROGRAM

The Water Resources of Peatlands: Summary of Two-Year Results



1981

Minnesota Department of Natural Resources

THE WATER RESOURCES OF PEATLANDS

SUMMARY OF TWO-YEAR RESULTS

by

John C. Clausen

Kenneth N. Brooks

David P. Guertin

Department of Forest Resources
College of Forestry
University of Minnesota

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

LIST OF FIGURES

LIST OF FIGURES (Cont'd.)

LIST OF TABLES

LIST OF TABLES (Cont'd.)

EXECUTIVE SUMMARY

WATER QUANTITY RESULTS

Water Budgets

- More snow accumulated on undisturbed natural areas and remained longer into spring than on cleared open areas.
- Clearing live vegetation on drained peatlands appears to reduce evapotranspiration.
- The change in seasonal water level appears to be less on the undrained area while daily fluctuations are greater on the drained mined area.
- The effect of mining on annual runoff cannot be determined at this time.

Stormflow

- Response factors were similar for Toivola and Corona but the mined area had a shorter lag time to peak discharge.

Groundwater Flow

- Groundwater was found to move horizontally through the Toivola peatland.
- Some change in vertical groundwater movement occurred with more downward movement after wet periods and more upward movement after dry periods.

Water Table Fluctuations

- Water levels fluctuated less at Toivola than at Corona.
- The water table at Corona generally follows the surface contours of the peatland.

Infiltration

- Final infiltration rates for a vegetated peat soil at Fens were greater than for bare peat.
- The Corona mined area had a lower infiltration capacity than Fens.
- Puddling of the peat surface caused by flooding with water reduces infiltration.

WATER QUALITY RESULTS

Study Area Characteristics

- Runoff from the fens was higher in mean pH, specific conductivity, calcium, magnesium, and alkalinity than bog runoff.

- Disturbed peatland (i.e., cleared, drained and cultivated or mined) ditch waters were higher in color, suspended sediment, acidity, sodium, aluminum, potassium, iron, zinc, copper, boron, and total-, nitrate-, ammonia-, and organic nitrogen than undisturbed peatland runoff. Undisturbed peatland runoff was higher in dissolved oxygen and percent saturation. Acidity and nitrogen appeared to fluctuate more in the disturbed peatlands whereas pH fluctuated more at Corona.

- Most of the nitrogen was in the reduced organic form and a large part of the remainder was ammonia. There was little nitrate-nitrogen.

- Spring minimum values and winter under ice maximums were observed for: pH, acidity, alkalinity, specific conductivity, calcium, magnesium, aluminum, iron, manganese, and the various nitrogen forms. Color was at maximum values under winter ice and in late summer during low flow periods. Chromium was also greater under the ice. Winter minimums occurred for dissolved oxygen and percent saturation while suspended sediment concentrations were highest during summer rainstorms.

- The Corona mined peatland runoff seemed to have unusually high values for specific conductivity, zinc and potassium.

Nutrient Loading

- The disturbed watersheds were annually exporting a greater mass of suspended sediment, aluminum, iron, sodium, and total- and ammonia-nitrogen. The fens were exporting more calcium and magnesium than the bogs. Fens export was extremely high for some nutrients, while Corona was quite high for total-nitrogen.

Mining Effects

- Runoff from Corona mined area was higher in color, suspended sediment, potassium, aluminum, sodium, manganese, total phosphorus, and total-, nitrate-, organic-, and ammonia-nitrogen than control runoff.

- These results are quite preliminary. Little or no difference in runoff concentrations between the mined and control areas was observed for zinc, copper, nickel, lead, chromium, cadmium, arsenic, or selenium. Higher mercury concentrations have so far been measured at the control.

Reclamation Effects

Ponds

- The constructed ponds are more like lake water than the control ditchwater. The ponds are more basic and clear, contain more oxygen, and have less dissolved constituents and nutrients than the control ditch. More nitrate and organic nitrogen was found in the ponds and less total and ammonia nitrogen than in ditchwater.

- The pond with its bottom in mineral soil was higher in pH, specific conductivity, dissolved oxygen, calcium, magnesium, and zinc than the pond with its bottom in peat. The mineral pond was also lower in color, aluminum, and iron than the peat pond.

Drainage and Forest Fertilization

- Clearing and draining the Fens peatland appears to have lowered total and ammonia nitrogen, total phosphorus and orthophosphate, and iron in soil solution. Potassium, specific conductivity, calcium, and magnesium concentrations were higher in soil solution samples on drained plots.

- Fertilization of the drained fen increased soil solution concentrations of total phosphorus and orthophosphate, potassium, nitrate, specific conductivity, calcium, and magnesium and decreased concentrations of aluminum and iron.

- Ditchwater surrounding the fertilized field was higher in potassium and specific conductivity than waters surrounding the unfertilized field.

Downstream Assimilation

- Peatland runoff was found to increase in pH, dissolved oxygen, and specific conductivity after mixing with downstream upland waters.

Water Quality Relationships

Discharge

- Concentrations of potassium, sodium, and total nitrogen at Corona and total and organic nitrogen at Fens were found to correlate positively with discharge except for sodium, which showed a negative correlation.

Temperature

- Air temperatures were found to be significantly correlated to concentrations of suspended sediment and total phosphorus at Toivola; sodium, total nitrogen and ammonia nitrogen at Corona; and calcium at Fens. Greater concentrations occurred at higher temperatures for all these constituents except ammonia nitrogen and calcium.

- Peat temperatures positively correlated with suspended sediment, calcium, aluminum, iron, total nitrogen, and organic nitrogen.

Constituent Interrelationships

- Most cation concentrations were interrelated. Phosphorus and nitrogen were also related to most cations.

- Greater concentrations of one constituent are usually associated with greater concentrations of other constituents.

- Interrelationships among constituents varied for each study area watershed.

INTRODUCTION

Recent increased demands for portions of Minnesota's three million hectares of peatlands for horticultural and energy uses have prompted the Minnesota Department of Natural Resources to investigate the potential effects of peat development on water resources. The College of Forestry began a field study of the water resources of peatlands in 1977 because the potential water resources impacts were largely unknown. The study as originally designed had several water quantity and water quality objectives:

Water Quantity Objectives:

1. To develop a method of predicting the impacts of large peatland developments on water quantity.
2. To identify the critical elements and processes in peatlands that control water volume and rate of movement.
3. To evaluate the effects of alternative harvesting methods and alternative reclamation schemes.

Water Quality Objectives:

1. To predict the impacts of large peatland developments on the quality of water resources.
2. To determine the important water quality parameters that may be affected by peatland development.
3. To evaluate the effects of alternative harvesting methods and alternative reclamation schemes.
4. To evaluate the process by which acid bog waters become buffered by receiving lakes and streams.

To accomplish these objectives a literature review was performed and field investigations were conducted. Field studies of water budgets and water quality monitoring were conducted at several peatlands including an area presently being mined for horticultural peat, an agricultural area being used for reclamation, and two natural areas. This report summarizes the results obtained from the first two years of field studies. The literature review of the water resources of peatlands was previously submitted (Clausen and Brooks 1980).

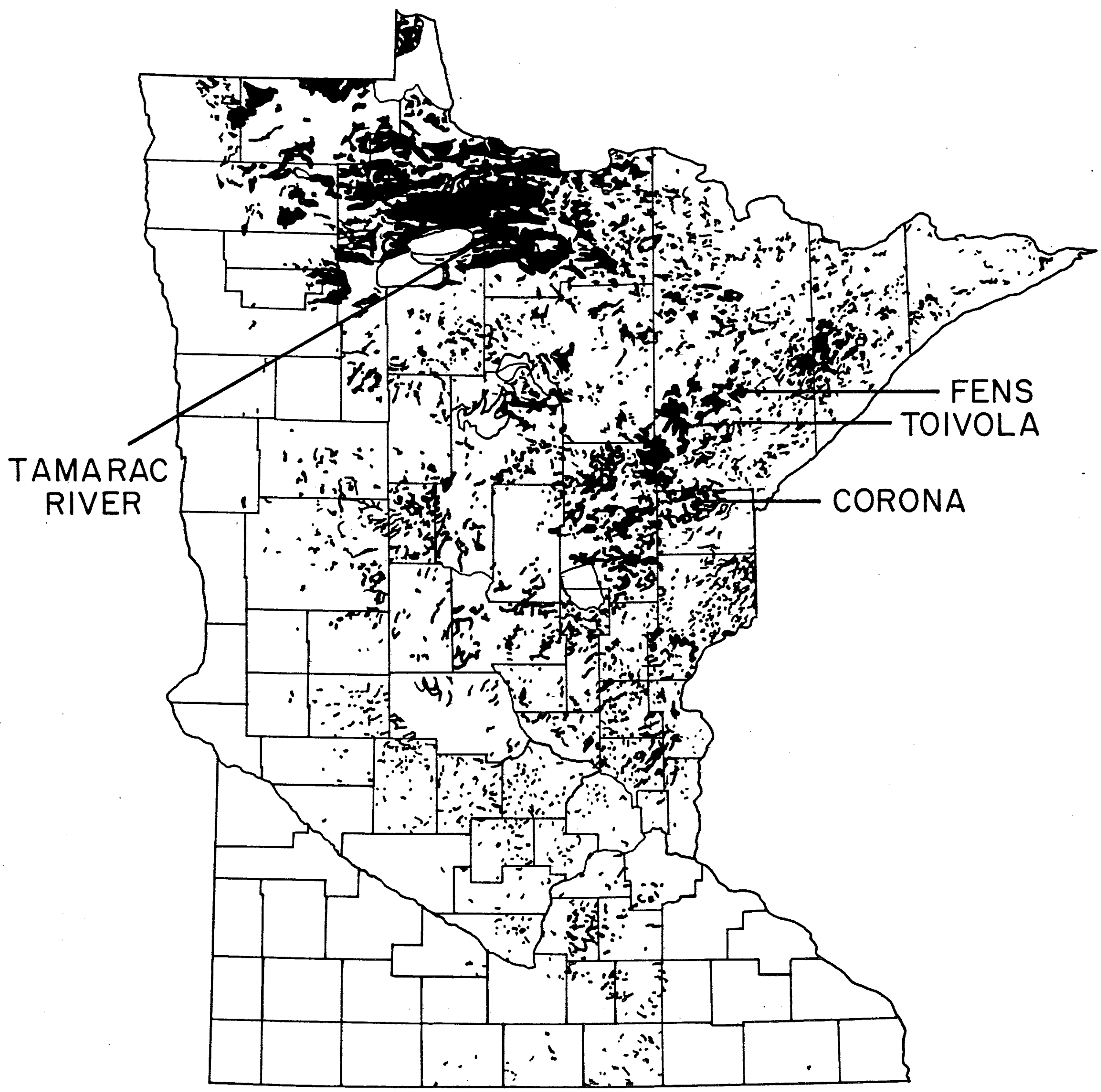
STUDY AREAS

Four major study areas in northern Minnesota are being investigated (Figure 1). Two of these peatlands are undisturbed natural areas; one is located in northwest Minnesota (Tamarac River) and one is in the northeast (Toivola). The other two peatlands have been drained. One area is presently being mined for horticultural peat moss (Corona), while the other area has been used for agriculture in the past and is currently the site of peatland reclamation studies (Fens). More detailed study area descriptions are given below and summarized in Table 1.

Table 1. Summary of study area characteristics.

Characteristic		undisturbed Toivola	 Tamarac R.	drained and mined Corona	 cultivated Fens
Peatland type		Transition	Fen	Bog	Fen
Watershed area	ha	3758	14349	155 (N)	93 (N)
	ha	--	--	284 (S)	36 (S)
Average slope	m/km	1.3	0.6	1.0	0.9
Average peat depth	m	3.7	2	4.6	1.6
Range	m	1.2 - 4.9		1.5 - 10.7	0.6 - 3.4
Peat type fibric	%	11			15
hemic	%	84			66
sapric	%	5			19
Peat pH < 4.5	%	14			0
4.5 - 5.0	%	10			0
> 5.0	%	76			100
Vegetation open	%	8		100	100
spruce and tamarack	%	89		0	0
Brush	%	3		0	0

FIGURE 1: MAP OF MINNESOTA SHOWING THE LOCATION OF PEATLAND WATERSHED STUDY AREAS.



Toivola

The Toivola peatland is a 3758 ha transition area that is undrained (Figure 2). Most of the peat is moderately decomposed hemic, although about ten percent of the watershed is raised bog (Olson *et al.* 1979). Peat depths range from 1.2 to 4.9 m and average 3.7 m. About 90 percent of the watershed is forested in either black spruce (*Picea mariana* [Mill.] B.S.P.) or tamarack (*Larix laricina* [Du Roi] K. Koch). The two raised bogs in the northern part of the watershed are vegetated with black spruce up to 9 meters in height whereas the black spruce found elsewhere is stunted. A relatively pure stand of tamarack of 8 meter height is located in the west center of the watershed. Eight percent of the watershed is open being vegetated with sedge (*Carex spp.*). The major open area lies just south of the ovoid-shaped raised bog, possibly as a watertrack. The remaining three percent is in brush, primarily alder (*Alnus spp.*) and willow (*Salix spp.*), most of which is located near the mineral islands in the center and bottom of the watershed. *Sphagnum*, leatherleaf (*Ledum groenlandicum* [Oeder]) and Labrador tea (*Chamaedaphne calyculata* [L.] Moench) are found throughout the peatland. The Toivola peatland slopes toward the south at an average of 1.3 m/km and is underlain by sand and silt.

The Toivola peatland has been instrumented for complete water budget and groundwater flow analysis (Figure 3). The weather station contains both a recording and nonrecording precipitation gauge, a recording air and peat thermograph, and a nonweighing bottomless lysimeter. In addition, 10 precipitation gauges are located at every other station along the east and west transects. Runoff from the watershed is recorded at the intersection of Joula Creek and County Road 133 in a stilling well at a box culvert. Along the east and west transects are located 20 stations, each spaced at about 1.6 km and containing a

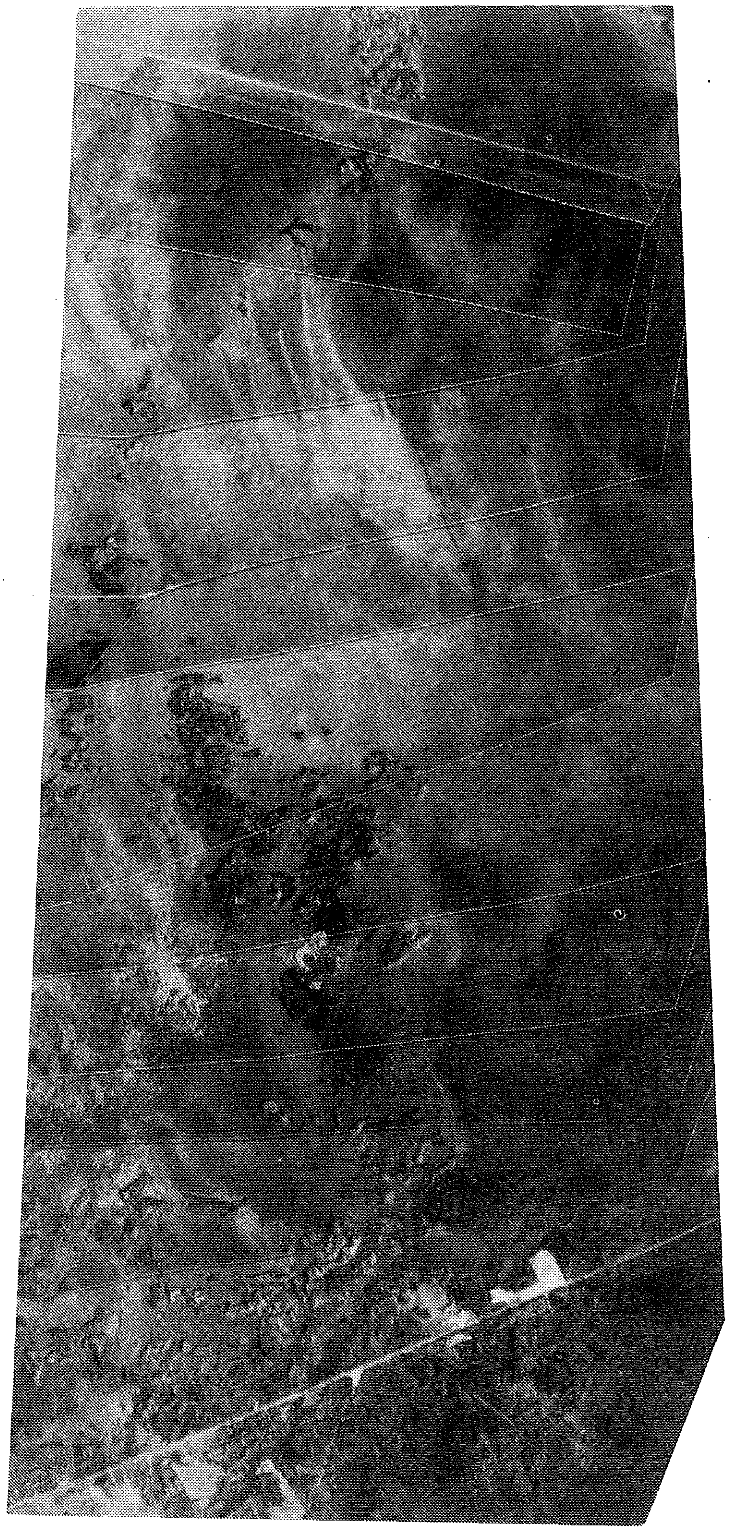


FIGURE 2. AERIAL PHOTOGRAPH MOZAIC OF THE TOIVOLA PEATLAND.

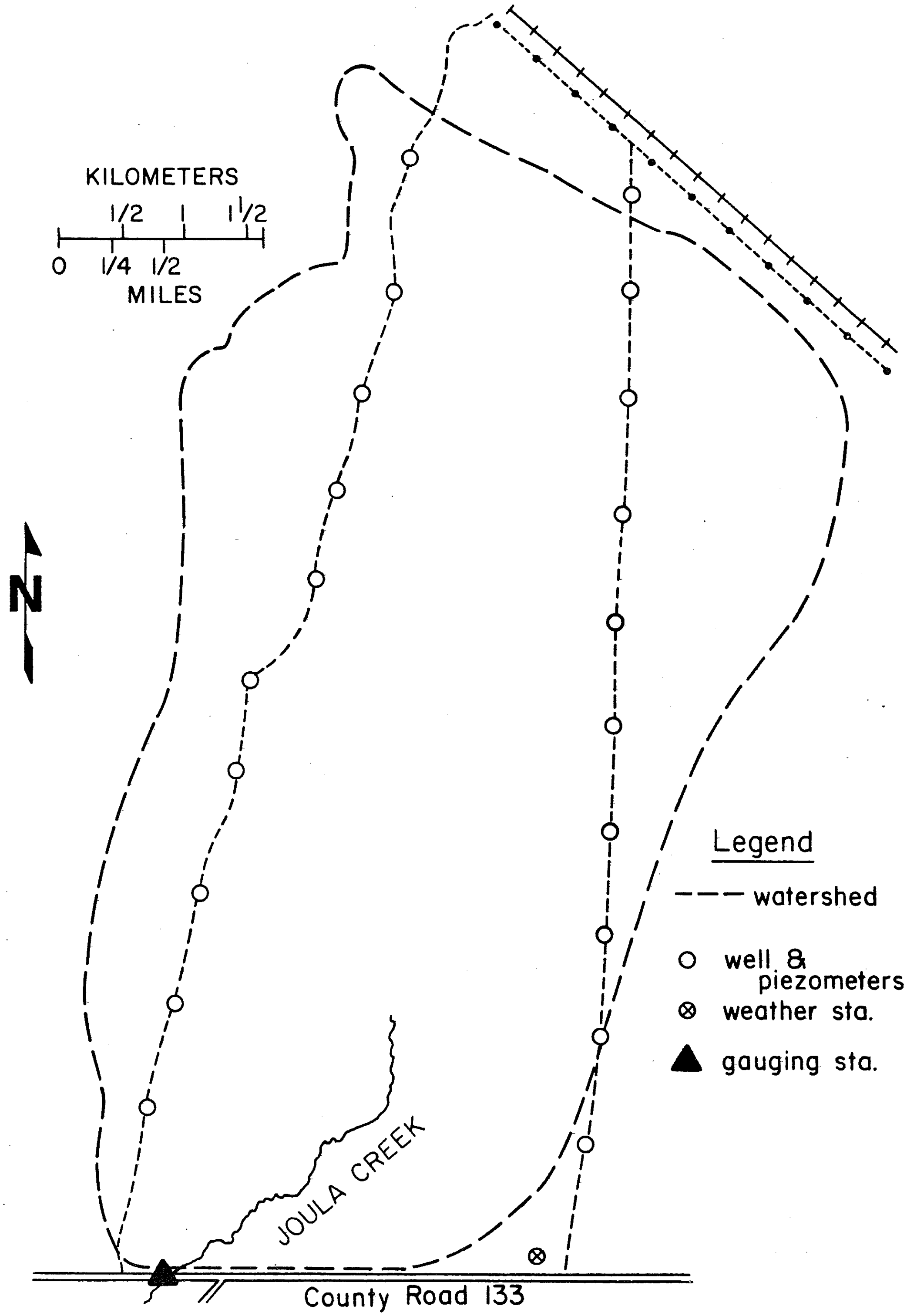


FIGURE 3 : MAP OF THE TOIVOLA PEATLAND.

water table well and three piezometers to determine the change in storage and the direction of groundwater flow. The groundwater level is continuously recorded at the third station from the south on the east transect.

Tamarac River

The Tamarac River drains a large (approximately 14,350 ha) fen into Upper Red Lake at Waskish (Figure 4). This peatland is composed mostly of hemic peat averaging 2 meters in thickness. There are several raised bogs and water tracks found within the peatland. Vegetation consists primarily of sedges with areas of alder brush and stunted black spruce and tamarack. The raised bogs contain larger black spruce with an understory of *Sphagnum*, Labrador tea, and leatherleaf. This peatland is relatively undisturbed although it contains 40 km of old ditches constructed in the early 1900's. The Tamarac River peatland is relatively flat with an average slope of 0.6 m/km.

This peatland has been instrumented for water budget analysis with the weather station and runoff gauging station located at the intersection of the Tamarac River and an old ditch bank road (Figure 5). Two additional precipitation gauges are located out in the watershed. No groundwater information is being collected.

Corona

The Corona area is a 290 ha *Sphagnum* bog that is currently being mined for horticultural peat moss using the milled-peat method (Figure 6). The area has been mined since 1958 by using pneumatic harvesters. The upper three meters of the bog is fibric *Sphagnum* moss, which is underlain by hemic reed-sedge peat with a substrate of sand and clay. The peat deposit ranges in thickness from 1.5 to 10.7 meters and averages 4.6 meters (Soper 1919). The watershed at

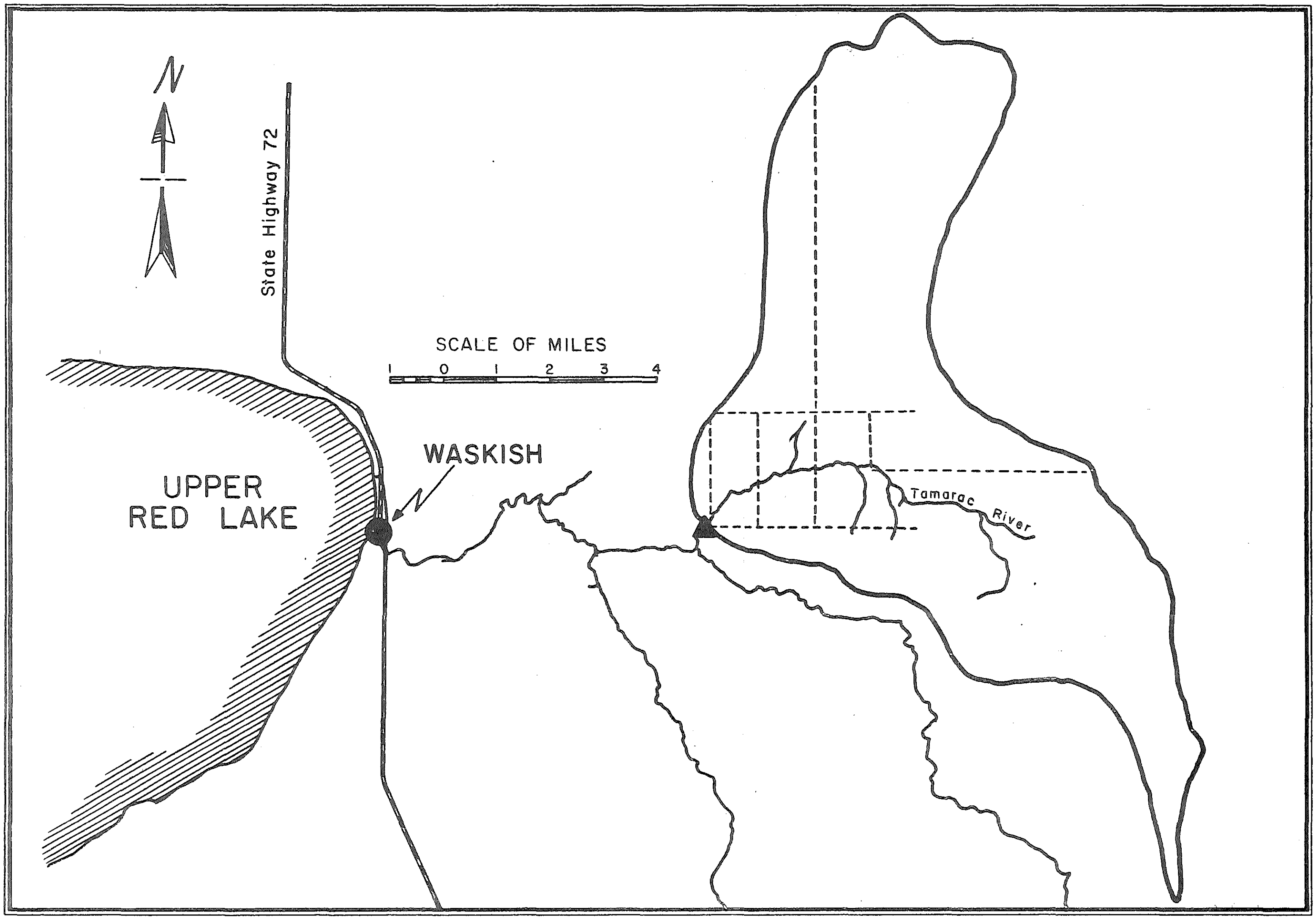


FIGURE 4 : MAP OF THE TAMARAC RIVER STUDY AREA.

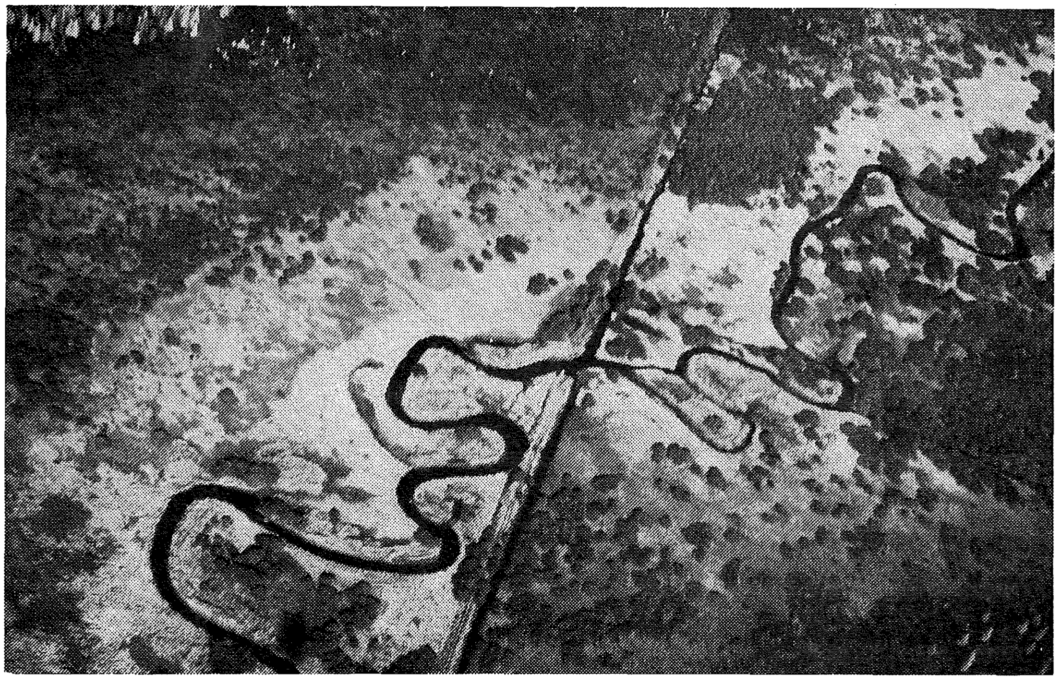


FIGURE 5: AERIAL PHOTOGRAPH OF THE TAMARAC RIVER GAUGING STATION.

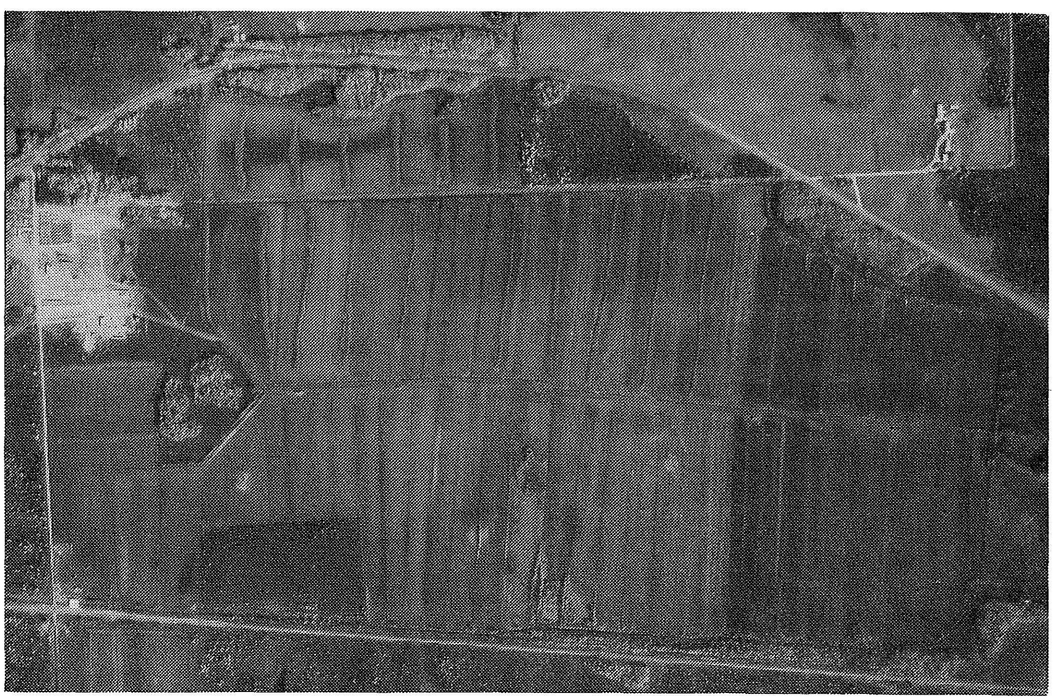


FIGURE 6: AERIAL PHOTOGRAPH OF THE CORONA MILLED PEAT MINING OPERATION.

present is almost entirely void of live vegetation, although prior to clearing there occurred spruce, tamarack, *Sphagnum*, leatherleaf, Labrador tea, sedge, and cotton grass (*Eriophorum spp.*) (Soper 1919). Ditches on the area are spaced at 60 to 100 meters and average 1.3 m deep. The surface slopes to the southwest at m/km.

The Corona area has been instrumented for water budget analysis (Figure 7). The weather station includes a recording air and peat thermograph and a recording and nonrecording precipitation gauge. Two other nonrecording precipitation gauges are located within the watershed. Three separate runoff gauging stations have been used at the Corona bog of which two are in current use. The Corona north gauging station drains 155 ha of mined area and Corona south drains 284 ha. The south station, located by the railroad tracks, drains the entire mined area but was abandoned because of water quality contamination from the old peat plant. The Corona control gauging station (not shown on map), draining a 58 ha bog, is located on the north side of state highway 210. A precipitation gauge is also located at the control. To determine the change in water storage within the peat, 35 nonrecording wells and one recording well were installed in the watershed. Two bottomless nonweighing lysimeters are located in the west central portion of the mined area, one on bare peat to measure evaporation from a mined surface and one in a vegetated unmined area to determine evapotranspiration. Two double-ring infiltrometers were installed near the lysimeters, one on bare peat, the other on vegetated peat. During 1980 an evaporation pan will be added to the weather station at Corona. Additional infiltration data will be gathered with several infiltrometers at Corona during 1980-81.

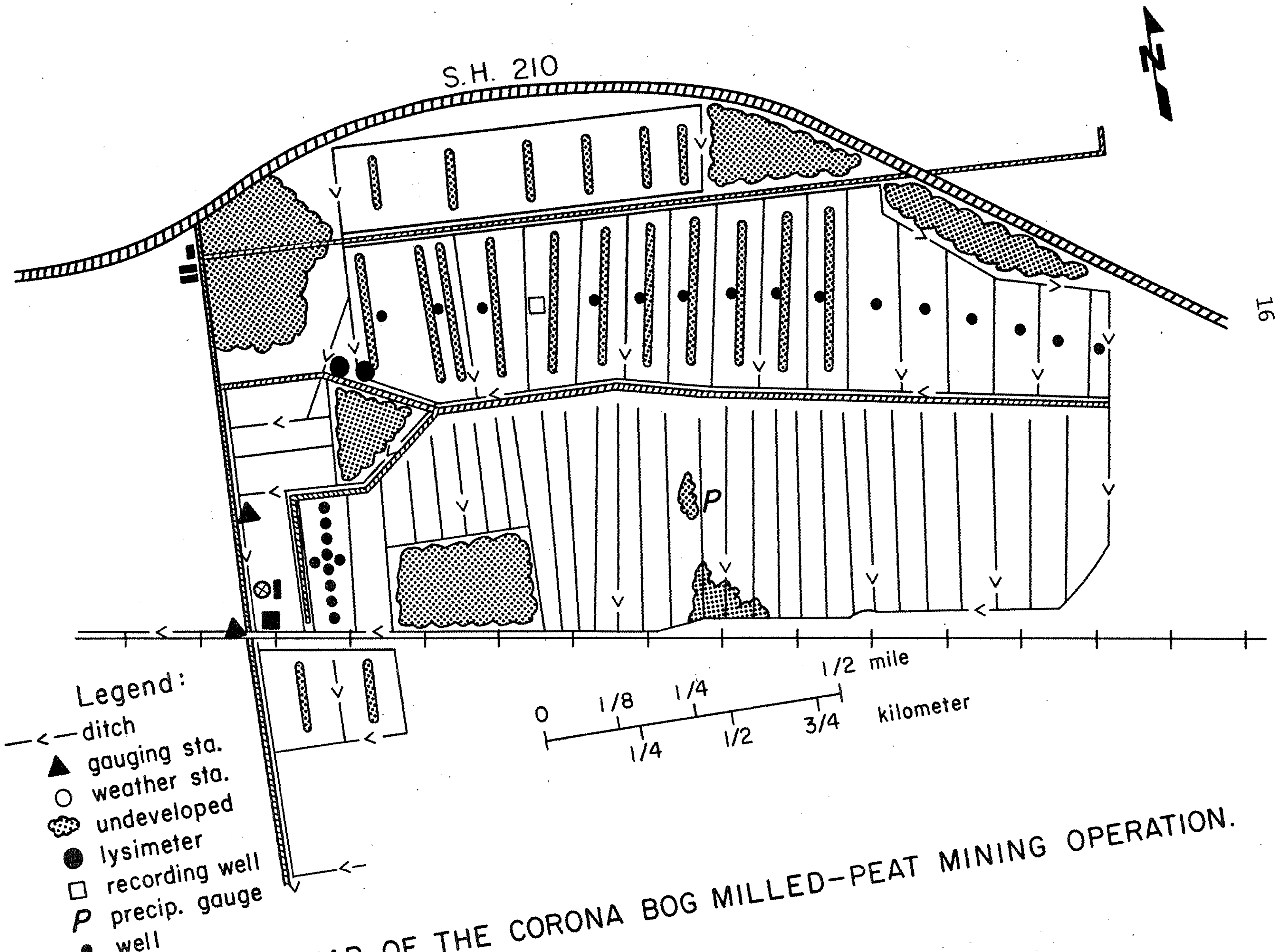


FIGURE 7: MAP OF THE CORONA BOG MILLED-PEAT MINING OPERATION.

Fens

Although the Fens study area was originally ditched in 1915, there has been extensive drainage and cultivation for only the past 25 years (Clapp 1916) (Figure 8). Ditches are spaced at 50 and 100 meters and average 2 meters deep. This peatland is composed primarily of hemic reed-sedge peat varying in thickness from 0.6 to 3.4 meters and averaging 1.6 meters (Farnham and Grubich 1970). The area, called Wilderness Valley Farms, has been used for vegetable, small

Figure 8. Aerial photograph of the Fens peatland reclamation area.

grain, and sod production in the past. The original vegetation consisted of alder and tamarack ranging from 9 to 15 meters tall with a diameter of 10 to 25 cm. The understory included grasses, ferns, heath plans, and *Sphagnum* (Clapp 1916).

Currently, Wilderness Valley Farms is the site of several peatland reclamation studies including agriculture, forestry, sewage treatment, and waterfowl ponds (Figure 9). Both agriculture and forestry reclamation experiments are being conducted on mined and unmined peat. Forest reclamation includes both fertilized and unfertilized treatments of several forest species. The three sewage treatment methods are the Finnish system, the peat-over sand filter, and sludge disposal. Two one-acre waterfowl ponds have been constructed, one with the bottom in peat, the other with the bottom in mineral soil. A control area is also being monitored.

Instrumentation at Wilderness Valley Farms is extensive. One weather station is located at the fertilized forestry field (F1) and includes a recording and nonrecording precipitation gauge; a recording air and peat thermograph; evaporation pan; two bottomless lysimeters, one bare and the other vegetated; and two infiltrometers, one bare and the other vegetated. Another recording precipitation gauge and a recording wind speed and direction meter are located at the Iron Range Resources and Rehabilitation Board offices. Before reclamation studies commenced, runoff was monitored at two locations, one draining the 93 ha north half, the other draining the 36 ha south half (Figure 9). After reclamation studies began, these stations were abandoned because waters were coming from several different reclamation treatments. Currently, runoff is recorded using V-notched wiers and stilling wells at five locations: the two forestry unmined plots, the mined area, and the two ponds.

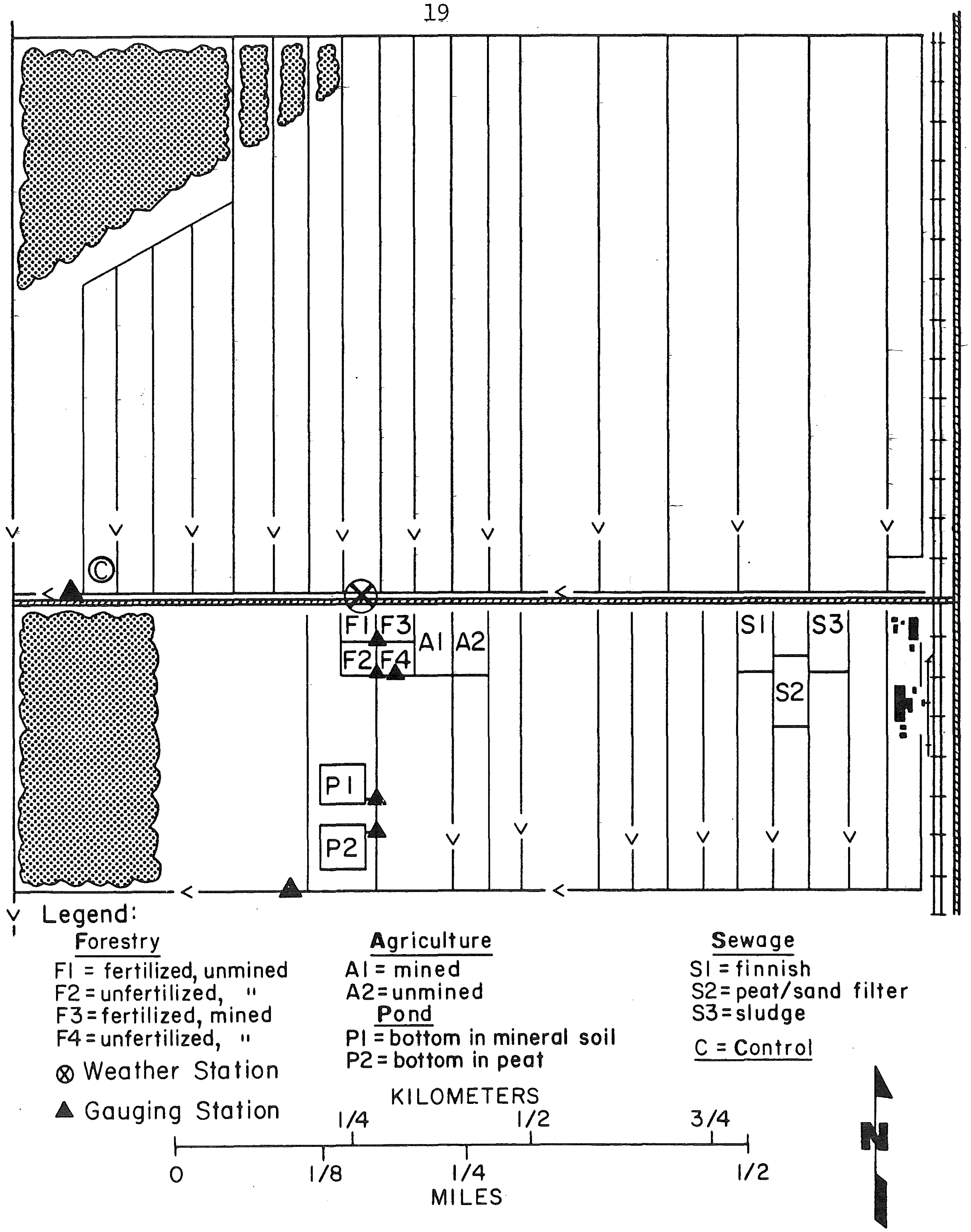


FIGURE 9: MAP SHOWING LOCATIONS OF RECLAMATION STUDIES AT WILDERNESS VALLEY FARMS.

To complete the water budget analyses, two recording wells are installed, one in the unmined forestry fertilized plot, the other in the unmined agricultural field. In addition, 64 wells are located in the forestry mined and unmined fields and the unmined agricultural field. Soil suction lysimeters have also been in stalled in the unmined forestry fields to monitor groundwater quality.

METHODS

A. WATER QUANTITY

To evaluate the potential effects of peat development on water quantity, the following components of the water balance equation were monitored: precipitation, runoff, evapotranspiration, and change in storage. Infiltration and groundwater flow were also measured. To evaluate the effects of peat development on peak discharge, response factor analysis was performed. The methods used to measure each component of the water balance equation and each process are discussed in greater detail.

1. Precipitation

All four of the study areas were instrumented with weighing bucket Belfort universal recording rain gauges with battery clocks and Altar windshields.[1] Clocks were weekly except at the Tamarac River, where a monthly clock was used. To determine basin precipitation and adjust recording precipitation, standard 8-inch Belfort nonrecording rain gauges were used in the watersheds: Toivola (11), Tamarac R. (3), Corona (3), and Fens (2). Rain gauges were run year-round with an antifreeze mixture of ethylene glycol, methyl alcohol, and 10W motor oil (Figure 10). Basin precipitation was determined by averaging the gauge readings for the watershed. Winter snow water equivalent was determined from snow courses by using the Mt. Rose snow tube as described by Haertel (1978).

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[1] Names and products are given for the convenience of the reader and do not indicate endorsement by the College of Forestry. Similar types can be obtained from other suppliers.

2. Runoff

Runoff was monitored using stilling wells and various types of control sections: wiers (Fens ponds and forestry plots), a box culvert (Toivola), circular culverts (Corona south and control), and a natural channel (Tamarac R.). At Corona north, both the natural channel and a box flume have been used. Stage of the ditch or stream was recorded in stilling wells constructed of 12" diameter PVC by using Belfort FW-1 portable water level recorders with battery clocks (Figure 11). Recorder clocks were weekly except at the Tamarac River, where they were monthly. Discharge stations were shut down during the winter of 1977-78 but were kept running during the winter of 1979-80 by using propane pilot light heaters. Discharge was determined from stage data by using rating equations developed from numerous discharge measurements obtained with a Gurley pygmy current meter and revolution counter. Low flows at Corona on several occasions required using the salt-dilution technique for discharge:

$$Q = q \frac{C_1 - C_2}{C_2 - C_0}$$

where Q = discharge (cfs), q = constant rate of added salt concentration (cfs = gpm x 0.00223), C_0 = background specific conductivity (μmhos/cm), C_1 = specific conductivity of salt solution, and C_2 = specific conductivity of ditch after mixing (U.S. Bureau of Reclamation 1967).

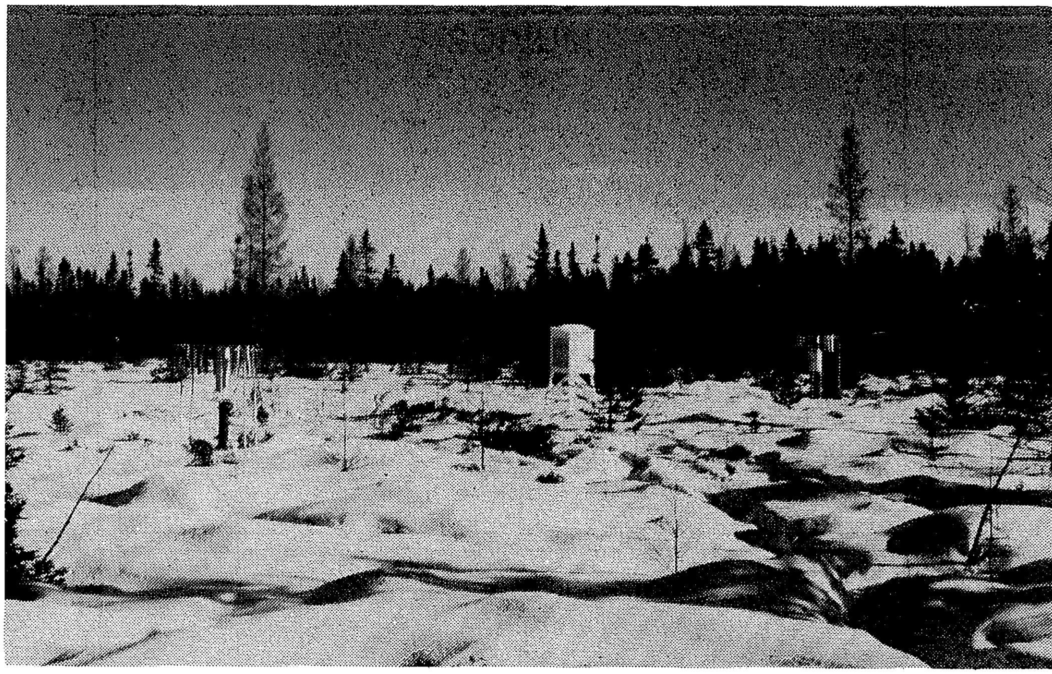


Figure 10. Photograph of the Toivola weather station.

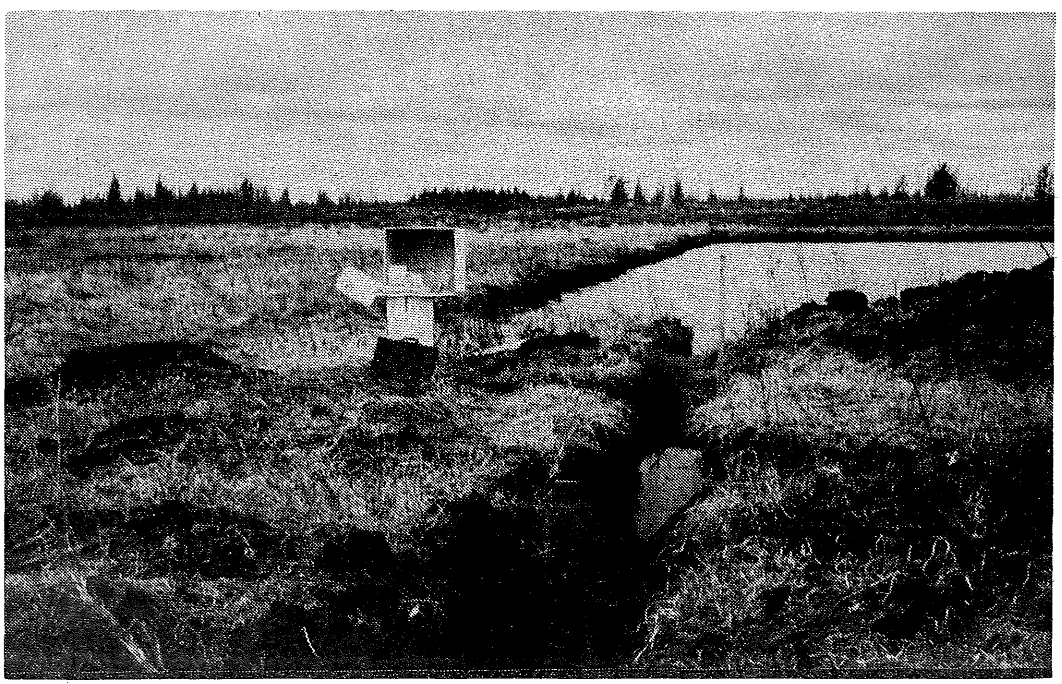


Figure 11. Photograph of the north pond outlet showing stilling well, recorder, and wier.

3. Evapotranspiration

Monthly potential evapotranspiration (PET) was determined for all study areas by using the method of Thornthwaite and Mather (1957). This method uses mean monthly temperature and station latitude in the relationships:

$$PET = 1.6\ (\frac{10T}{I})^{A}$$

$$\text{and} \quad I = \Sigma i \cdot \text{where } i = (T_M/5)^{1.514}$$

$$\text{and} \quad A = 6.75 \times 10^{-7}\ (I)^3 - 7.71 \times 10^{-5}\ (I)^2 + 1.792 \times 10^{-2}\ (I) + 0.49239$$

where PET = potential evapotranspiration (cm), T = mean monthly temperature (^{O}C), T_M = normal mean monthly temperature (^{O}C), and i = monthly heat index. Monthly values of PET are adjusted for day length using correction factors based on station latitude. Mean monthly temperature was obtained from a recording Belfort thermograph with battery clock in a standard instrument shelter (Figure 10). Initially, all charts except at the Tamarac River were weekly, but since only daily maximum and minimum temperatures were needed, clocks were made monthly.

Vegetated bottomless lysimeters were used to estimate evapotranspiration at all areas except at the Tamarac River. Lysimeters at Fens were constructed of 10 ga. galvanized corregated culverts 1.2 m in diameter by 1.8 m deep and installed by gradual lowering and pressing as outside peat layers were removed by using a post hold digger (Figure 12). The remaining lysimeters were constructed of 16 ga. galvanized sheet metal 1.2 m deep by 0.9 m in diameter. These smooth wall lysimeters were much easier to press into the peat. All lysimeters were sunk to the mineral substrate underlying the peat. Aluminum water talbe wells were installed inside and outside the lysimeters to measure

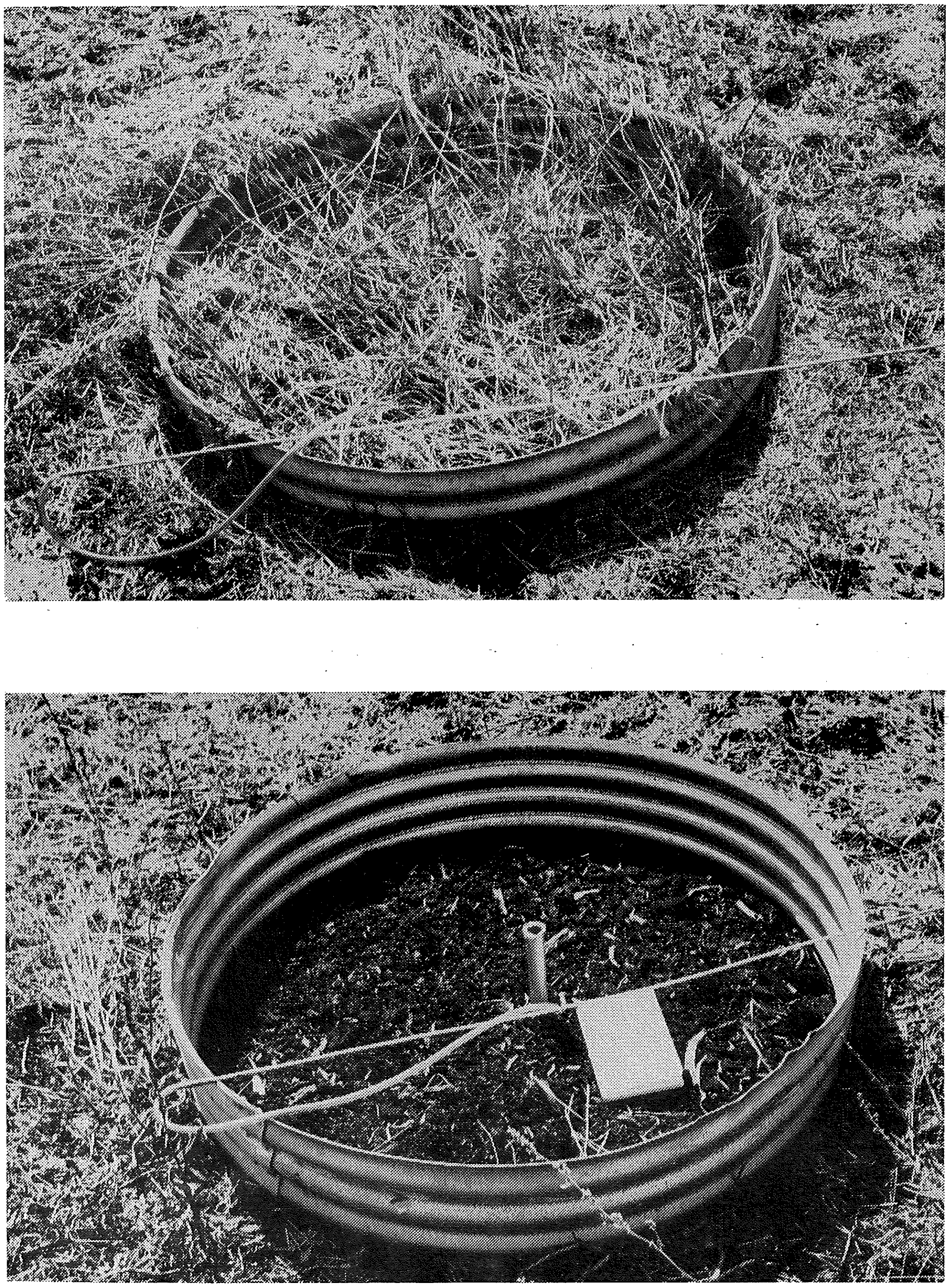


FIGURE 12. PHOTOGRAPHS OF VEGETATED AND BARE LYSIMETERS AT FENS.

water levels. Evapotranspiration was determined from changes in lysimeter water levels by using water yield coefficients (see Change in Storage section). Additional lysimeters without any surface vegetation were installed at Fens and Corona to determine evaporation from an exposed (mined) peat surface. Generally, weekly lysimeter readings were taken during the frost-free period.

A standard U.S. Weather Bureau evaporation pan was also used at Fens during 1979 to estimate evapotranspiration (Figure 13). The water balance method was also used to estimate ET on all areas by using the equation:

$$ET = P - RO \pm \Delta S$$

where ET = evapotranspiration, P = precipitation, RO = runoff, and ΔS = change in storage. The ΔS term was not used for the Tamarac River watershed.

Figure 13. Photograph of the evaporation pan at Fens.

4. Change in Storage

The change in storage was determined from recording and nonrecording water table wells. Recording wells, located on all areas except the Tamarac River, were constructed of 15 cm diameter PVC pipe that was perforated and pressed into a hole made with a post hole digger. Water table levels were monitored by using a Belfort water level recorder. Recording wells were shut down during the winter of 1977-78, but the Corona well and the Fens forestry well were kept running during the winter of 1979-80 by using propane pilot light heaters (Figure 14).

Nonrecording water table wells were constructed of 3.8 cm O.D. aluminum tubing that was perforated and pinched at one end and pounded into the peat. Levels were run each year on well top elevations. Biweekly readings were taken with a bubbler tube.

Water yield coefficients, used to convert the change in water level to the change in storage, were determined by correlating precipitation amount to the rise in water level over a short time span by using the methods described by Heikurainen (1963).

5. Infiltration

Several infiltration curves were run for bare and vegetated sites at Fens and Corona with double ring infiltrometers by using the methods described by Black *et al.* (1965) except that a shorter time period of 90 minutes and a constant head of 9 cm were used (Figure 15).

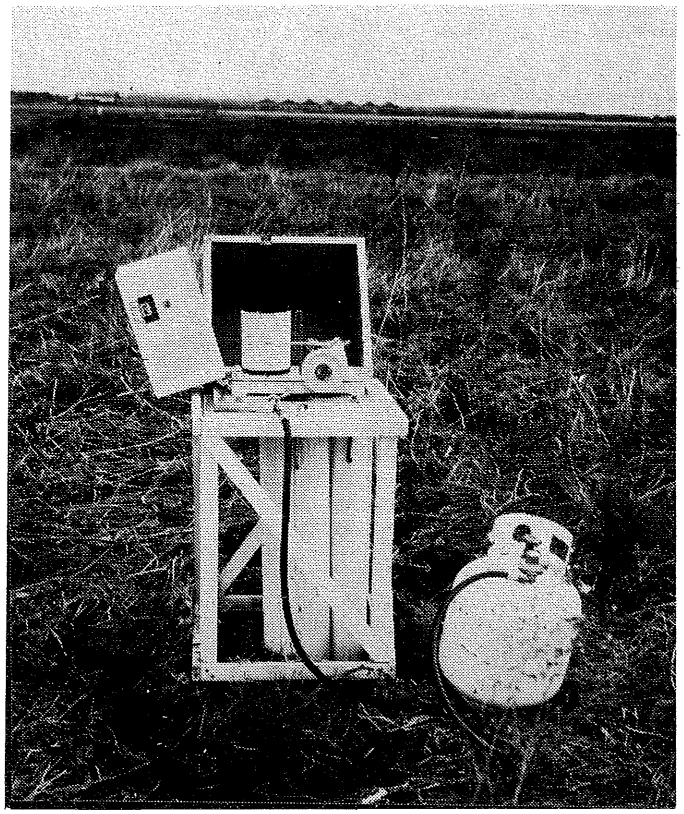


Figure 14. Photograph of the recording well with heater at Fens.

Figure 15. Photograph of double-ring infiltrometer at Fens.

6. Groundwater Flow

Sixty piezometers in clusters of three at 1.6 km spacings were located throughout the Toivola peatland along two transects (Figure 3). Piezometers were constructed of 3.8 cm O.D. aluminum tubing that was pinched and perforated at one end. At each of 20 stations, a cluster of piezometers was installed at three depths: at the bottom of the peat or 3.66 m whichever was less, at 0.6 to 1.0 m below the surface, and at an intermediate depth between the former two. Piezometers were placed in a line about 3 m apart with the cluster being at least 15 m from the access trail. Piezometer runs were made monthly by using a Muskeg Carrier bombadier. Elevations of piezometers and the peat surface were determined from benchmarks made of galvanized pipe augered through the peat into the mineral substrate.

7. Response Factors

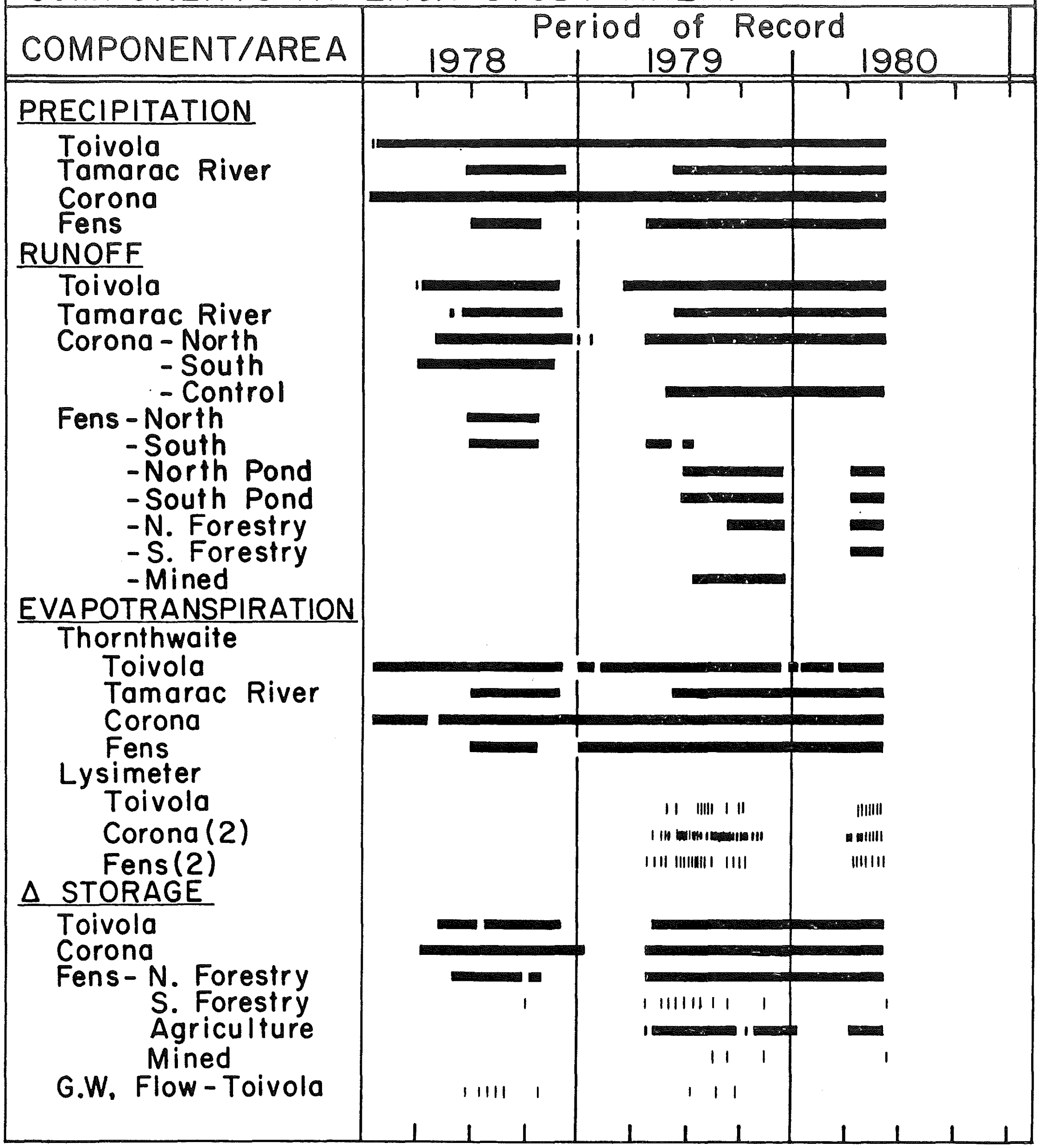
The hydrologic response factor is the ratio of stormflow to precipitation where stormflow equals total flow minus baseflow (Hewlett and Hibbert 1967; Hewlett and Moore 1976). Precipitation events greater than 3.8 mm were used for the analysis of response factors at Toivola and Corona. A variable baseflow separation line was determined for each hydrograph beginning at the hydrograph rise and ending at the inflection point of the recession.

Basin lag times were calculated as the time from the centroid of the total precipitation event to the peak discharge.

8. Summary

The period of record for each component of the water balance equation for each area studied is given in Table 2 from installation to May 31, 1980. More winter data was collected during the second year of the project.

TABLE 2 : PERIOD OF RECORD FOR WATER BALANCE COMPONENTS AT EACH STUDY AREA.



(I) - Indicates instantaneous measurement.

B. WATER QUALITY

Water quality samples were collected from both surface and ground water. Samples were collected weekly from study area outlets during 1978 and monthly in 1979. Samples were not taken during summer when flow ceased or during winter when the stream froze to the bottom. The methods used for determining water quality values are separated into collection, preservation and storage, and analysis.

1. Collection

Samples were collected in polyethylene bottles that had been washed with no-phosphate detergent and rinsed in acid and distilled water. Samples were taken just below the water surface with care given to prevent disturbing the bottom. In-situ measurements were made of temperature, dissolved oxygen, and specific conductivity by using the appropriate instruments (Table 3). pH was measured immediately from one of the collected samples. Sediment samples were collected in prewashed glass bottles by using a DH-48 depth integrated sampler except in shallow water when a grab sample was taken to prevent bottom stirring of sediment.

2. Preservation and Storage

All samples removed from the site for later analysis were kept in cold storage at $4^{o}C$ in a 12V/110 refrigerator/freezer. Refrigeration inhibits bacterial action and retards chemical reaction rates (U.S. Environmental Protection Agency 1976). No additional preservative was used for color, alkalinity, acidity, or suspended sediment, which were analyzed within 24 hours. Nitrogen and phosphorus forms were preserved at the site with $HgCl_2$, a bacterial inhibitor, to give a concentration of 40 mg/l. A 5 ml sample for metals and a

Table 3. Methods of water quality analysis.

Constituent	Method
Temperature	YSI Model 33 S-C-T Meter[a]
Specific conductivity	YSI Model 33 S-C-T Meter[a]
Dissolved oxygen	YSI Model 57 Oxygen Meter[a]
% saturation	Rawson's Nomogram
pH	Radiometer PHM 29 pH Meter[b]
Color	Hellige Aqua Tester[c]
Acidity	Titration to pH 8.3[d]
Alkalinity	Titration to pH 4.6[d]
Suspended sediment	Fitration - .45 glass fiber filter
K, Ca, Mg, Al, Fe, Na	Inductively Coupled Emmission
Mn, Zn, Cu, B, Pb, Ni, Cr, Cd	Spectroscopy (Plasma)[e]
Hg	AA cold water vapor technique[f]
As	AA Gaseous hydride
Se	AA Gaseous hydride
Total phosphorus	Technicon Auto Analyzer II - digested[g]
Total kjeldahl nitrogen	Technicon Auto Analyzer II - digested[h]
$NO_3 + NO_2$-N	Technicon Auto Analyzer II[i]
NH_4-N	Technicon Auto Analyzer II[h]
Organic-N	TKN - (NH_4-N)

[a]Instruction Manual, Yellow Springs Instrument Co., Yellow Springs, Ohio 45387.

[b]Instruction Manual, Radiometer, Copenhagen.

[c]Hellige Inc. Tech. Info. No. 611-9.

[d]Standard Methods for the examination of water and waste water. 14th ed. 1976. APHA.

[e]Spectrochimica Acta. Vol. 32B. Pp. 327-345. Pergamon Press. 1977. England.

[f]Environmental Protection Agency. 1972. Provisional Method.

[g]Technicon Industrial Method AAII. no. 100-71W, Nov. 1971.

[h]Technicon Industrial Method AAII. no. 325-74W, Sept. 1974.

[i]Technicon Industrial Method AAII. no. 100-70W, Jan. 1971.

250-ml sample for mercury, arsenic and selenium were preserved at the site with concentrated HCL at a ratio of 1:5 to give a pH < 2.0. Acidification prevents metal precipitation (U.S. Environmental Protection Agency 1976).

3. Analysis

Water quality samples were analyzed at three different locations: at the site, the Cloquet Forestry Center Laboratory, and the Research Analytical Laboratory in St. Paul. In-situ measurements were made of temperature, specific conductivity, and dissolved oxygen by using the appropriate field instrument (Table 3). Specific conductivity was corrected to 25°C (American Public Health Association 1976). The percent oxygen saturation was obtained from Rawson's nomogram by using temperature and oxygen concentrations. pH was determined immediately at the site by using a field meter.

Measurements of color, acidity, alkalinity, and suspended sediment were performed at the Cloquet Forestry Center Laboratory within 24 hours after sample collection. Apparent color (unfiltered) was determined with the Hellige Aqua Tester and color discs. Based on the A.P.H.S. - Hazen Platinum - Cobalt Scale, one color unit is equivalent to the color of water containing 1 mg/l of platinum. Dilutions were used for colors beyond 70 units. Acidity was determined by titration of a 200-ml sample with 0.01N NaOH to pH 8.3. Alkalinity titrations were to pH 4.6 with 0.01N HCL. Suspended sediment samples were analyzed by filtration through a 0.45 μ glass fiber filter. A bank of six samples was run simultaneously with millipore filter flasks and a vacuum pump.

The remaining samples were analyzed at the Research Analytical Laboratory in St. Paul. The 14 cations were analyzed by inductively coupled plasma-optical emission spectroscopy. Mercury was determined by the atomic-absorption (AA) cold vapor technique. Both arsenic and selenium were analyzed by the AA gaseous hydride method. Concentrations of total phosphorus and total Kjeldahl nitrogen were determined by digesting with fuming sulphric acid, with mercuric oxide as a catalyst and then analyzed on a three-channel Technicon Autoanalyzer II. This method for total Kjeldahl nitrogen includes ammonia and most organic nitrogen compounds but does not include nitrate or nitrite-nitrogen. Nitrate and nitrite, and ammonia concentrations were also determined on the Autoanalyzer II (Table 3). Organic-nitrogen was determined as the difference between total Kjeldahl nitrogen and ammonia-nitrogen.

The Detection limits for analysis performed at the Research Analytical Laboratory are given in Table 4.

Table 4. Detection limits for water quality analysis.

Constituent	Detection limit (mg/l)	Constituent	Detection limit (mg/l)
K	<.75	Total P	<.01
Pb	<.13	Total KN	<.1
Na	<.12	$NO_3 + NO_2$-N	<.1
Ni	<.04	NO_2-N	<.01
Zn	<.03	NH_4-N	<.1
Al, Fe, Mn, Cu	<.01	Hg, As, Se	<.001
B, Cr, Cd	<.01		

RESULTS AND DISCUSSION

A. WATER QUANTITY

Water quantity results for the first two years of the study include water budgets, stormflow, water table fluctuations, groundwater flow, and infiltration rates.

1. Water Budgets

Monthly water budgets for the Toivola, Corona, and Tamarac River peatlands are given in Figures 16, 17, and 18 and Tables 5, 6, 7, respectively. Monthly water budgets were determined from the water balance equation:

$$P = PET + RO \pm R$$

where P = precipitation, PET = potential evapotranspiration, RO = runoff, and R = residual. A change in storage term (ΔS) was included in the Corona water budget. The year 1979 rather than 1978 was used for the Tamarac River because a longer period of record existed. Daily values for water balance components, except evapotranspiration, are shown in Figures 19, 20, and 21 for Toivola, Corona, and the Tamarac River, respectively. Water budgets are discussed with respect to each component.

a. Precipitation

Annual precipitation amounts for Toivola and Corona indicate above normal precipitation at Toivola in 1978 and 1979 and below normal precipitation at Corona for the two years (Table 8). Generally, annual precipitation was greater in 1979 than in 1978 for the areas studied.

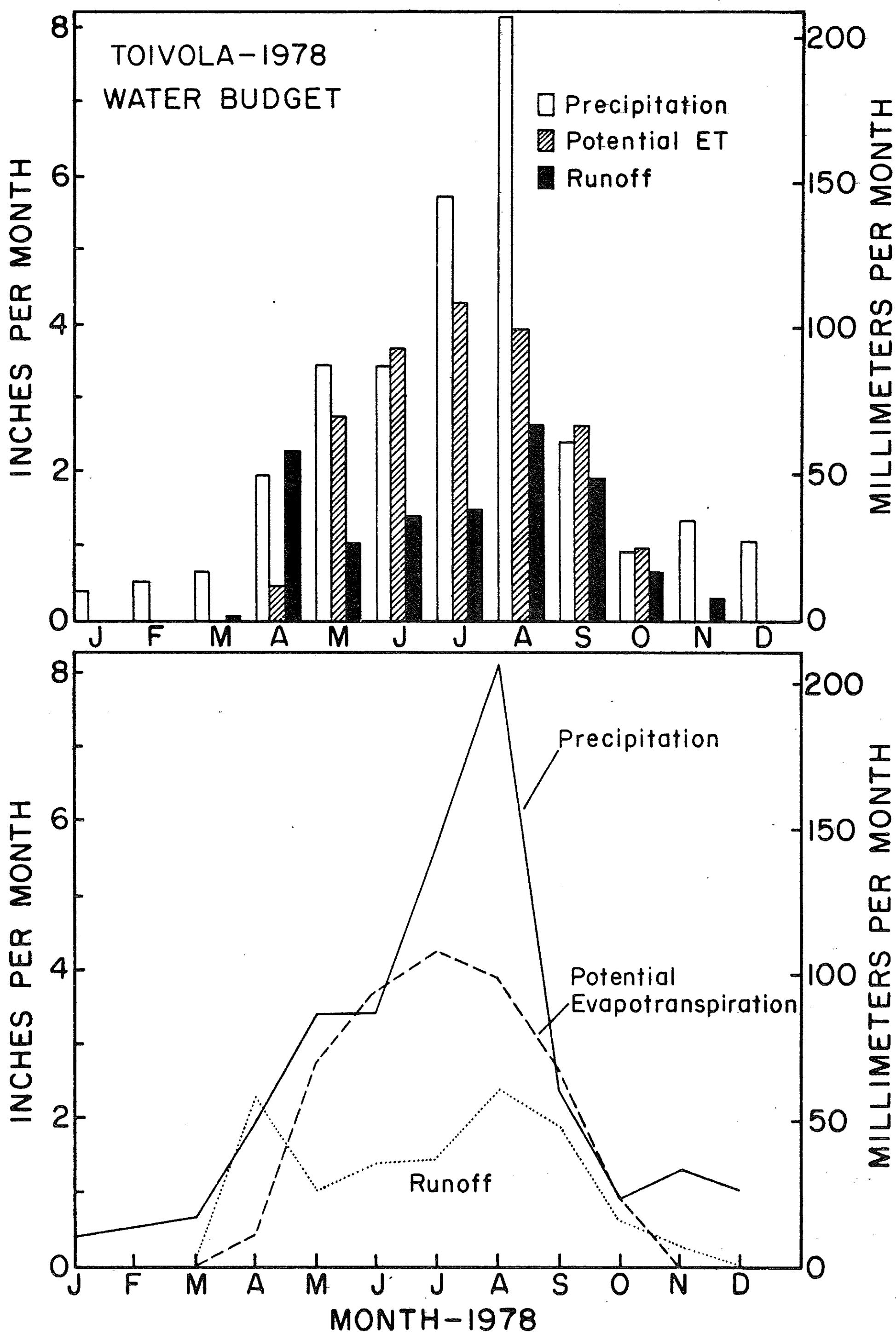


FIGURE 16 : MONTHLY WATER BUDGET FOR TOIVOLA-1978.

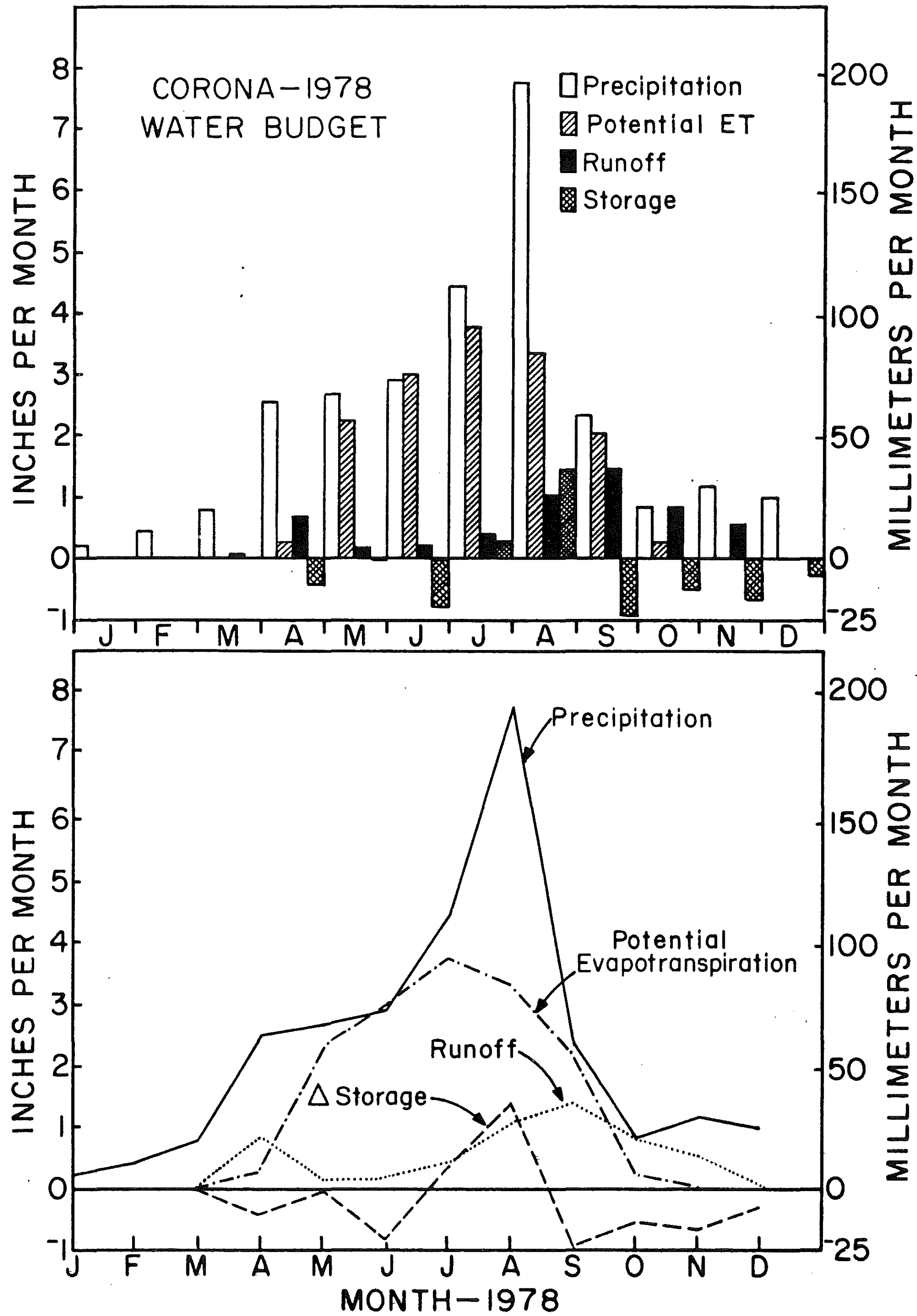


FIGURE 17: MONTHLY WATER BUDGET FOR CORONA, 1978.

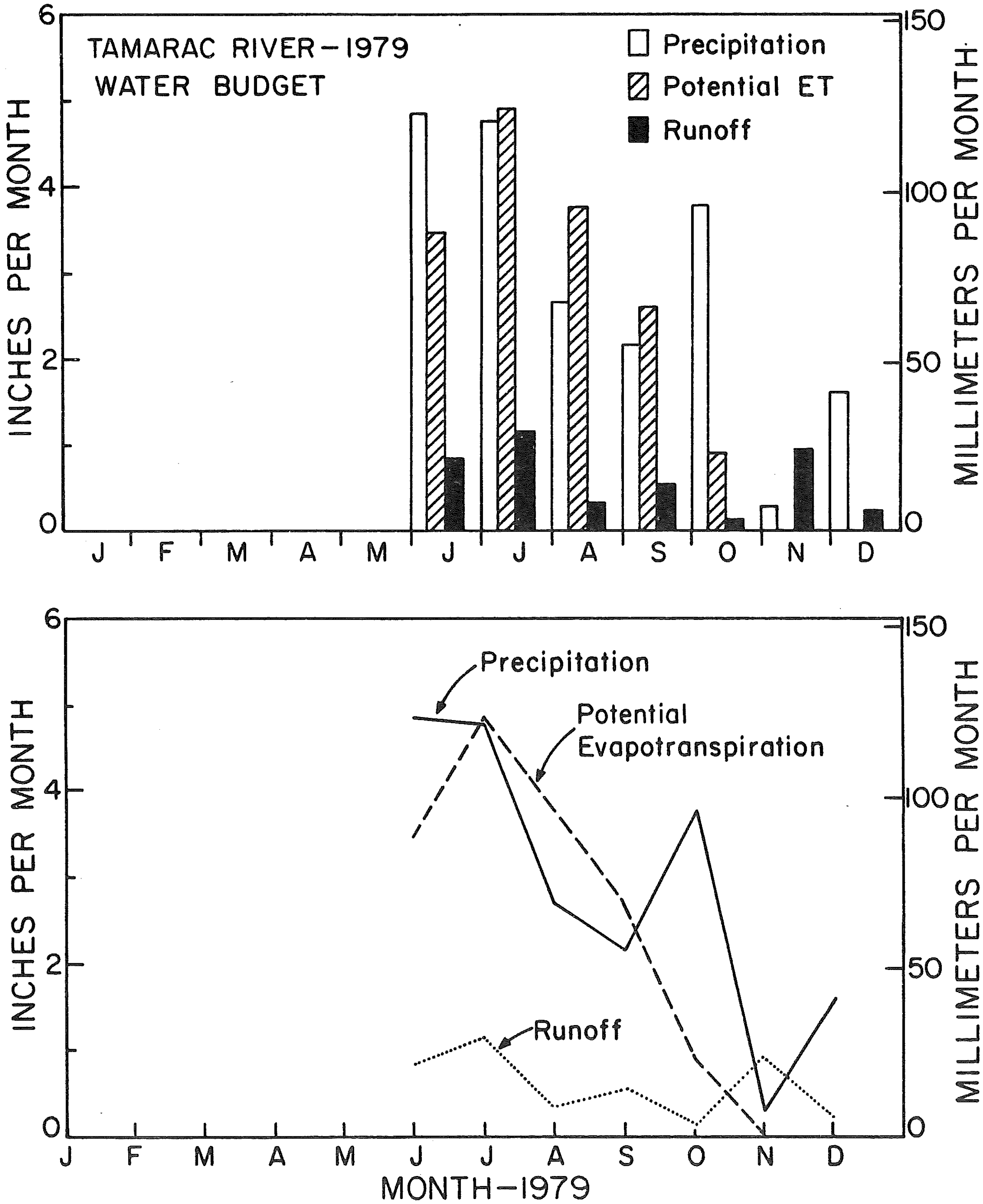


FIGURE 18: MONTHLY WATER BUDGET FOR TAMARAC RIVER – 1979.

Table 5. Monthly water budget for Toivola, 1978.

Month	Precipitation	Potential Evapotranspiration	Runoff	Residual[a]
	centimeters			
January	1.02	0.00	--	1.02
February	1.35	0.00	--	1.35
March	1.65	0.00	.18	1.47
April	4.98	1.22	5.79	2.03
May	8.66	6.96	2.62	.91
June	8.69	9.32	3.56	4.19
July	14.50	10.87	3.76	0.13
August	20.65	9.93	6.07	4.65
September	6.07	6.65	4.83	5.41
October	2.34	2.44	1.63	1.73
November	3.40	0.00	.76	2.64
December	2.69	0.00	--	2.69
Total	76.00	47.40	29.18	-0.58
% of precipitation	100	62.4	38.4	-0.01

[a] R = P - PET - RO

Table 6. Monthly water budget for Corona north, 1978.

Month	Precipitation	Potential Evapotranspiration	Runoff	Δ Storage	Residual[a]
	centimeters				
January	0.53	0.00	--	--	.53
February	0.99	0.00	--	--	.99
March	2.06	0.00	.13	--	1.93
April	6.38	0.71	2.11	-1.07	4.62
May	6.81	5.77	0.36	- .13	.81
June	7.34	7.59	0.58	-2.06	1.30
July	11.15	9.52	1.02	.71	- .10
August	19.56	8.43	2.62	3.66	4.85
September	5.92	5.28	3.61	-2.39	- .58
October	2.13	0.64	2.11	-1.32	.71
November	3.02	0.00	1.47	-1.63	3.18
December	2.51	0.00	0.00	- .74	3.25
Total	68.40	37.95	13.92	-4.83	21.49
% of precipitation	100	55.5	20.3	-7.2	31.4

[a] $R = P - PET - RO \pm \Delta S$

Table 7. Monthly water budget for the Tamarac River, 1979

Month	Precipitation	Potential Evapotranspiration	Runoff	Residual[a]
	centimeters			
Start of record June 1, 1980				
June	12.29	8.79	2.08	1.40
July	12.09	12.40	2.87	-3.18
August	6.76	9.52	.76	-3.53
September	5.41	6.83	1.30	-2.72
October	9.60	2.29	.30	6.86
November	0.74	0.00	2.34	-1.60
December	4.01	0.00	.56	3.45
Total	50.90	39.83	10.24	0.84
% of precipitation	100	78	20	2

[a] R = P - PET - RO

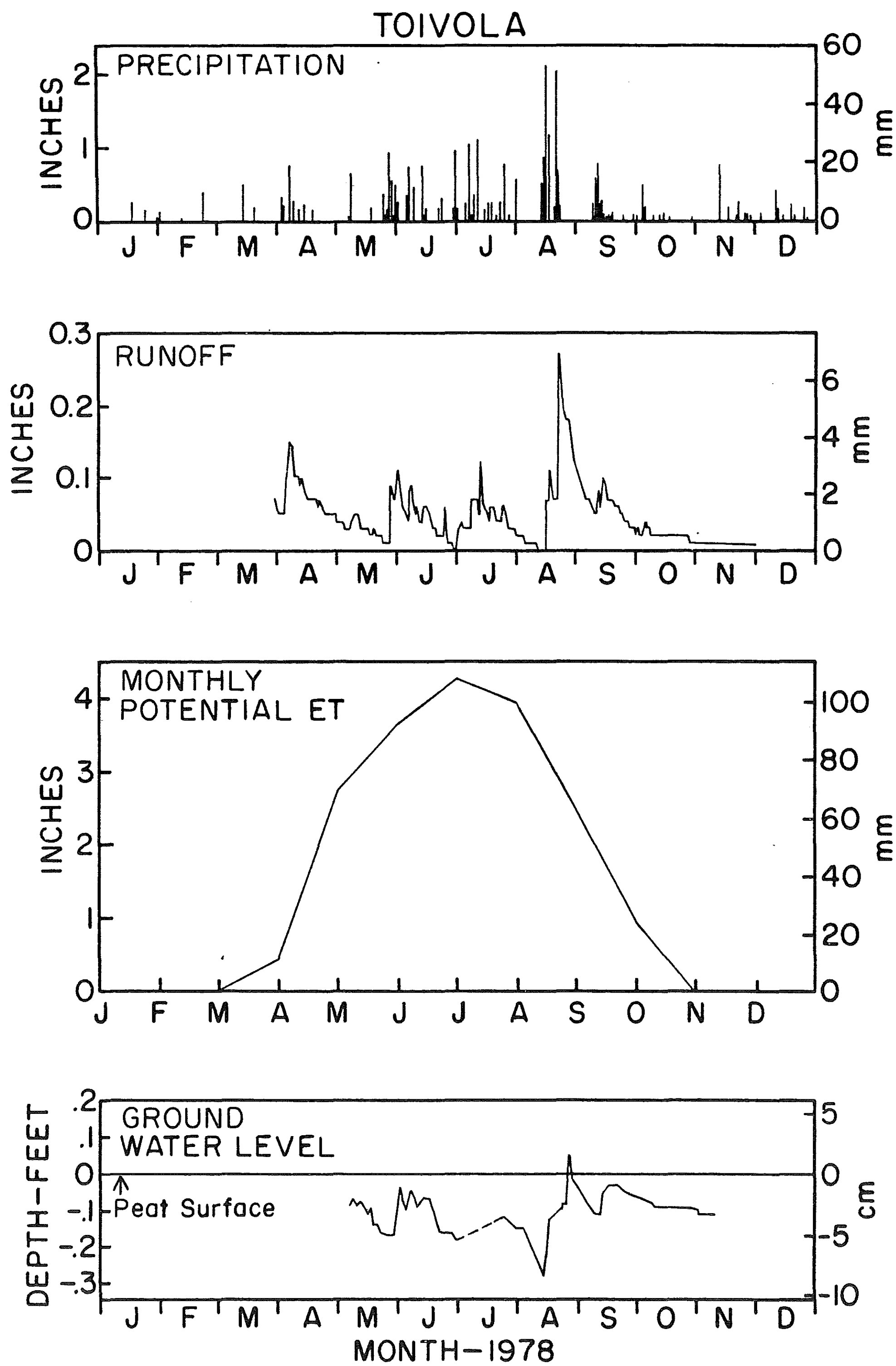


FIGURE 19: DAILY VALUES OF WATER BALANCE COMPONENTS FOR THE TOIVOLA PEATLAND-1978.

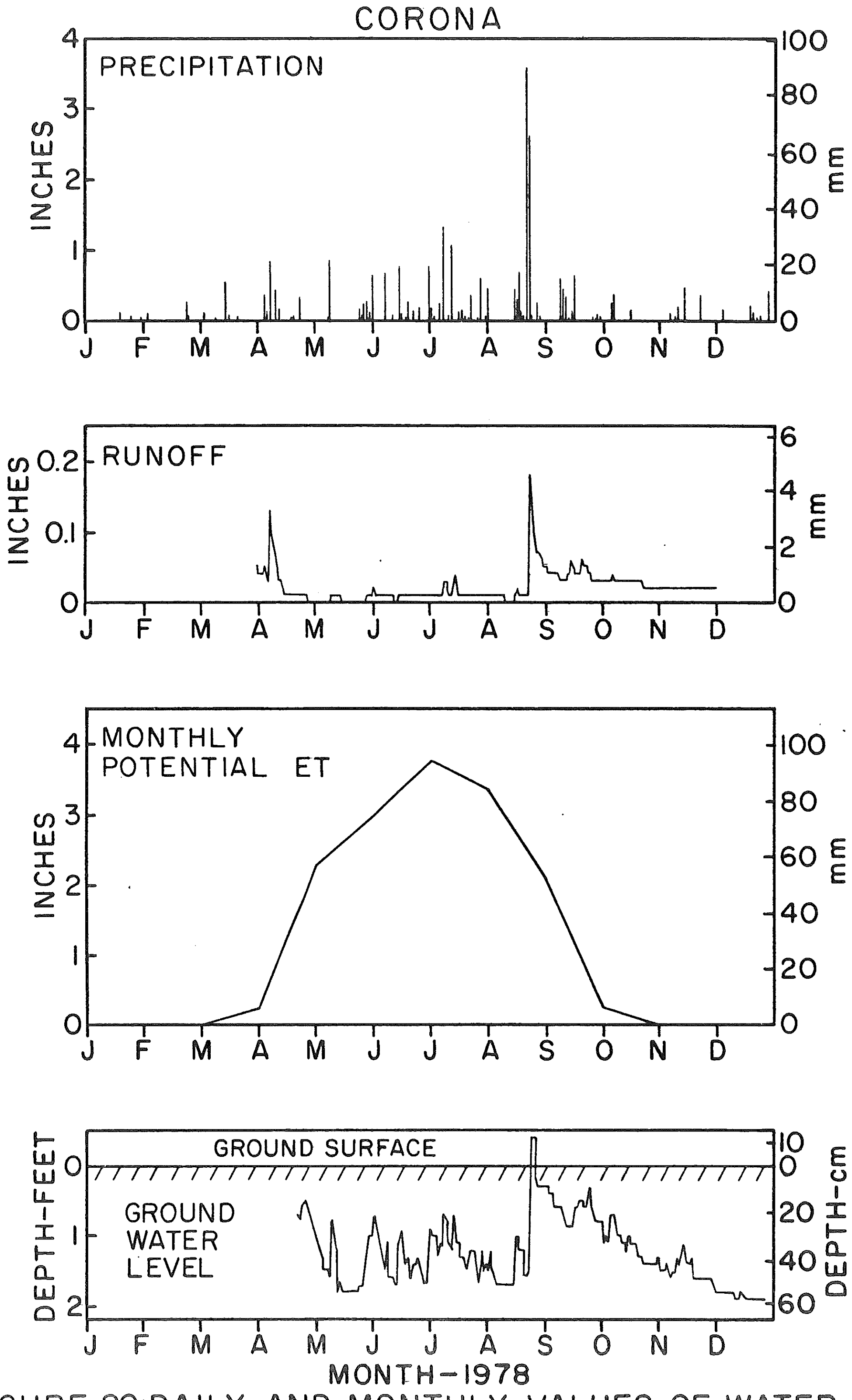


FIGURE 20: DAILY AND MONTHLY VALUES OF WATER BALANCE COMPONENTS FOR THE CORONA PEATLAND-1978.

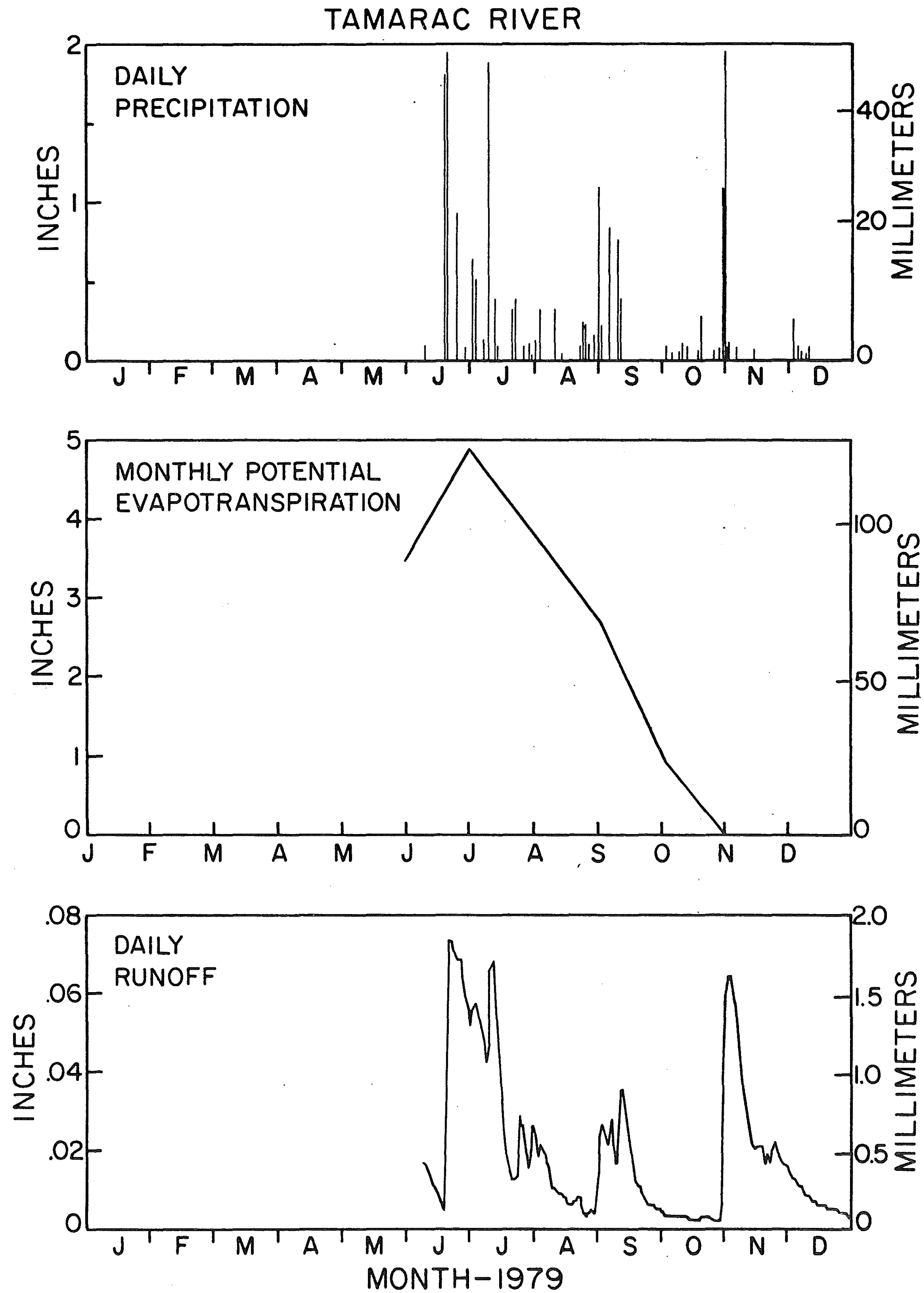


FIGURE 21: DAILY AND MONTHLY VALUES OF WATER BALANCE COMPONENTS FOR THE TAMARAC RIVER PEATLAND, 1979.

Table 8. Annual and normal precipitation for peatland study areas.

Area	Precipitation (cm) Normal	1978	1979	National Weather Service Station
Toivola	71.20	76.00	80.85	Meadowlands
Tamarac R.	66.95	38.05[a]	50.90[b]	Big Falls
Corona	76.89	68.90	73.99	Cloquet
Fens	70.97	40.51	54.94[c]	Virginia

[a] June-October

[b] June-December

[c] April-December

In northern Minnesota, about 20 percent of the annual precipitation occurs in the form of snow, amounting to about 12.7 cm (5 inches) of water each year (Weitzman and Bay 1959). Since the spring snowmelt period usually produces the highest peak discharges, snow accumulation and timing of melt are important aspects of snowpack water yield that may be altered by peatland development. Snowpack accumulation is generally influenced by wind and the presence of obstacles, such as vegetation, which affects air movement (Kuz'min 1973). Snowmelt is strongly influenced by vegetative shading (Solomon *et al.* 1975).

Based upon snow surveys conducted at Corona and Fens in 1978, more snow accumulated in natural undisturbed areas than in cleared open areas (Haertel 1978). The natural areas accumulated about 1.7 to 1.8 times as much snow as the open areas (Table 9). It is likely that snow blows off the open areas. Snow also remained longer in the natural areas than in the open (Figure 22). The snow water equivalent in natural areas was about ten times more variable than in the cleared open areas.

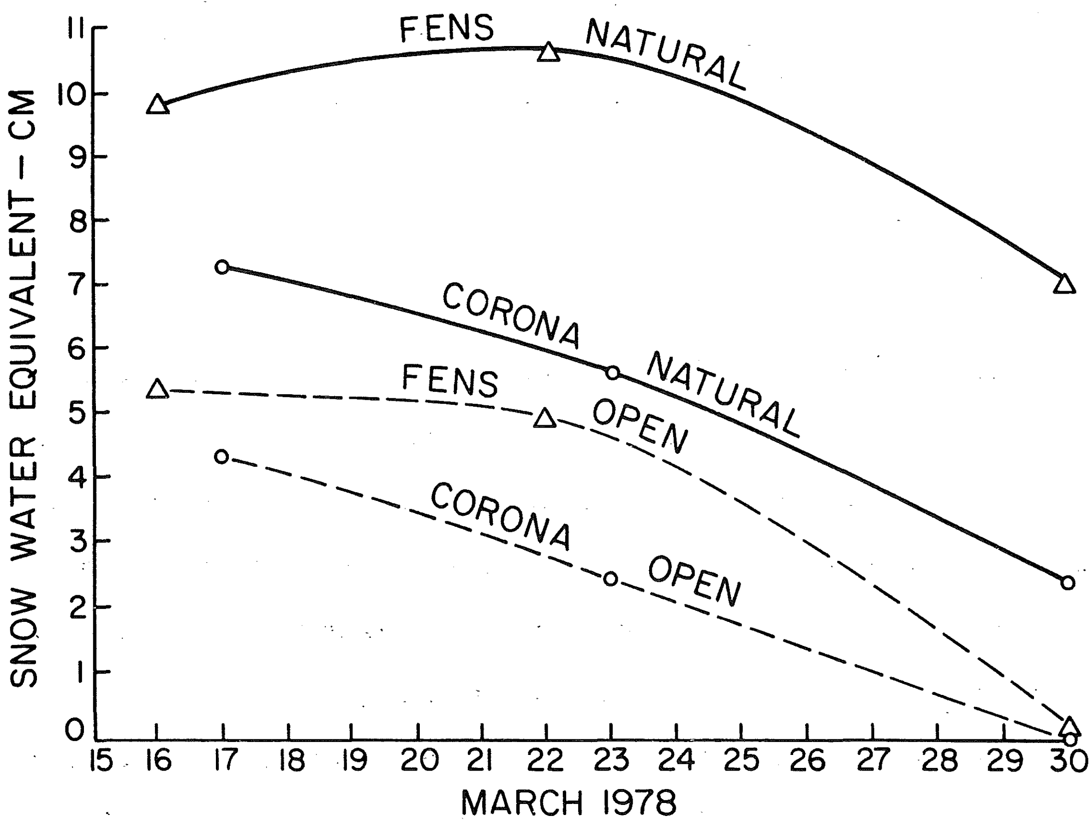


FIGURE 22: COMPARISON OF MEAN SNOW WATER EQUIVALENT FOR THE OPEN AND NATURAL AREAS AT CORONA AND FENS.

Table 9. Mean snow water equivalent for natural and open areas at Corona and Fens on March 16-17, 1978.

Location	Mean snow water equivalent (cm) Natural	Open	df	s^2	t
Corona	7.23	4.34	49	6.277	4.06**
Fens	9.78	5.34	42	11.053	4.20**

** significant at 0.1% level.

For both the 1978-79 and 1979-80 winters, the Toivola area had more snow water equivalent than either Corona or Fens (Table 10).

Table 10. Mean snow water equivalent at Toivola, Corona, and Fens for the winters 1978-79 and 1979-80.

Location	Mean snow water equivalent (cm) 1978-79	1979-80
Toivola	8.70	6.24
Corona	4.34	4.47
Fens	5.34	5.11

b. Evapotranspiration

Thornthwaite potential evapotranspiration (PET) was the primary method for initially estimating ET from the study areas. Since partial data exist for the Tamarac River and Fens watersheds, only Toivola and Corona are discussed (Table 11). As expected, PET was similar from both areas because the method used is based primarily on temperature, which did not differ greatly. Because lowering the water table has been reported to reduce evapotranspiration, several other methods of estimating evapotranspiration were used including: water balance, evaporation pan, and lysimeters (Romanov 1961, Heikurainen and Laine 1968, Boelter, 1972, and Paivanen 1976).

Table 11. Annual Thornthwaite potential evapotranspiration at Toivola and Corona for the years 1978 and 1979.

	PET (cm)		% of P	
Location	1978	1979	1978	1979
Toivola	47.40	42.52	62.4	52.6
Corona	37.95	42.88	55.5	58.0

Annual water balance ET was determined with the equation:

$$ET = P - RO - \Delta S$$

where ET = evapotranspiration, P = precipitation, RO = runoff, and ΔS = change in storage. Water balance ET was 96 and 157 percent of Thornthwaite PET at Toivola and Corona, respectively. Such a high water balance ET at Corona is not expected and since there was a large residual in the water balance there may be a large groundwater input (Table 6). Additional years will substantiate these results.

Pan evaporation at Fens during 1979 was 118 percent of Thornthwaite PET which yields a pan coefficient of 0.85. During 1980 evaporation pans will be maintained at both Fens and Corona.

Lysimeter ET (vegetated) was determined at Toivola, Corona, and Fens during 1979 and lysimeter E (bare) was measured at Corona and Fens (Table 12). Unexpectedly, lysimeter ET exceeded PET at all stations, but leakage is suspected. Additional years of record will clarify this preliminary result. Lysimeter evaporation from the unvegetated peat surface at Corona and Fens was less than evapotranspiration from vegetated lysimeters. Evaporation was 68 percent of ET at Corona and 47 percent of ET at Fens in 1979. Clearing peatlands of live vegetation on drained sites appears to reduce evapotranspiration.

Table 12. Annual Thornthwaite PET, lysimeter ET and E at Toivola, Corona, and Fens, 1979.

Location	Thornthwaite PET cm	Lysimeter Evapotranspiration cm	Lysimeter Evapotranspiration % of PET	Lysimeter Evaporation cm	Lysimeter Evaporation % of PET
Toivola	48.77	60.12	138	--	--
Corona	42.88	44.86	105	30.43	71
Fens	45.34	58.45	129	27.38	60

Correlations of monthly evapotranspiration determined by different methods indicate that Thornthwaite PET was significantly correlated to lysimeter E and ET but not to pan evaporation at the 5% level. The following regression equations were also determined:

Lysimeter ET = 1.24 (Thornthwaite PET) - 0.81 $R^2 = 0.949^*$

Lysimeter ET = 1.31 (pan evaporation) - 0.93 $R^2 = 0.808^*$

Lysimeter E = 1.19 (Thornthwaite PET) - 0.64 $R^2 = 0.978^*$

where ET, E, and PET are in inches. These relationships are quite different from those reported by Bay (1966).

c. Runoff

Annual area runoff from Corona was half the runoff from Toivola and accounted for 20.3 percent of precipitation as compared to 36.6 percent at Toivola (Tables 5, 6). Better comparisons will be made with Corona control in the future. Annual runoff has usually increased after drainage of forested peatlands (Heikurainen 1964, Huikari 1968, Seuna 1974, Mustonen and Seuna 1975) and after drainage and cultivation (Bulavko and Drozd 1975, Mikulski and Lesniak 1975, Burke 1975). The effects of drainage and peat mining on annual runoff have not been reported in the literature. Discharge from both Toivola and Corona ceased during the winter when the outlets froze solid to the bottom of the channel. These results are considered quite preliminary and will be further substantiated over the next two years.

d. Change in storage

Monthly change in storage was determined from continuous water table measurements (Figures 19, 20). The change in water level over the period was converted to change in storage by using the water yield coefficients of 14 and 12 percent for Corona and Fens, respectively. No satisfactory water yield coefficient was determined for Toivola and additional methods will be used during the next two years.

It is evident from summer water table fluctuations that the change in storage at Toivola was much less than at Corona or Fens (Table 13). Such results are expected since Toivola is undrained.

Table 13. Water table fluctuations for the frost-free period for study watersheds.

Location	Δ water level (cm) 1978	1979
Toivola	-1.52	-5.79
Corona	-46.94	-68.58
Fens Forestry	-40.54	-107.76
Fens Agriculture	---	-110.64

e. Water budget summary

Based upon preliminary water budgets developed for the study areas it would appear that draining and clearing peatlands result in reduced evapotranspiration and increased storage. Annual runoff was unexpectedly less from the mined Corona area in comparison to the natural areas but no conclusion can be made as to the effect of mining on annual runoff at this time. The seasonal change in water level was less at Toivola while daily water level fluctuations appear to be greater on the drained and mined area (Figures 19, 20).

2. Stormflow

Questions have been raised about the effect of peat mining on peak flow and the timing of flow. Response factors were quite similar for Toivola and Corona, but the mined area had a shorter basin lag time to peak discharge (Table 14). However, the runoff efficiency was lower at Corona than Toivola, resulting in lower stormflow volumes. The 1978 peak discharge on an area basis was greater at Corona than Toivola while the mean daily area discharge for Toivola was about twice as great as Corona in 1978.

Table 14. Stormflow characteristics for the Toivola and Corona watersheds.[a]

Characteristic		Toivola	Corona
Mean response factor[b]	%	2.9	2.0
Std. dev.	%	0.0264	0.0178
Mean base line slope	cfs/hr	.0181	.00183
Mean lag time[a]	hrs	12.30	8.36
Std. dev.	hrs	5.232	3.296
Runoff efficiency[c]	%	37	20
1978 max. discharge	CSM	8.0	10.9
1978 mean discharge	CSM	2.0×10^{-3}	0.9×10^{-3}

[a] Storms: Toivola (n = 14), Corona (n = 6).

[b] Response factor = stormflow ÷ precipitation

[c] Runoff efficiency = annual RO ÷ annual P.

Significant correlations between the response factor and precipitation, peak discharge, and direct runoff occurred at both Toivola and Corona (Figure 23). The response factor, direct runoff, and peak discharge were also found to vary with precipitation (Figures 23, 24, 25). Lag time did not correlate well with other parameters.

Although some comparisons have been made between the Toivola and Corona mined watersheds, the effects of mining on stormflow cannot be determined until enough data exists to compare Corona control against Corona mined.

3. Groundwater Flow

Generally, groundwater was found to move horizontally through the 37.8 km^2 Toivola watershed (Figures 26, 27). Flow lines are perpendicular to equipotential lines. The flow direction is from high potential to low. Flow patterns during a wet period (July 5, 1979) changed during a dry period (August 16, 1979). More downward movement occurred during the wet period and more upward movement during the dry period. This change in flow direction is especially evident for the west transect (Figure 27). Along the transects from the top of the watershed to the bottom there were no consistent regions of recharge (downward movement) or discharge (upward movement).

4. Water Table Fluctuations

Daily water table levels at Toivola and Corona are shown in Figures 19 and 20, for one site within each peatland. During most of the year, water levels fluctuated within 10 cm of the surface at Toivola and from 20 to 60 cm at Corona. Water table profiles at Corona in 1978 show that the local effect of ditching extended about 15 m into the field (Figure 28). Water table profiles across the entire north fields at Corona in 1979 showed that the water

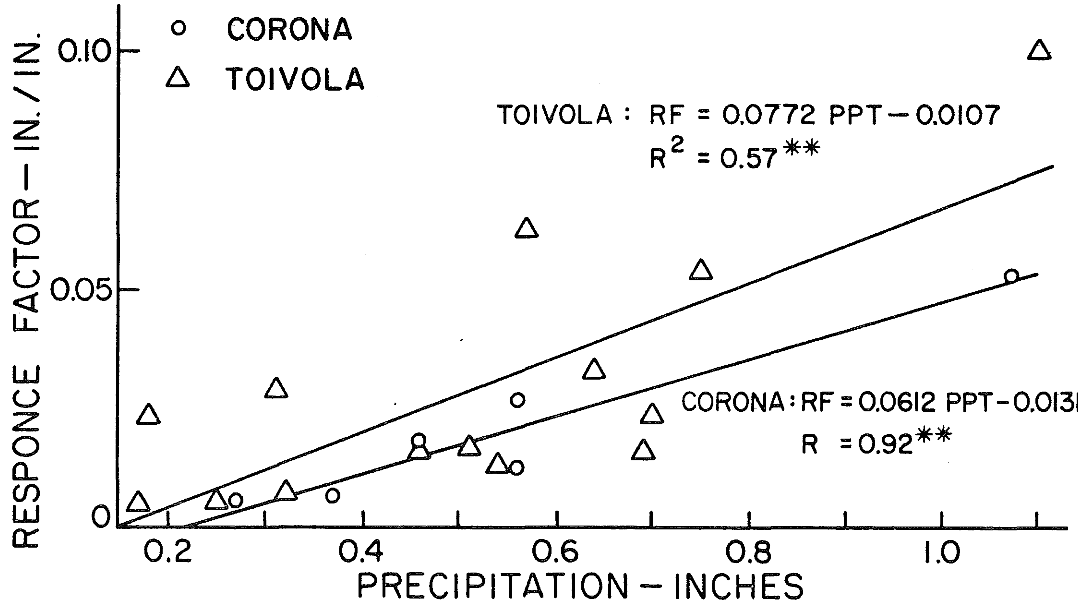


FIGURE 23: RESPONSE FACTOR AS A FUNCTION OF PRECIPITATION FOR CORONA AND TOIVOLA.

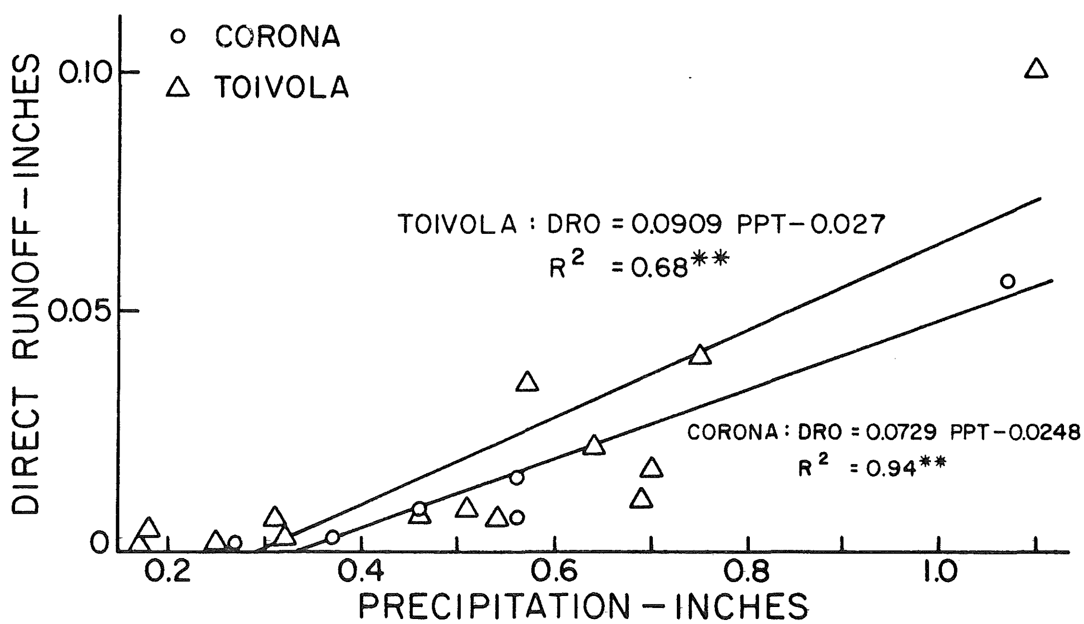
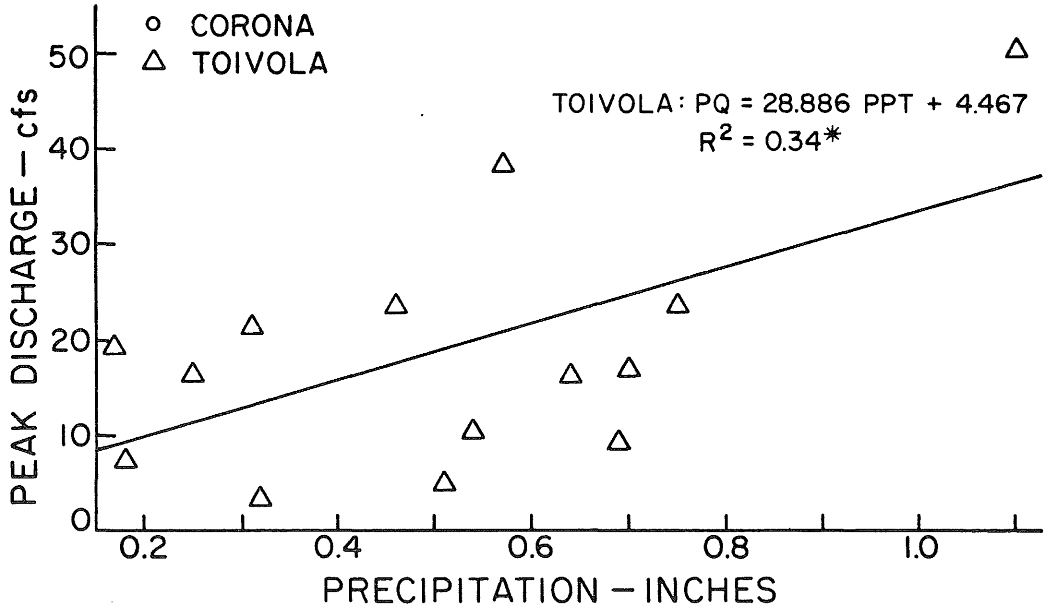


FIGURE 24: DIRECT RUNOFF AS A FUNCTION OF PRECIPITATION FOR CORONA AND TOIVOLA.



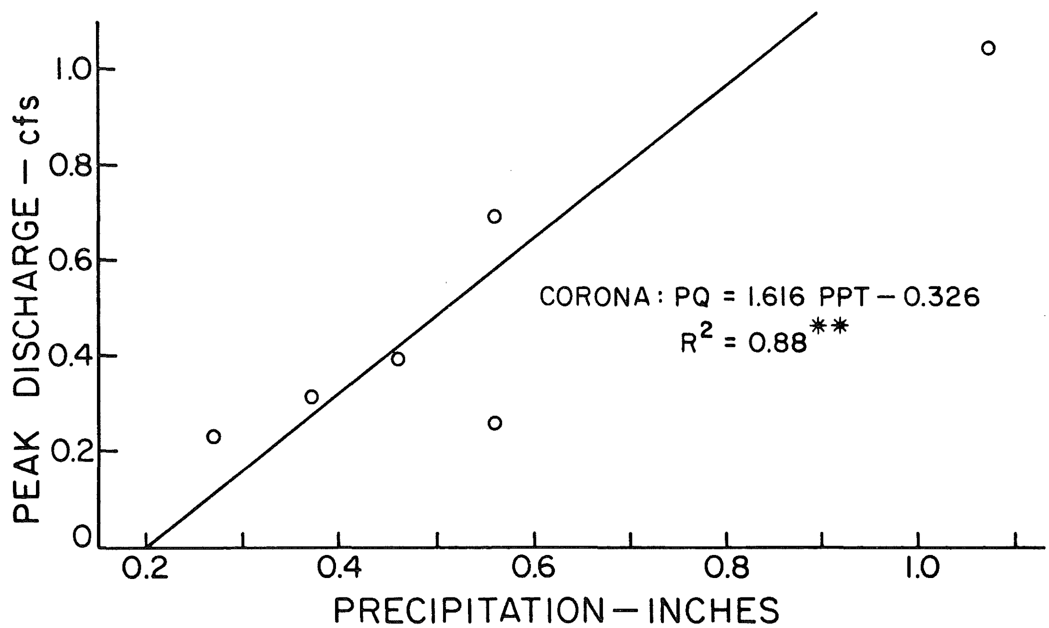
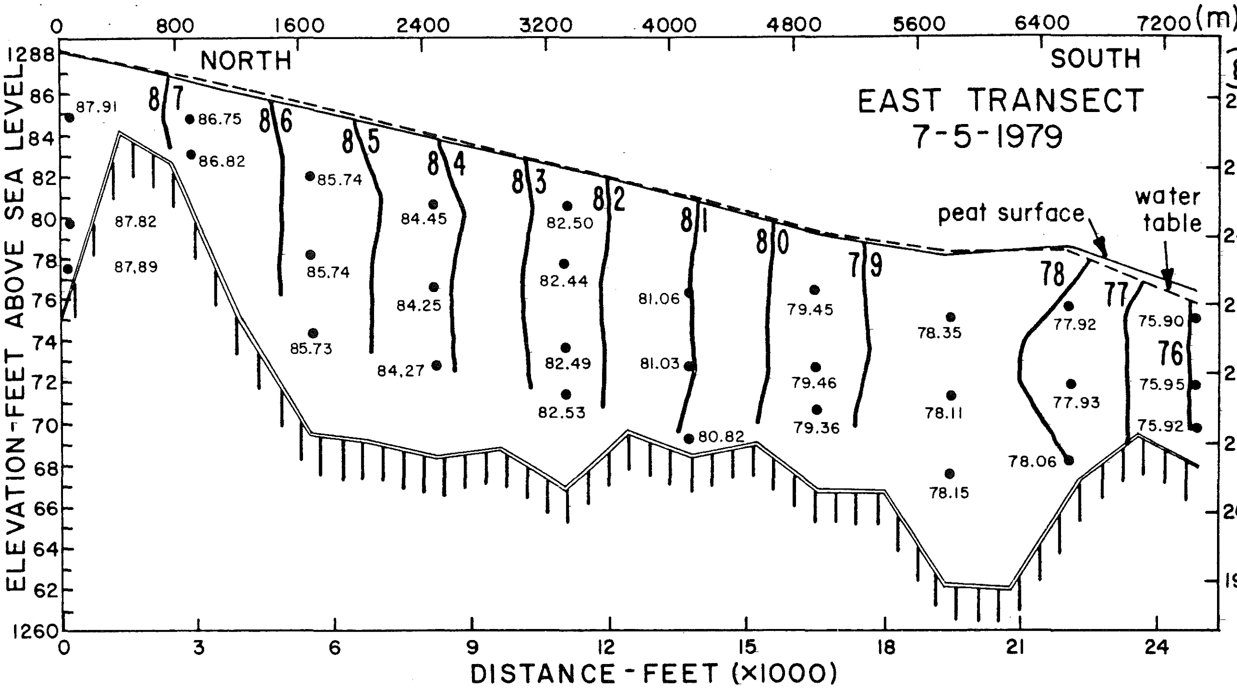


FIGURE 25: PEAK DISCHARGE AS A FUNCTION OF PRECIPITATION FOR CORONA AND TOIVOLA.



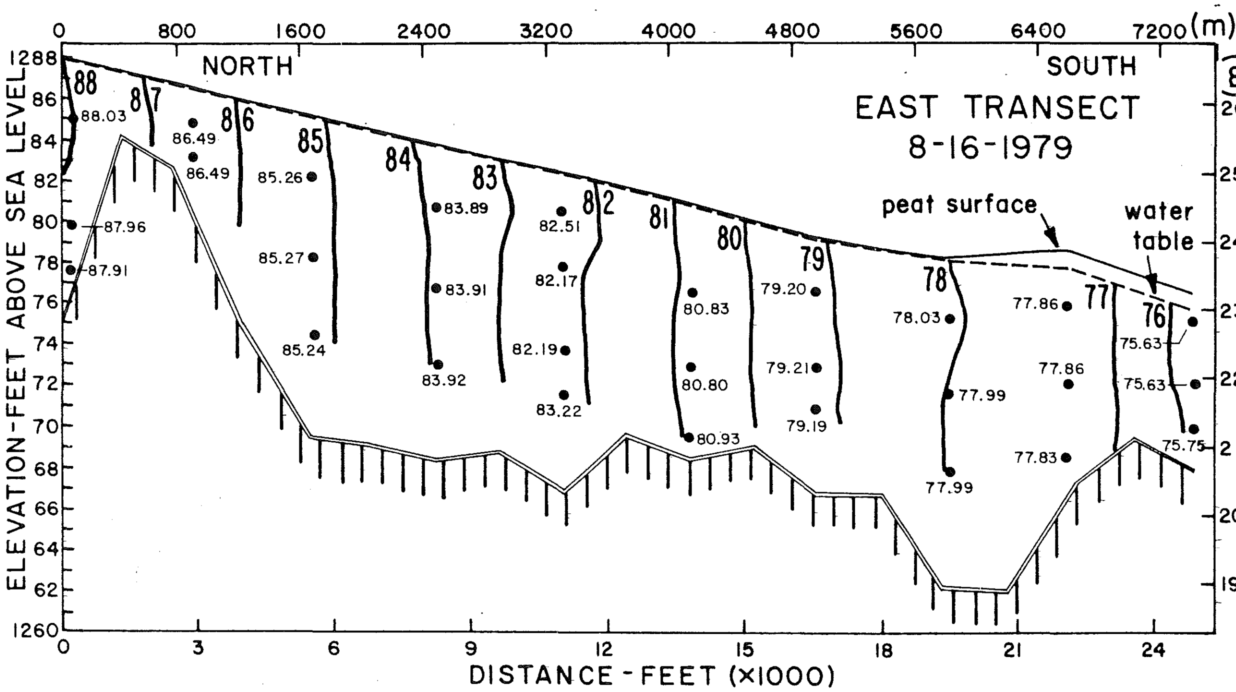
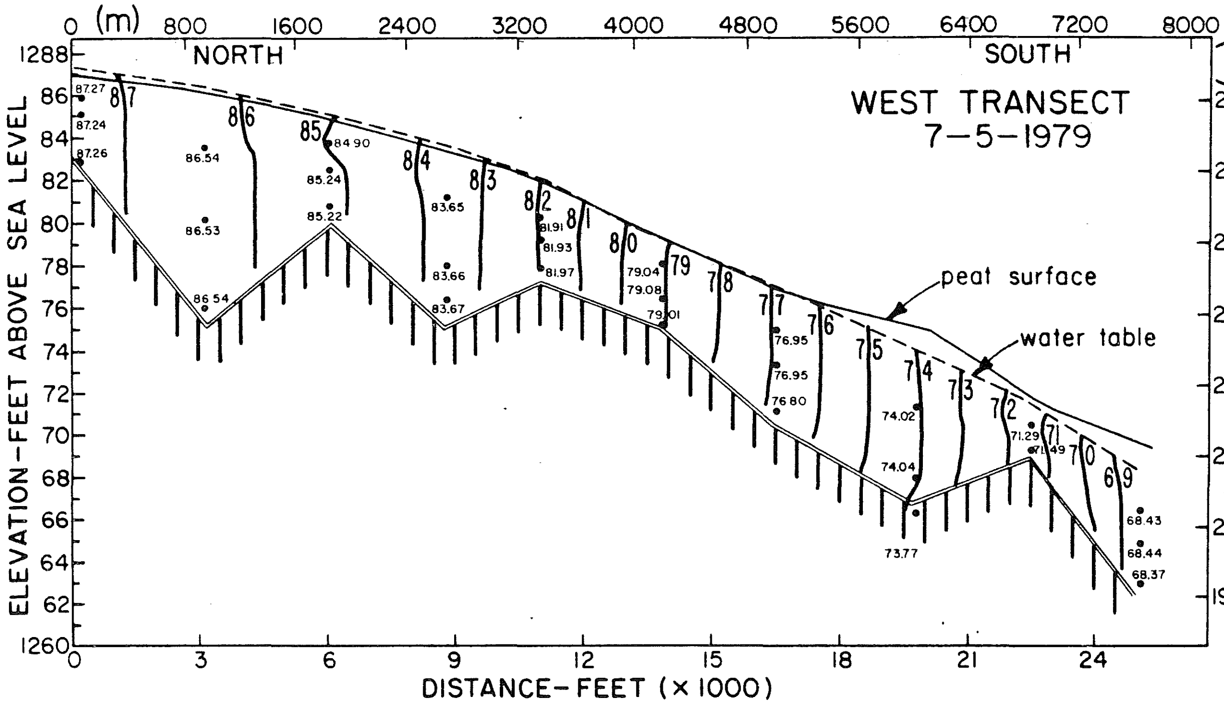


FIGURE 26: EQUIPOTENTIAL LINES FOR THE TOIVOLA EAST TRANSECT (numbers indicate hydraulic head at that point).



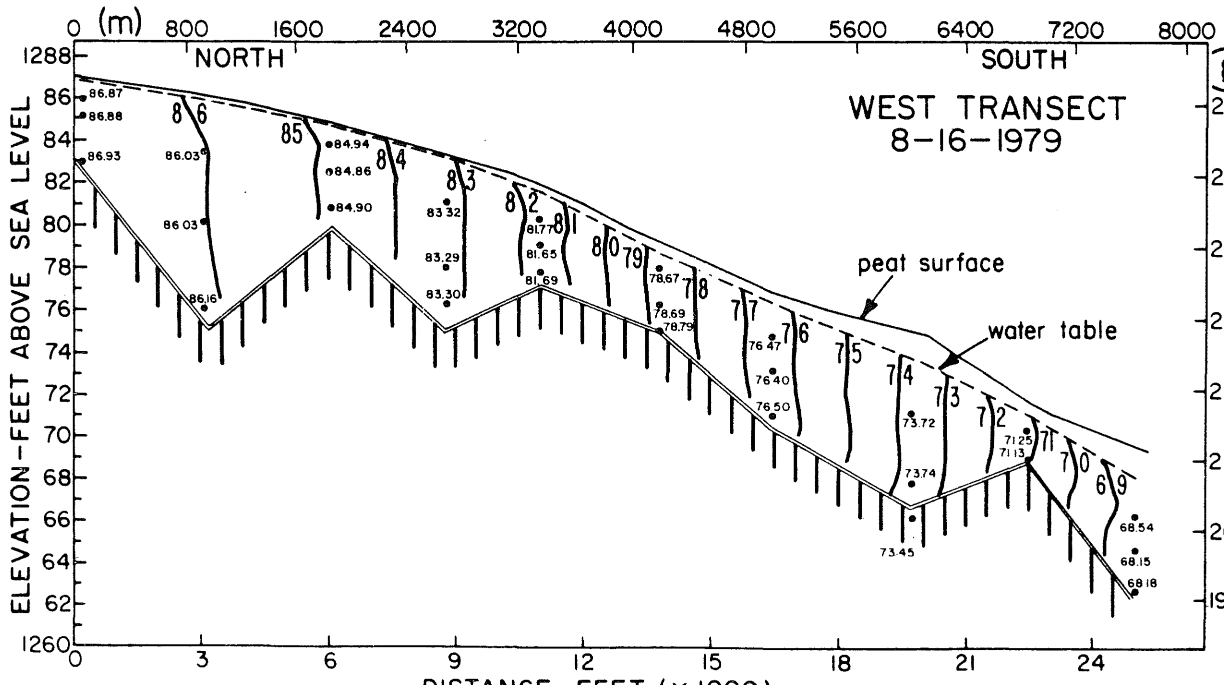


FIGURE 27 : EQUIPOTENTIAL LINES FOR THE TOIVOLA WEST TRANSECT (numbers indicate hydraulic head at that point).

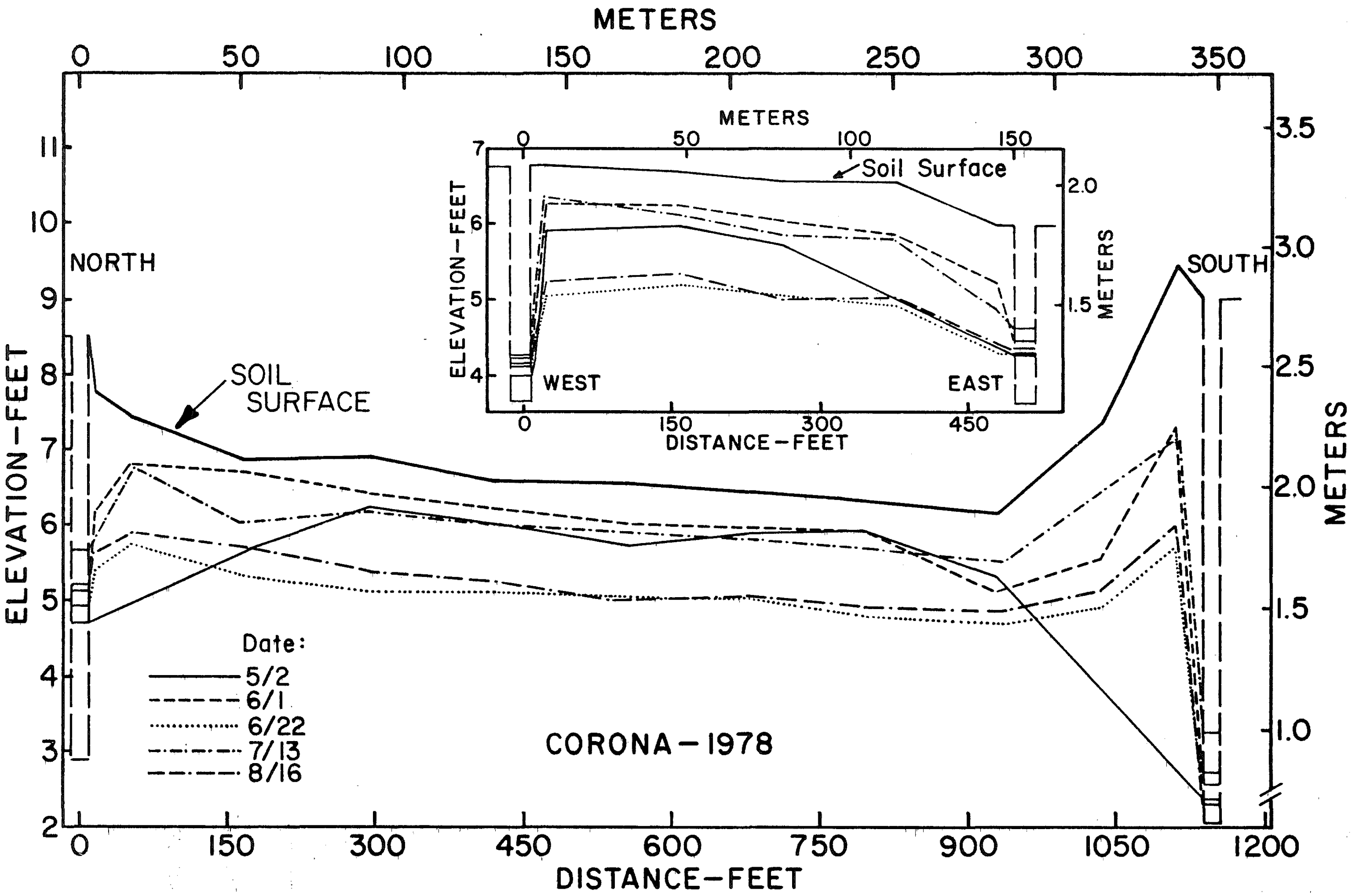


FIGURE 28: WATER TABLE PROFILES AT CORONA—1978.

table follows the surface contours of the peatland (Figure 29). Correlations between recording and nonrecording water levels will be made so that only recording values are needed to determine change in storage.

5. Infiltration

The infiltration capacity on the vegetated plot was greater than on the nonvegetated site at Fens (Table 15). The Corona mined area had the lowest infiltration capacities. Flooding of the base peat surfaces at Fens and Corona during tests appeared to cause puddling which reduced infiltration rates during subsequent infiltration tests (Figure 30). Milling of the peat surface may interrupt puddling. Reduced infiltration capacities for extended periods could result in more overland flow and quicker stormflow response.

Table 15. Final infiltration rates for peat and mineral soils.

Location	Final infiltration rate (cm/hr)		
	First run	Mean	Std. Dev.
Fens vegetated	39.9	32.8	5.3
Fens bare	39.6	22.2	13.0
Corona bare	9.9	3.9	3.1
Loamy fine sand[a]	--	31.0	--
Silt loam[b]	--	4.6	--

[a] Rhodes *et al.* (1964).

[b] Linnartz *et al.* (1966).

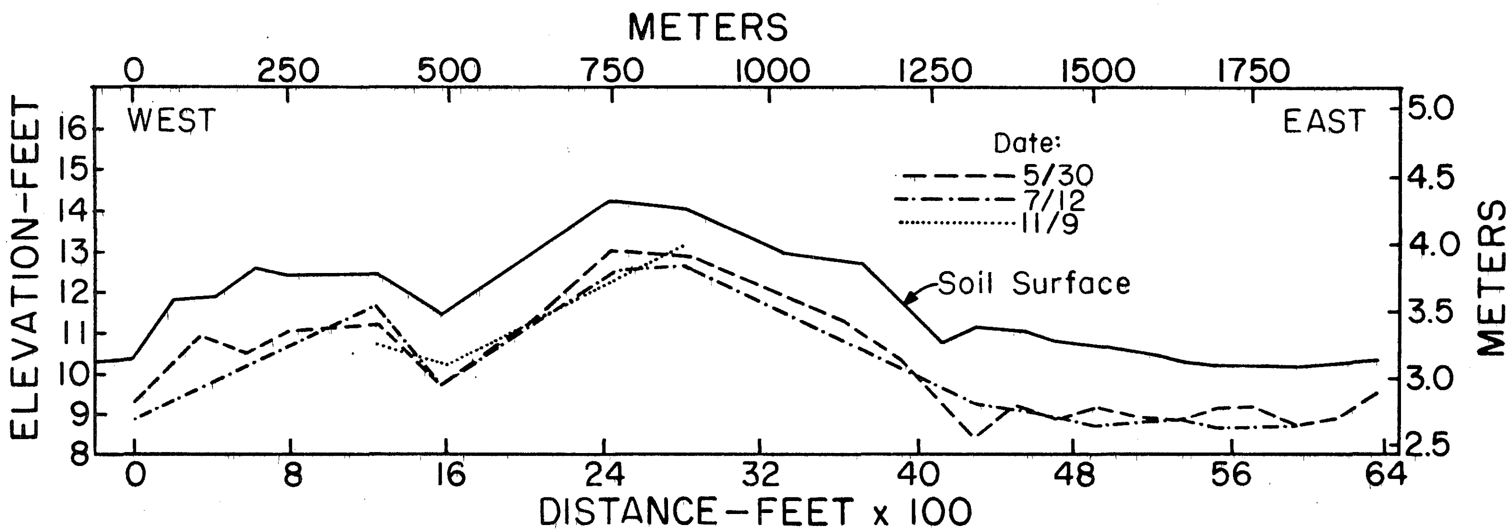


FIGURE 29: WATER TABLE LEVELS AT CORONA-1979.

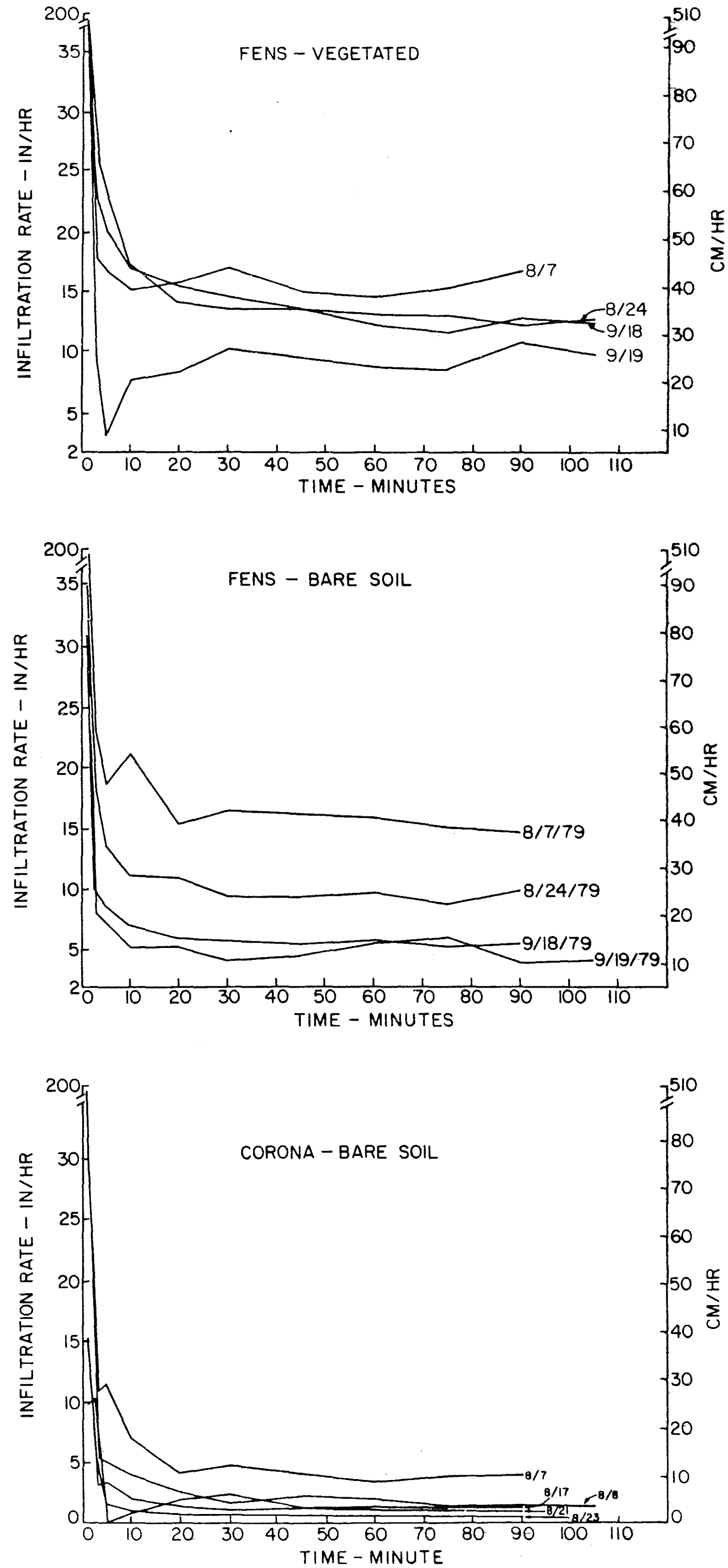


FIGURE 30: INFILTRATION RATES AT FENS AND CORONA.

B. WATER QUALITY

Water quality results for the first two years of the study include a characterization of each study area, nutrient loading, mining effects, reclamation effects, downstream assimilation studies, and water quality relationships.

1. Study Area Characterizations

Means, ranges, and standard deviations for 32 water quality parameters for each of the four major study areas are given in Tables 16-19. Monthly values for 30 of these parameters are graphed in Figures 31-39 to show seasonal patterns.

a. pH, alkalinity, and acidity

The pH of runoff from the minerotrophic fens, Tamarac River and Fens, was higher than the pH of runoff from the transition peatland (Toivola) or the bog (Corona). The lowest water pH ever observed was 4.0 at Corona whereas a maximum pH of 7.4 was measured in the Tamarac River near Upper Red Lake. The pH of Corona runoff fluctuated more than all other areas. All areas exhibited a lower pH during the spring during both 1978 and 1979 (Figure 31). This depression is characteristic of streamflow where snowmelt is acidic. Fens are expected to have higher pH's than bogs (Verry 1975). Increases in pH after drainage and mining have been observed in the USSR (Largin 1976). Drainage alone has also resulted in increased pH in runoff from forested peatlands in Czechloslovakia and Finland (Ferda and Novak 1976; Heikurainen *et al.* 1978).

Alkalinity was also higher in fen runoff water and, like pH, displayed a spring minimum (Figure 31). The Corona mined peatland, which had the lowest pH, also had the lowest alkalinity whereas the Tamarac River had the highest.

Table 16. Toivola water quality summary, 1978-79.

PARAMETER		MEAN[a]	RANGE	STD. DEV.
Temperature	^{o}C	9	0- 23	7.547
pH		6.1	5.3 - 6.7	0.299
Specific conductivity[b]	µmhos/cm	51	9 -198	36.937
Dissolved oxygen	mg/l	6.2	1.0 - 11.3	3.241
% saturation	%	49	7 -104	22.624
Color Pl./Co.	units	266	65 -600	123.288
Acidity	mg/l	21.0	7.9 - 55.7	9.871
Alkalinity	"	24.7	6.0 -116.9	29.325
Suspended sediment	"	3.9	0.0 - 15.3	3.640
K	"	1.29	<.75- 7.09	1.290
Ca	"	10.26	2.40- 31.26	7.543
Mg	"	2.96	0.80- 10.18	2.497
Al	"	0.26	<.01- 1.17	0.243
Fe	"	2.98	0.34- 20.18	3.849
Na	"	1.18	<.12- 4.90	1.128
Mn	"	1.00	.02- 5.50	1.680
Zn	"	.04	<.03- 0.32	0.050
Cu	"	<.01	<.01- .03	0.007
B	"	.01	<.01- .04	0.011
Pb	"	<.13	<.13- .23	0.037
Ni	"	<.04	<.04- .06	0.006
Cr	"	.01	<.01- .07	0.016
Cd	"	<.01	<.01- .02	0.004
Hg	µg/l	2.6	<1.3 - 4.0	1.018
As	"	3	<1 - 10	3.355
Se	"	1	<1 - 2	0.553
TOTAL - P	mg/l	.15	<.01- 1.80	0.342
TOTAL - N	"	1.5	0.4 - 6.8	1.086
$NO_3 + NO_2 - N$	"	<.1	<.01-	0
$NO_2 - N$	"	<.01	<.01- .01	0.002
ORGANIC - N	"	1.2	0.2 - 5.7	0.944
$NH_4 - N$	"	0.2	<.1 - 1.8	0.390

a Means of 47 samples.

b At 25^{o}C.

Table 17. Tamarac River water quality summary, 1978-79.

PARAMETER		MEAN[a]	RANGE	STD. DEV.
Temperature	°C	15	0 - 22	7.453
pH		7.0	6.5 - 7.4	0.229
Specific conductivity[b]	μmhos/cm	105	77 -131	16.882
Dissolved oxygen	mg/l	7.2	2.4 - 10.8	2.437
% saturation		72	27 -105	23.334
Color Pl./Co.	units	129	50 -300	58.309
Acidity	mg/l	12.6	5.1 - 29.9	7.003
Alkalinity	"	56.1	37.6 - 71.0	10.014
Suspended sediment	"	2.4	.5 - 5.9	1.887
K	"	<.75	<.75- 1.76	0.436
Ca	"	17.14	13.89- 20.52	2.335
Mg	"	6.23	4.72- 7.81	0.967
Al	"	.08	<.01- .27	0.072
Fe	"	.40	.07- .77	0.227
Na	"	1.59	.76- 2.57	0.519
Mn	"	.11	<.01 .50	0.317
Zn	"	.04	<.03- .11	0.032
Cu	"	<.01	<.01- .04	0.010
B	"	.01	<.01- .05	0.013
Pb	"	<.13	<.04- .16	0.028
Ni	"	<.04	<.04- .15	0.036
Cr	"	<.01	<.01- .02	0.004
Cd	"	<.01	<.01-	0
Hg	μg/l	2.4	<1.3 - 6.0	1.852
As	"	2	<1 - 4	1.276
Se	"	1	<1 - 2	0.707
TOTAL - P	mg/l	.04	.01- .13	0.032
TOTAL - N	"	1.2	.2 - 2.9	0.712
$NO_3 + NO_2 - N$	"	<.1	<.1 -	0
$NO_2 - N$	"	<.01	<.01-	0
ORGANIC - N	"	1.1	.2 - 2.8	0.701
$NH_4 - N$	"	<.1	<.1 - .1	0.025

a Means of 13 samples.

b At 25°C.

Table 18. Corona water quality summary, 1978-79.

PARAMETER		MEAN[a]	RANGE	STD. DEV.
Temperature	^{o}C	11	0 - 26	8.661
pH		5.2	4.0 - 6.0	0.435
Specific conductivity[b]	µmhos/cm	66	14 -107	15.010
Dissolved oxygen	mg/l	4.4	0.8 - 11.6	3.340
% saturation		40	5 -126	31.909
Color Pl./Co.	units	372	125 -750	138.462
Acidity	mg/l	45.7	16.3 -111.3	23.765
Alkalinity	"	10.7	0 - 38.0	9.676
Suspended sediment	"	15.8	0.1 -185.0	29.599
K	"	1.89	<.75- 8.17	1.477
Ca	"	4.26	1.17- 11.87	1.754
Mg	"	1.73	0.52- 3.73	0.603
Al	"	.73	0.22- 2.35	0.429
Fe	"	4.04	0.69- 12.82	2.325
Na	"	3.30	0.76- 5.86	1.025
Mn	"	0.15	.05- .45	0.066
Zn	"	0.06	<.03- .72	0.130
Cu	"	0.01	<.01- .09	0.015
B	"	0.02	<.01- .06	0.016
Pb	"	<.13	<.13- .49	0.083
Ni	"	<.04	<.04- .13	0.019
Cr	"	.02	<.01- .05	0.015
Cd	"	<.01	<.01- .12	0.020
Hg	µg/l	2.9	<1.3 - 6.0	1.857
As	"	3	<1 - 7	1.862
Se	"	1	<1 - 2	0.559
TOTAL - P	mg/l	0.11	<.01- .59	0.108
TOTAL - N	"	3.6	1.2 - 12.7	1.950
$NO_3 + NO_2 - N$	"	0.1	<.1 - .8	0.129
$NO_2 - N$	"	0.01	<.01- .02	0.007
ORGANIC - N	"	1.7	0.7 - 5.1	0.873
$NH_4 - N$	"	2.2	<.1 - 7.6	2.442

a Means of 46 samples.

b At 25^{o}C.

Table 19. Fens water quality summary, 1978-79.

PARAMETER		MEAN[a]	RANGE	STD. DEV.
Temperature	°C	18	2 - 32	7.064
pH		6.5	6.1 - 6.7	0.206
Specific conductivity[b]	µmhos/cm	202	155 -235	22.238
Dissolved oxygen	mg/l	2.8	.4 - 7.7	2.209
% saturation		30	4 - 85	25.230
Color Pl./Co.	units	529	215 -887	175.584
Acidity	mg/l	51.5	27.0 - 80.5	17.874
Alkalinity	"	74.5	34.5 -110.0	21.310
Suspended sediment	"	16.7	0.6 - 92.3	26.128
K	"	1.77	<.75- 3.99	1.177
Ca	"	34.95	30.58- 42.50	3.555
Mg	"	9.76	9.76- 12.15	1.262
Al	"	.38	.15- .60	0.137
Fe	"	8.16	3.53- 21.78	5.220
Na	"	2.97	1.48- 3.82	0.733
Mn	"	1.14	.07- 2.83	0.687
Zn	"	.06	<.03- .30	0.085
Cu	"	.01	<.01- .04	0.012
B	"	.04	<.01- .08	0.026
Pb	"	<.13	<.13- .18	0.039
Ni	"	<.04	<.04-	0
Cr	"	<.01	<.01- .02	0.005
Cd	"	<.01	<.01- .02	0.005
Hg	µg/l	3.7	<1.3 - 8.0	3.315
As	"	<1	<1 - 2	0.585
Se	"	<1	<1 - 1	0.336
TOTAL - P	mg/l	.64	.08- 1.41	0.432
TOTAL - N	"	6.3	3.6 - 9.8	1.904
$NO_3 + NO_2 - N$	"	.2	<.1 - 1.6	0.467
$NO_2 - N$	"	.01	<.01- .04	0.011
ORGANIC - N	"	5.2	2.3 - 8.2	1.673
$NH_4 - N$	"	1.1	.4 - 4.3	1.091

[a] Means of 12 samples.

[b] At 25°C.

Acidity concentrations were greatest in runoff from the disturbed Corona and Fens peatlands. Verry (1975) has previously reported higher acidity values for bog runoff. Acidity for the disturbed peatlands also fluctuated more than for the natural peatlands. Seasonally, minimum acidity concentrations occurred in the spring and fall while higher values occurred under the ice and during the summer (Figure 31).

b. Oxygen and temperature

The mean dissolved oxygen concentration was less in ditches in the disturbed peatlands than in streams draining undisturbed peatlands. Concentrations as low as 0.4 mg/l occurred at Fens and a minimum of 0.8 mg/l was measured at Corona. Concentrations below 5 mg/l were measured under the ice and during the fall in runoff from all four study areas. Such low concentrations persisted 57 percent of the time at Corona, but only 40 percent at Toivola (Figure 32). Dissolved oxygen concentrations of 5 mg/l or more are satisfactory for most life stages and activities of freshwater fish (McKim *et al.* 1975). Low dissolved oxygen concentrations also enhance the effects of toxic substances on fish (McKee and Wolf 1963).

The mean percent saturation was also somewhat lower in ditches in the disturbed peatlands than in streams draining undisturbed areas. The Tamarac River maintained the highest mean percent saturation. Seasonal variations followed dissolved oxygen concentrations, being lowest under the ice and in the fall (Figure 32).

Water temperatures followed the expected curve of summer maximum and winter minimum. Temperature differences between watersheds cannot be evaluated at this time.

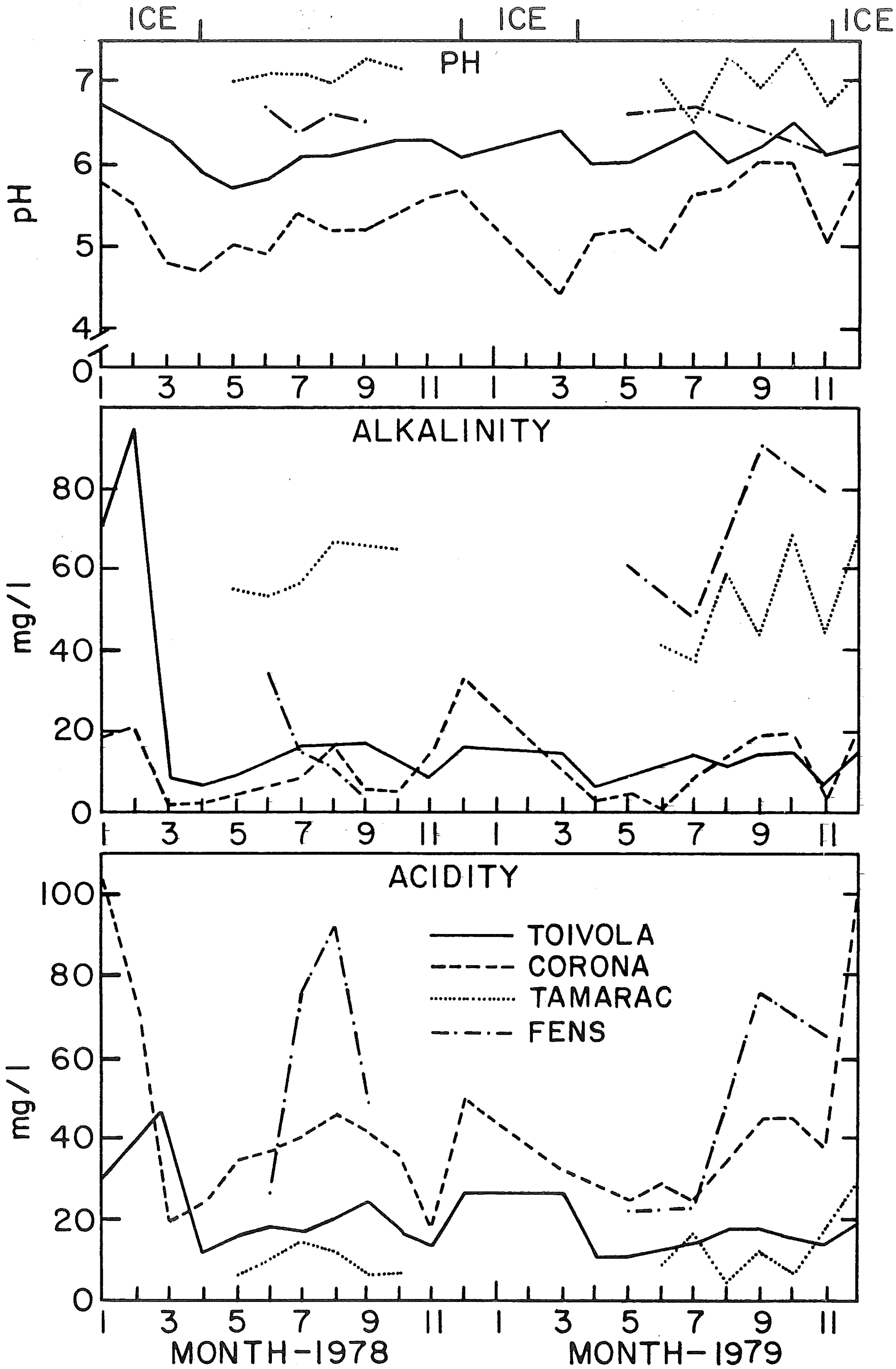


FIGURE 31: MONTHLY VALUES OF PH, ACIDITY AND ALKALINITY

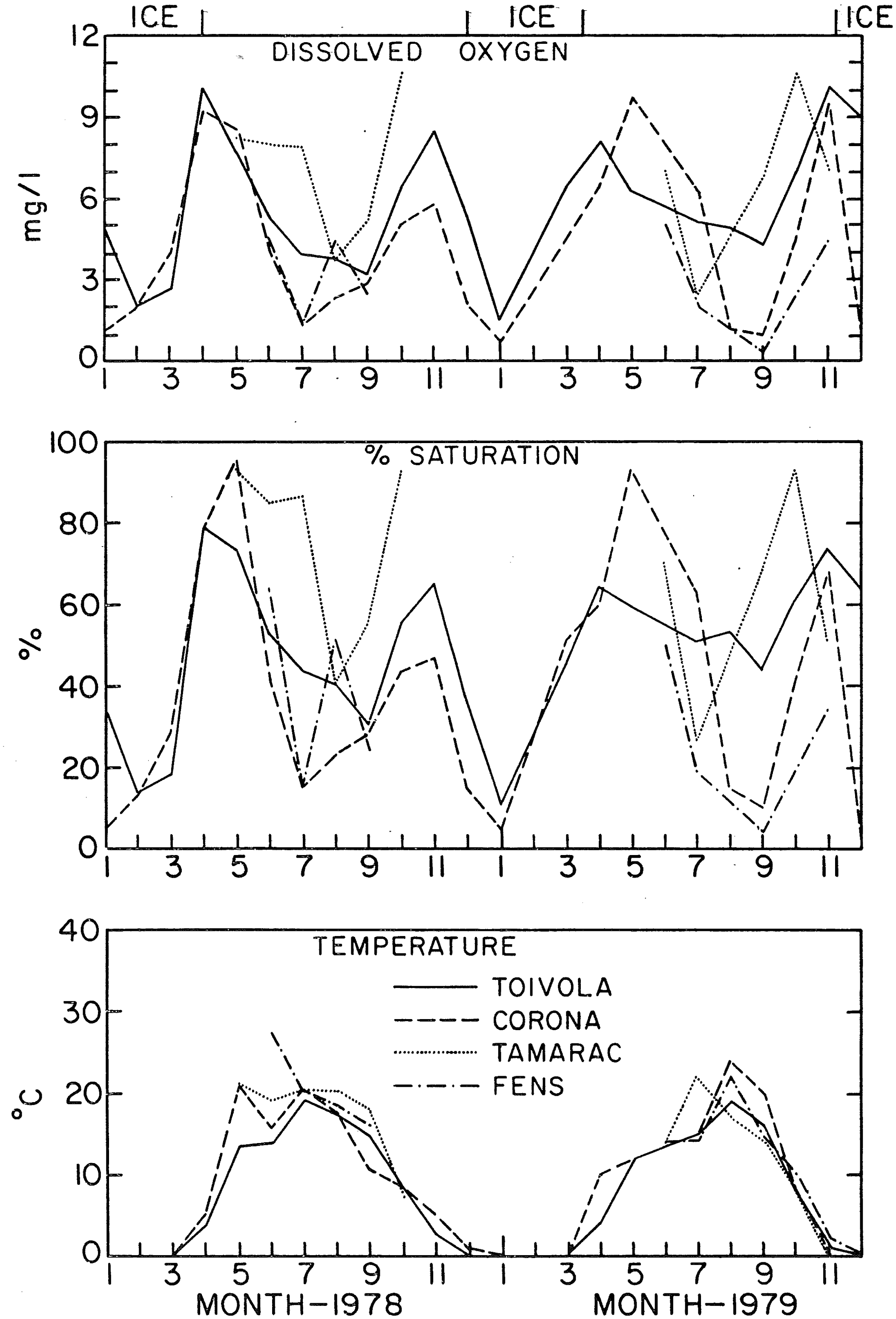


FIGURE 32: MONTHLY VALUES OF DISSOLVED OXYGEN, % SATURATION AND TEMPERATURE.

c. Conductivity, Ca, and Mg

Specific conductivities of runoff from the fens averaged higher than those of runoff from the bogs. Although bogs are expected to have the lowest conductivity, the runoff conductivity at the mined bog (Corona) was higher than for the transition Toivola peatland. Conductivities were lowest in spring and highest during the winter under ice (Figure 33). The Fens area, which had the highest conductivity, has been ditched and cultivated during the past 25 years. Specific conductivity in runoff water was found to increase 90 percent after cultivation and fertilization of an Ontario peatland (Nicholls and MacCrimmon 1974). Drainage of a forested sedge bog in Finland resulted in an increase in conductivity but the opposite effect was observed in Czechoslovakia (Heikurainen *et al.* 1978; Ferda and Novak 1976).

Both calcium and magnesium concentrations were higher in fen runoff than in bog waters. Like specific conductivity, calcium and magnesium concentrations were lowest in the spring and highest under the ice (Figure 33). Forest drainage of Czechoslovakian peatlands has resulted in slight increases in calcium concentrations in runoff (Ferda and Novak 1976). Drainage and mining of peatlands in the USSR resulted in increased calcium and magnesium concentrations in runoff from bogs but only increased magnesium concentrations in runoff from fens (Largin 1976).

d. Na, Al, K, Fe

Runoff from the disturbed peatlands averaged higher in sodium concentrations than runoff from the undisturbed areas. Forest drainage has previously been reported to increase sodium concentrations (Ferda and Novak 1976). The mined bog (Corona) waters had the highest sodium values; normally bog waters

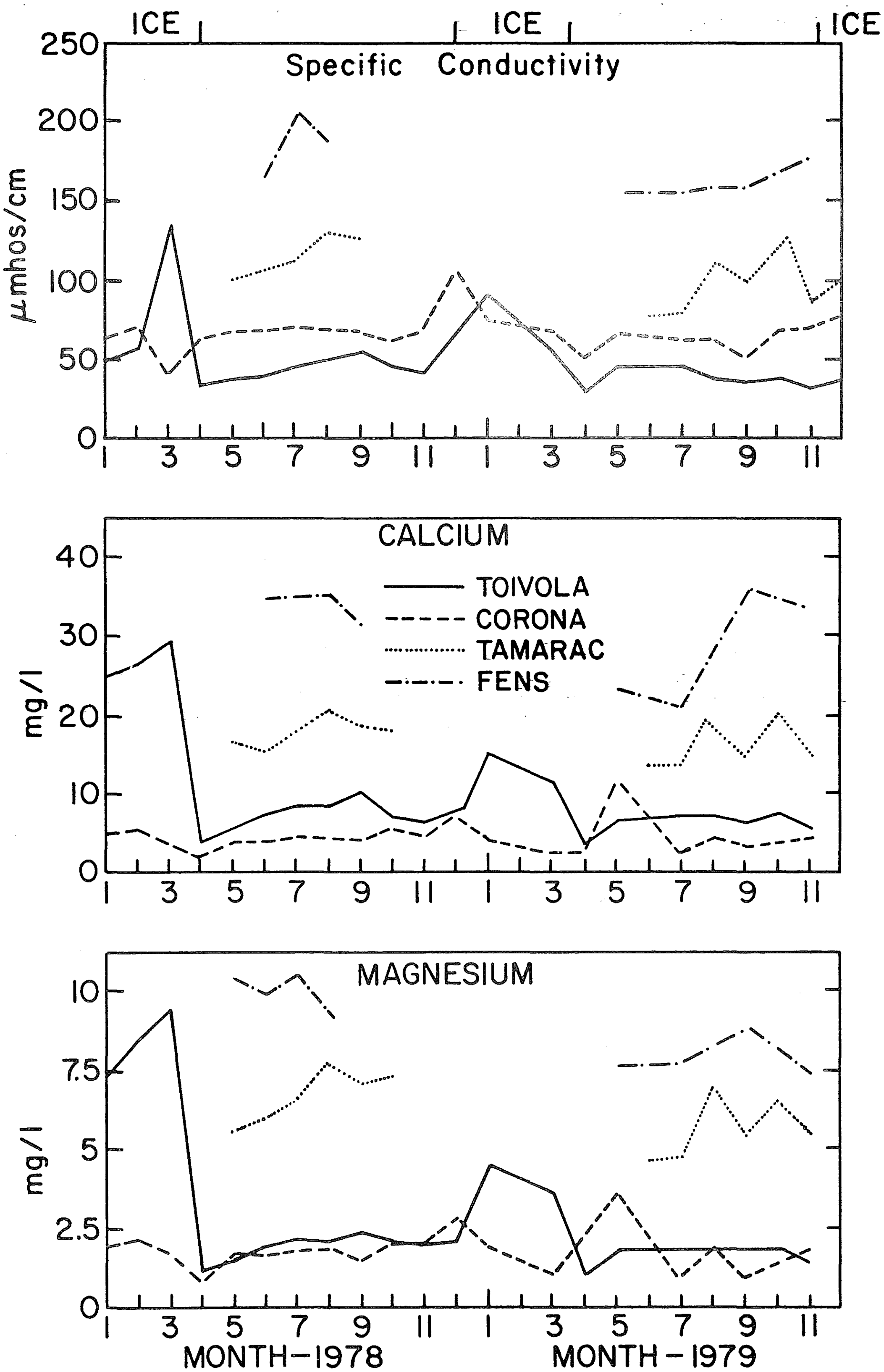


FIGURE 33: MONTHLY SPECIFIC CONDUCTIVITIES AND CONCENTRATIONS OF CALCIUM AND MAGNESIUM.

are lower in sodium than fens (Verry 1975; Walmsley and Lavkulich 1975). Seasonal patterns in sodium concentrations are inconsistent among study areas (Figure 34).

Aluminum concentrations in runoff from the disturbed areas were also higher as compared to the undisturbed areas runoff. The Corona mined area had concentrations as high as 2.35 mg/l. The Tamarac River aluminum concentrations were quite low and averaged 0.08 mg/l. Although Verry (1975) reported lower aluminum concentrations in spring, such trends were not evident during the first two years of monitoring. Higher concentrations of aluminum under the ice did occur (Figure 34).

Mean potassium concentrations in runoff from the disturbed peatlands were higher than concentrations in runoff from the undisturbed peatlands. Corona waters had the highest concentrations while Tamarac River the lowest. Although Walmsley and Lavkulich (1975) found Canadian fens to have more potassium than bogs, such differences were not observed in this study. Seasonally, higher concentrations were observed under the ice and lower values occurred in spring and during the summer (Figure 34).

Iron concentrations were also higher on the disturbed peatlands. Iron was lowest in spring and highest under the ice (Figure 34). The Fens peatland had the highest iron concentration and the Tamarac River the lowest.

e. Mn, Zn, Cr

Manganese concentrations showed no definite trends between bogs and fens or disturbed and natural peatlands. Concentrations were lowest in spring and greatest under the ice (Figure 35). Toivola had quite high manganese concentrations under the ice.

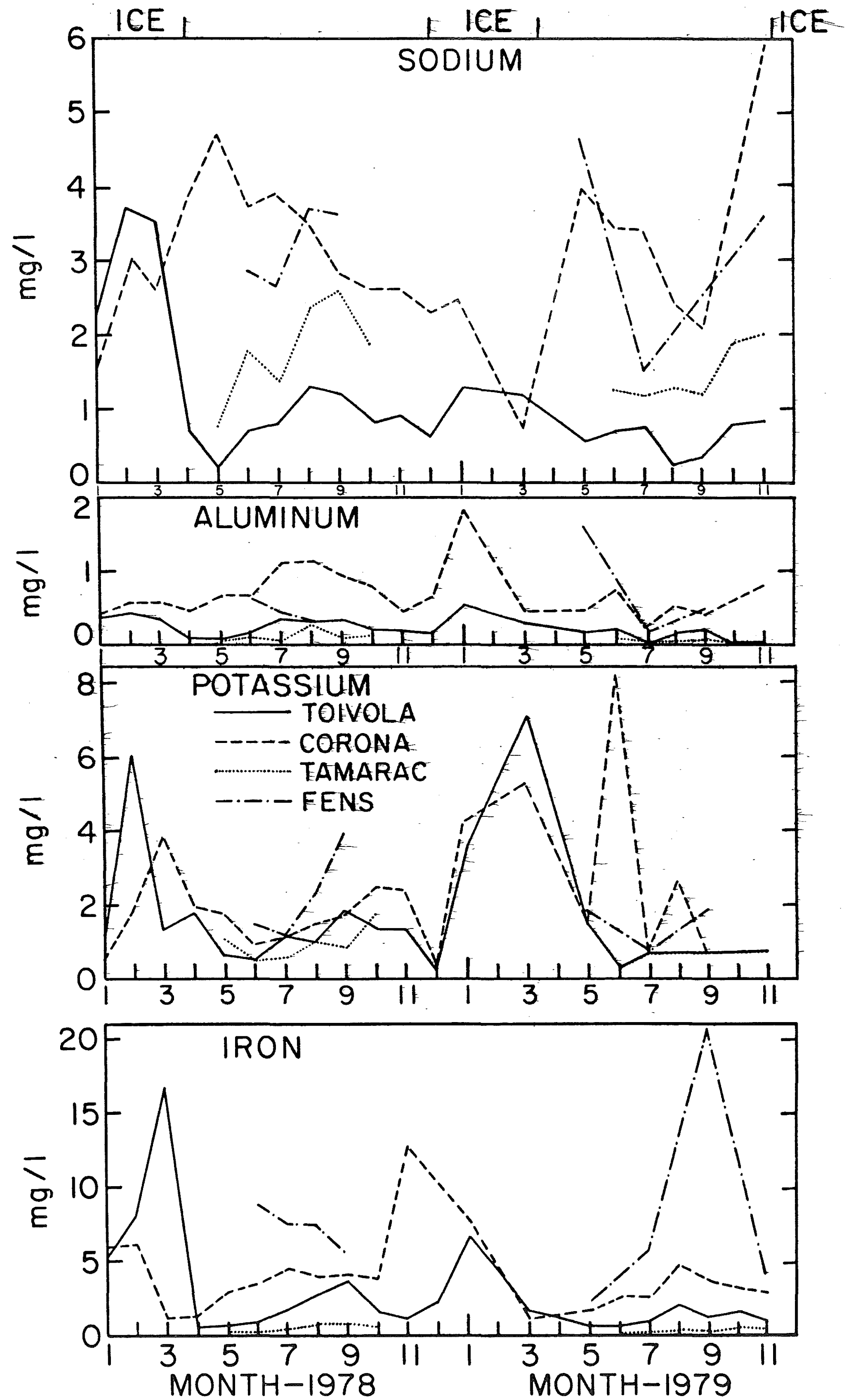


FIGURE 34: MONTHLY VALUES OF SODIUM, ALUMINUM, POTASSIUM, AND IRON.

Zinc concentrations were similar for all watersheds studied, although the disturbed peatlands were slightly higher. The Corona mined peatland had the highest zinc concentrations.

Chromium concentrations, quite low in runoff from all watersheds, were near the detection limit of <0.01 mg/l. Minimum values occurred during the summer and maximum concentrations occurred under the ice (Figure 35).

f. Cu, Ni, Pb, B

All study areas were low in copper, nickel, lead, and boron. The disturbed peatlands averaged slightly higher in copper and boron. All areas averaged below the detection limit of 0.04 mg/l for nickel and 0.13 mg/l for lead. Seasonal patterns for these constituents were not evident (Figure 36).

g. Hg, As, Se

Corona and Toivola peatland runoff was higher in mercury than Fens or Tamarac River runoff, but concentrations averaged just above the detection limit of 1.3 mg/l. Arsenic concentrations were also higher at Corona and Toivola, and variability was quite high in 1979 (Figure 37). Selenium concentrations were low, near the detection limit of 1 mg/l.

h. Total phosphorus

Average total phosphorus concentrations were highest in runoff from Fens and lowest from the Tamarac River. Runoff phosphorus concentrations from Toivola were usually less than from Corona except under the ice during the 1978-79 winter (Figure 38). These unusually high values cannot be explained at this time. Drainage and cultivation of peat in Florida and Ontario has been reported to increase orthophosphate concentrations in runoff (Hortenstine and Forbes 1972; Nicholls and MacCrimmon 1974). Peatlands drained for forest

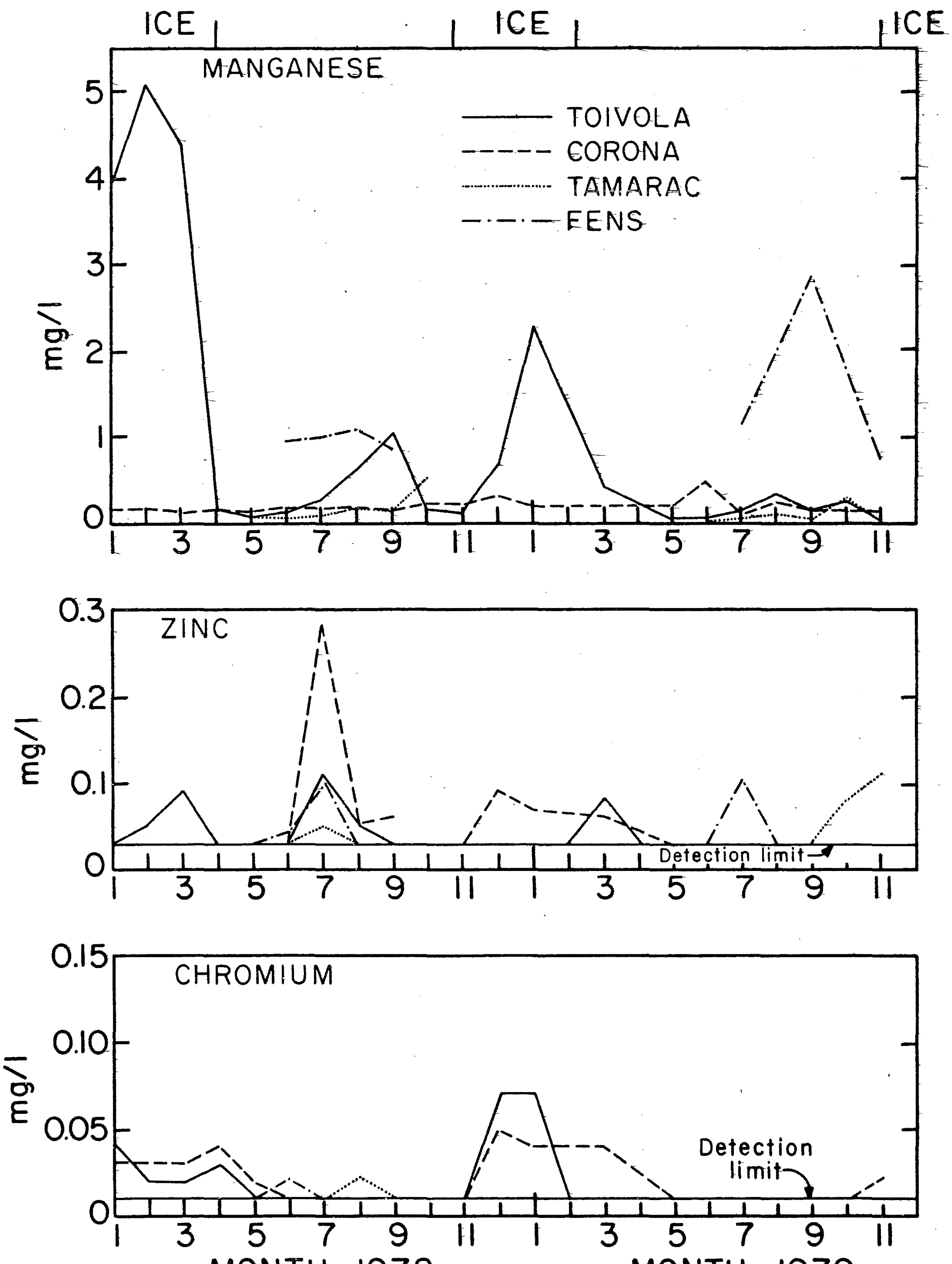


FIGURE 35: MONTHLY VALUES OF MANGANESE, ZINC AND CHROMIUM.

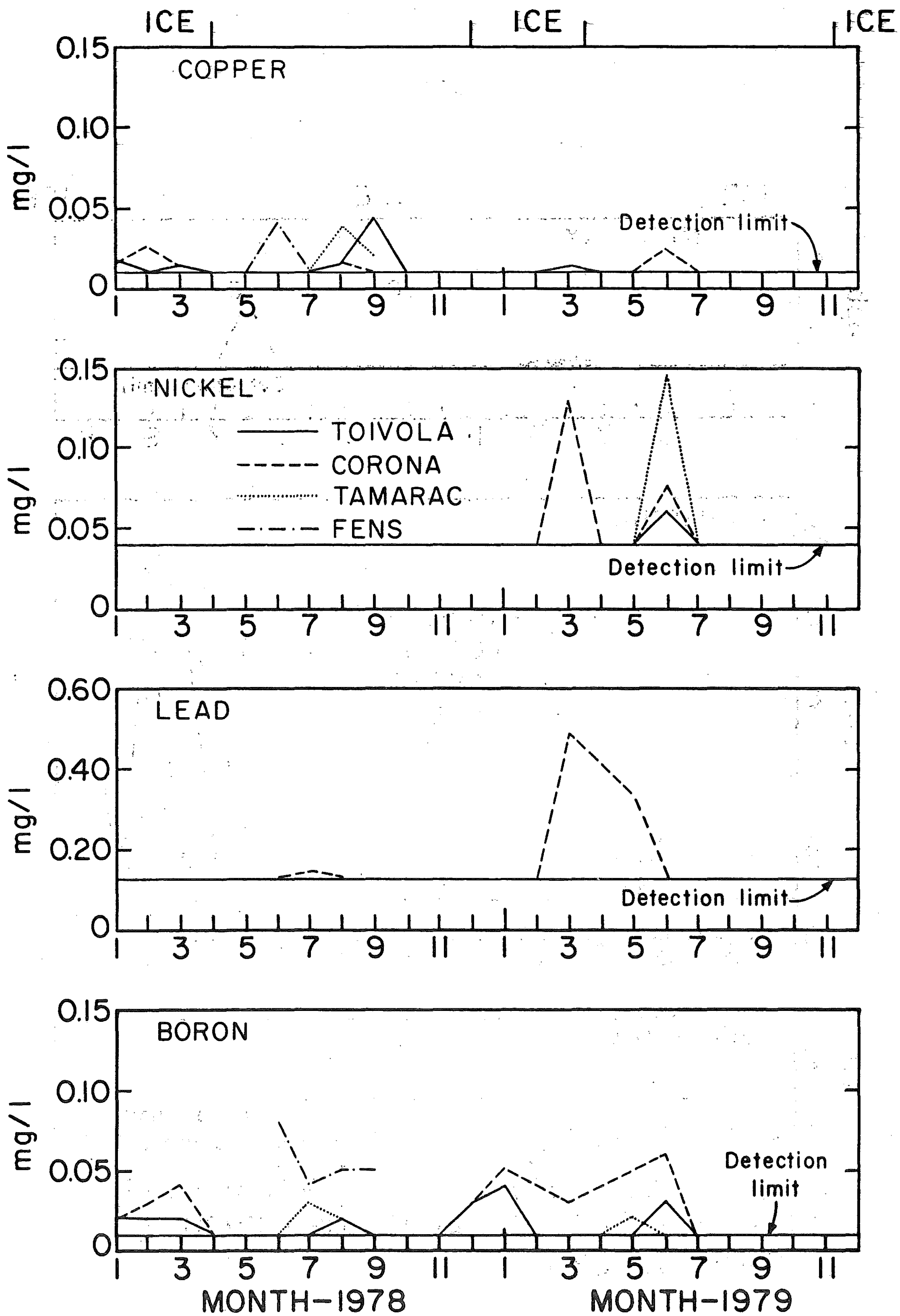


FIGURE 36: MONTHLY VALUES OF COPPER, NICKEL, LEAD AND BORON.

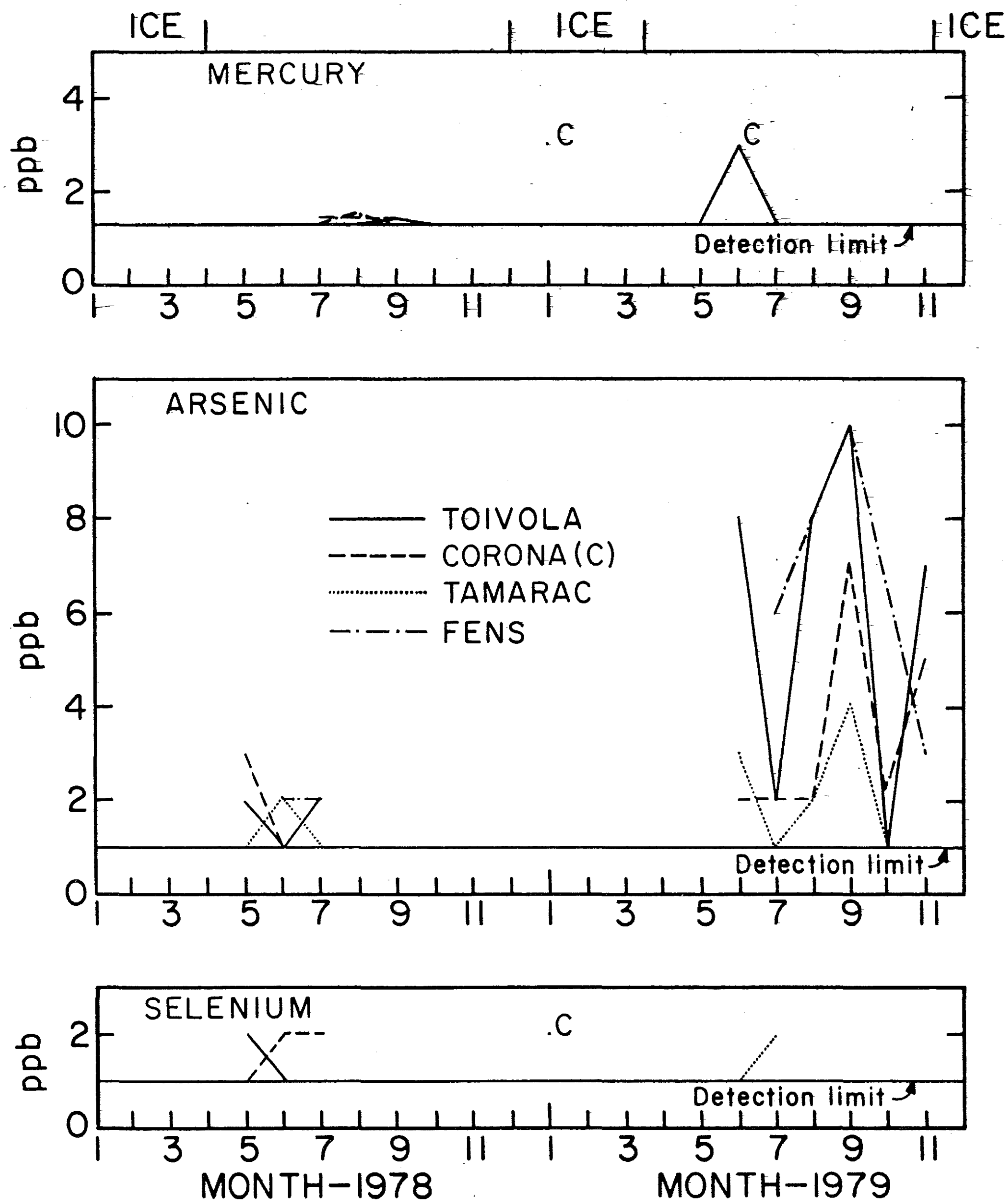


FIGURE 37: MONTHLY VALUES OF MERCURY, ARSENIC, SELENIUM.

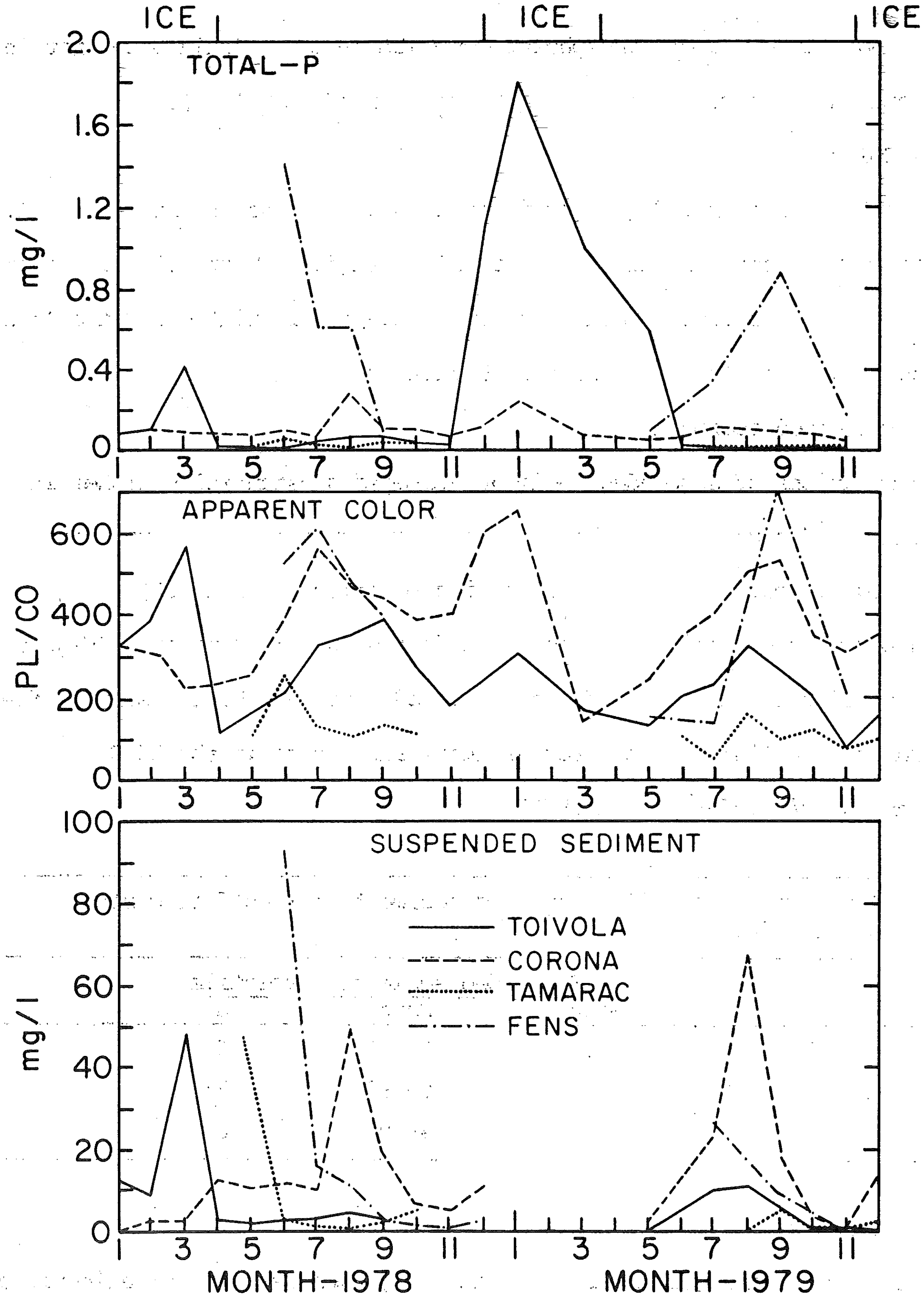


FIGURE 38 : MONTHLY VALUES OF TOTAL PHOSPHORUS, COLOR, AND SUSPENDED SEDIMENT.

production had higher runoff phosphorus concentrations in Finland but not in Czechloslovakia (Heikurainen *et al.* 1978, Ferda and Novak 1976).

i. Color

Apparent color averaged greater in disturbed peatland runoff. Normally, bog runoff in Minnesota is darker than runoff from fens (Verry 1975). Color appears to have two seasonal peaks, one under the ice in winter and the other in late summer during low flow periods (Figure 38).

j. Suspended sediment

Concentrations of suspended sediment averaged substantially higher in runoff from the disturbed watersheds. A high proportion of the suspended matter is organic matter as evidenced by its volatility (Table 20). Higher suspended sediment concentrations occurred during summer rainstorms (Figure 38). Increased concentrations of suspended sediment have been observed after forest drainage in Finland and after drainage and mining in the USSR (Heikurainen *et al.* 1978; Largin 1976).

Table 20. The percent volatile suspended sediment in runoff from study watersheds.

	Suspended sediment % volatile		
Location	Mean	Range	n
Toivola	71	37-100	6
Corona	75	30- 90	7
Fens	72	64-100	6

k. Nitrogen

Average concentrations of total-, nitrate-, ammonia-, and organic-nitrogen were higher in runoff from the disturbed peatlands. Drained forested peatlands in Finland and drained and mined peatlands in the USSR also had higher concentrations of various nitrogen species in runoff (Heikurainen *et al.* 1978; Largin 1976). Nitrogen variability was also greater in the disturbed peatlands. Minimum nitrogen concentrations were observed during spring runoff, and maximum values were measured during winter under the ice (Figure 39). About 80 to 92 percent of the nitrogen was present in the organic form except at Corona, where 47 percent was organic. Most of the remaining nitrogen was in the ammonia form and only a small amount (<0.1 to 0.2 mg/l) was found as nitrate-nitrogen. This finding is quite different from Ontario values reported by Miller (1974) for drained and cultivated peatland runoff in which nitrate comprised 80 to 91 percent of the nitrogen. Both in Michigan and New York more than half of the nitrogen was also in the nitrate form (Erickson and Ellis 1971; Duxbury and Peverly 1978).

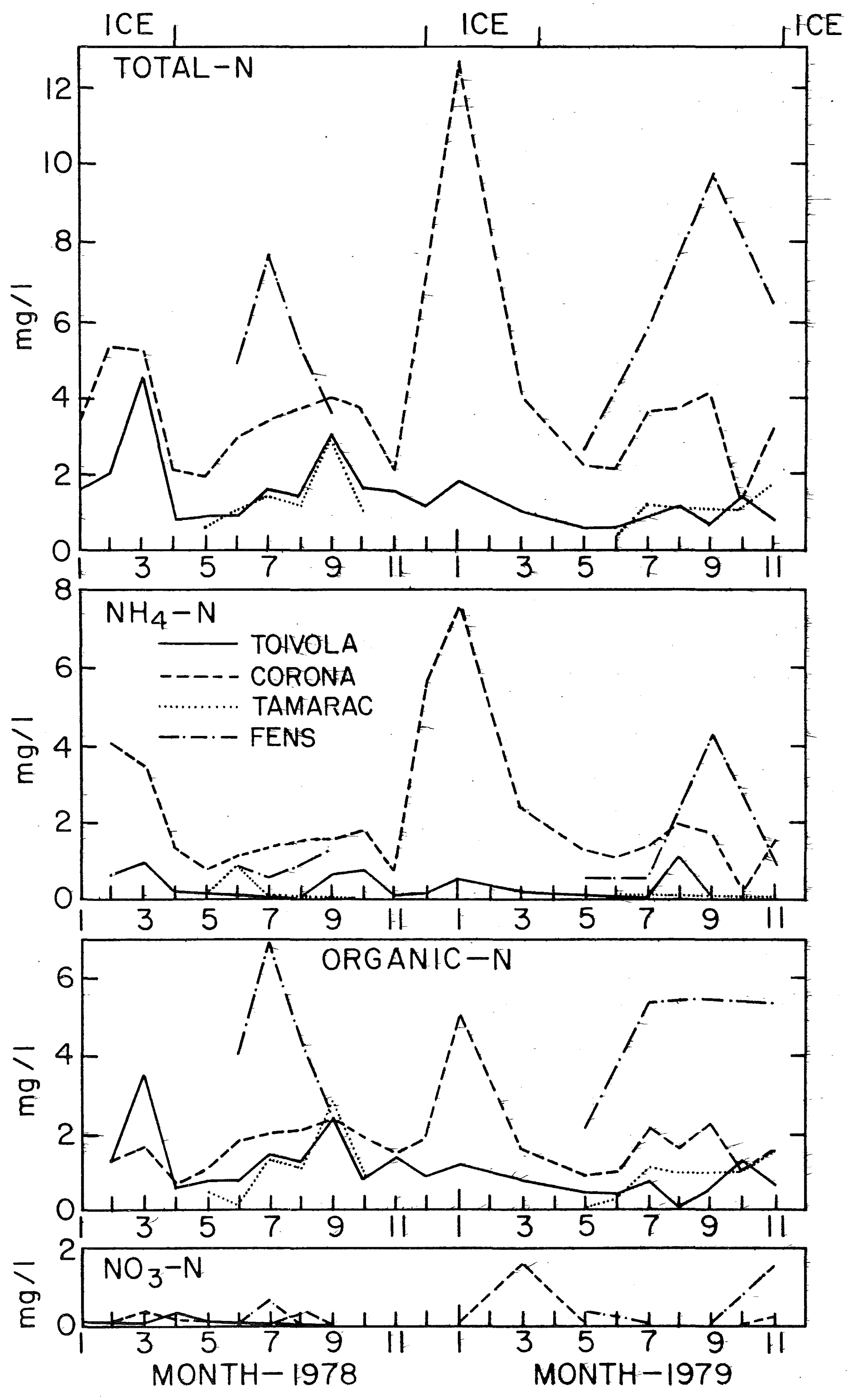


FIGURE 39: MONTHLY VALUES OF NITROGEN SPECIES.

Summary

The fen runoff had higher values of pH, specific conductivity, calcium, magnesium, and alkalinity than did bog runoff. Disturbed peatland (cleared, drained and cultivated or mined) ditch waters were higher in color, suspended sediment, acidity, sodium, aluminum, potassium, iron, zinc, copper, boron, and total-, nitrate-, ammonia-, and organic-nitrogen, whereas undisturbed peatlands' runoff was higher in dissolved oxygen and percent saturation (Table 21). Acidity and nitrogen appeared to fluctuate more in the disturbed peatlands while pH fluctuated more at Corona. Seasonal variations were evident in the concentrations of several water quality parameters. Spring minimum values and winter under ice maximums were observed for pH, acidity, alkalinity, specific conductivity, calcium, magnesium, aluminum, iron, manganese, and the various nitrogen species. In addition, chronium and color values were high under the ice in winter, and color was also high in late summer during low flow periods. Winter minimums occurred for dissolved oxygen and percent saturation while suspended sediment concentration were highest during summer rainstorms. The Corona peatland runoff seemed to have unusually high values for specific conductivity, zinc, and potassium. At this time, it cannot be stated conclusively that the disturbances of clearing, draining, and cultivating or mining actually caused the water quality differences observed among study areas. Additional information, now being collected, will assist in developing more definite conclusions.

2. Nutrient Loading

To eliminate the variables of watershed area and the effect of discharge on some water quality constituents, concentrations can be converted to annual export (kg/ha/yr) by knowing the discharge and the watershed area.

Table 21. Summary of mean water quality values, 1978-79.

PARAMETER		Undisturbed Toivola	Undisturbed Tamarac R.	Mined Corona	Drained and Cultivated Fen
Peatland type		transition	fen	bog	fen
Temperature	°C	9	15	11	18
pH		6.1	7.0	5.2	6.5
Specific conductivity[1]	μmhos/cm	51	105	66	202
Dissolved oxygen	mg/l	6.2	7.2	4.4	2.8
% saturation	%	49	72	40	30
Color Pl.Co.	units	266	129	372	529
Acidity as $CaCo_3$	mg/l	21.0	12.6	45.7	51.5
Alkalinity as $CaCo_3$	"	24.7	56.1	10.7	74.5
Suspended sediment[3]	"	3.9	2.4	15.8	16.7
K	"	1.29	<.75	1.89	1.77
Ca	"	10.26	17.14	4.26	34.95
Mg	"	2.96	6.23	1.73	9.76
Al	"	0.26	.08	.73	.38
Fe	"	2.98	.40	4.04	8.16
Na	"	1.18	1.59	3.30	2.97
Mn	"	1.00	.11	.15	1.14
Zn	"	.04	.04	.06	.06
Cu	"	<.01	<.01	.01	.01
B	"	.01	.01	.02	.04
Pb	"	<.13	<.13	<.13	<.13
Ni	"	<.04	<.04	<.04	<.04
Cr	"	.01	<.01	.02	<.01
Cd	"	.01	<.01	<.01	<.01
Hg	μg/l	1.5	<1.3	1.7	<1.3
As	"	3	2	3	<1
Se	"	1	1	1	<1
TOTAL - P	mg/l	.15	.04	.11	.64
TOTAL - N	"	1.5	1.2	3.6	6.3
$NO_3 + NO_2 - N$	"	<.1	<.1	.1	.2
$NO_2 - N$	"	<.01	<.01	.01	.01
ORGANIC - N	"	1.2	1.1	1.7	5.2
$NH_4 - N$	"	0.2	<.1	2.2	1.1
No. of samples		46	14	46	12

[1] At 25°C.

The disturbed watersheds annually exported a greater mass of suspended sediment, aluminum, iron, sodium, and total- and ammonia-nitrogen (Table 22). The fens exported more calcium and magnesium than the bogs. Fens export was extremely high for some nutrients, while Corona was quite high for total-nitrogen.

Table 22. Mean nutrient export (kg/ha/yr) from study watersheds for select water quality parameters.

Parameter	Undisturbed Toivola	Undisturbed Tamarac R.	Mined Corona	Drained and Cultivated Fens
Suspended sediment	17.2	8.9	49.1	194.3
K	8.4	2.8	6.6	33.7
Ca	47.3	58.0	16.9	213.3
Mg	12.8	21.4	6.9	70.7
Al	1.4	0.3	3.1	1.9
Fe	11.1	1.7	16.3	42.3
Na	5.0	5.8	14.1	34.7
Mn	2.3	0.6	0.6	4.2
Total - P	1.0	0.1	0.4	5.9
Total - N	8.2	5.0	117.3	36.5
NH_4 - N	1.9	0.2	6.0	8.0
Organic - N	6.9	4.7	6.7	28.5
n	38	6	26	9

3. Mining Effects

Table 23 summarizes the means of 10 water quality samples from both the Corona mined and control areas. Because the Corona control outlet is a ditch passing through mineral soil such parameters as pH, specific conductivity, acidity, alkalinity, calcium, and magnesium cannot be compared. The Corona mined runoff was higher in values of color, suspended sediment, potassium, aluminum, soidum, manganese, total phosphorus, and total-, nitrate-, organic-, and ammonia-nitrogen than runoff from the control. Little or no difference was observed for zinc, copper, nickel, lead, chromium, cadmium, arsenic, and selenium.

Table 23. Mean water quality of mined versus control at Corona, 1979.

PARAMETER		MINED	CONTROL
Temperature	^{o}C	9	8
pH		5.3	5.9
Specific conductivity[1]	μmhos/cm	65	75
Dissolved oxygen	mg/l	4.7	3.7
% saturation	%	41	32
Color Pl./Co.	units	372	272
Acidity as $CaCO_3$	mg/l	41.3	39.4
Alkalinity as $CaCO_3$	"	7.5	25.2
Suspended sediment	"	17.0	6.6
K	"	2.90	1.07
Ca	"	4.54	11.29
Mg	"	1.74	3.94
Al	"	.68	0.22
Fe	"	3.29	3.10
Na	"	3.03	1.97
Mn	"	.20	.07
Zn	"	<.03	<.03
Cu	"	<.01	<.01
B	"	.03	.02
Pb	"	.15	<.13
Ni	"	.04	<.04
Cr	"	.02	.03
Cd	"	.02	.04
Hg	μg/l	3	6
As	"	4	4
Se	"	1	1
TOTAL - P	mg/l	.09	.06
TOTAL - N	"	4.1	2.2
$NO_3 + NO_2 - N$	"	.1	<.1
$NO_2 - N$	"	.01	.01
ORGANIC - N	"	2.2	1.0
$NH_4 - N$	"	1.9	1.2

[1] At 25^{o}C.

Higher mercury concentrations have so far been measured in control runoff but the reasons for this or its significance are unknown. These results are quite preliminary and based on a small number of samples. Additional testing will be conducted in 1980 and 1981.

4. Reclamation Effects

a. Ponds

Table 24 summarizes the means of eight samples from two waterfowl ponds at Wilderness Valley Farms and from the control. The results show that the waters in the ponds are more like lake waters than ditch water. The ponds are more basic, clearer, contain more oxygen, and generally have less dissolved constituents and nutrients than the control ditch waters. More nitrate and organic-nitrogen and less total- and ammonia-nitrogen are found in the ponds. The pond with the bottom in mineral soil is more basic, has higher specific conductivity, dissolved oxygen, calcium, magnesium, and zinc than the pond with its bottom in peat. The mineral pond is also lower in color, aluminum, and iron than the peat pond.

b. Drainage and forest fertilization

Soil solution samples from 50 and 100-cm depths and ditch waters were tested for three plots at Fens, a natural undrained wooded plot and two cleared, drained, and reforested plots, one of which was fertilized (Martin 1979). The fertilizer used was NPK applied at a rate of 115-77-135 kg per hectare.

Clearing and draining this fen peatland appears to have lowered total- and ammonia-nitrogen, total- and orthophosphate, and iron in soil solution. Potassium, specific conductivity, calcium, and magnesium increased in soil solution after drainage (Table 25). Nitrate-nitrogen concentrations were low and did not appear affected by clearing and drainage. pH also did not change.

Table 24. Mean water quality of ponds and control at Wilderness Valley Farms 1979.

PARAMETER		Pond with Bottom in MINERAL	PEAT	CONTROL
Temperature	^{o}C	12	12	18
pH		7.4	7.0	6.5
Specific conductivity [1]	µmhos/cm	111	74	202
Dissolved oxygen	mg/l	10.0	9.0	2.8
% saturation	%	94	84	30
Color Pl./Co.	units	85	100	529
Acidity as $CaCO_3$	mg/l	4.0	3.6	51.5
Alkalinity as $CaCO_3$	"	41.2	22.0	74.5
Suspended sediment	"	---	---	16.7
K	"	1.27	1.67	1.77
Ca	"	15.26	8.36	34.95
Mg	"	5.54	2.98	9.76
Al	"	.05	.19	.38
Fe	"	.05	.11	8.16
Na	"	3.62	2.54	2.97
Mn	"	.01	.01	1.14
Zn	"	.14	.04	.06
Cu	"	<.01	<.01	.01
B	"	<.01	<.01	.04
Pb	"	<.13	<.13	<.13
Ni	"	<.04	<.04	<.04
Cr	"	<.01	.02	<.01
Cd	"	<.01	<.01	<.01
Hg	µg/l	3	<1.3	<1.3
As	"	3	3	<1
Se	"	1	2	<1
TOTAL - P	mg/l	.04	.04	.64
TOTAL - N	"	1.8	1.6	6.3
$NO_3 + NO_2 - N$	"	.4	.3	.2
$NO_2 - N$	"	.01	<.01	.01
ORGANIC - N	"	1.6	1.6	1.1
$NH_4 - N$	"	<.1	<.1	5.2

[1] At 25^{o}C.

Table 25. Mean soil solution concentrations for the control, fertilized, and unfertilized plots at Fens.[1]

Parameter		Undrained wooded		Drained unfertilized		Drained fertilized	
		50cm	100cm	50cm	100cm	50cm	100cm
pH		6.0	6.0	6.0	6.1	5.9	6.1
specific conductivity	μmhos/cm	167	161	195	245	225	352
Ca	mg/l	20.9	19.0	25.6	31.4	27.8	34.3
Mg	"	8.2	7.2	9.2	10.8	10.2	11.3
Al	"	0.6	0.4	0.8	0.5	0.4	0.3
Fe	"	3.4	4.0	0.8	5.1	0.6	4.1
Total - N	"	5.3*	5.0*	4.3	4.4	3.8	4.3
NH_4 - N	"	2.6*	3.0*	1.0	1.7	0.7	1.6
NO_3 - N	"	<.1	<.1	<.1	<.1	0.3*	<.1
Total - P	"	0.11*	0.17*	0.05	0.10*	0.07	0.23*
Ortho - P	"	0.10*	0.15*	0.03*	0.07*	0.06*	0.23*
K	"	1.0*	1.1*	2.0*	2.0*	20.0*	18.0*

[1] Means of 30 samples, from Martin (1979).

* Means significantly different at the 5% level from other values at the same depth.

Fertilization of the drained fen increased soil solution concentrations of total and ortho-phosphate at the 100-cm depth, potassium and nitrate-nitrogen at 50-cm depth, and specific conductivity, calcium and magnesium. Total- and ammonia-nitrogen were not affected by fertilization. Fertilization also appeared to decrease asluminum and iron in soil solution. Water samples from ditches surrounding the plots indicate that only potassium and specific conductivity were consistently higher in the fertilized ditch water (Table 26). During the period of this study in 1978, the water table fluctuated near the 50-cm depth.

5. Downstream Assimilation

To evaluate the effect of peatland runoff on downstream water quality, samples were taken at several points along Joula Creek, from its origin in the Toivola peatland, 7.4 km downstream to its confluence with the Floodwood River.

Table 26. Mean ditch water quality of the unfertilized and fertilized plots for the study period.[1]

Water Quality Parameter		Unfertilized Ditch Water	Fertilized Ditch Water
Total N	mg/l	4.8	5.1
$NH_4 - N$	"	0.1	0.3
$NO_3 - N$	"	<0.1	<0.1
Organic N	"	4.7	4.8
Total P	"	0.22	0.30
$PO_4 - P$	"	0.07	0.09
K	"	6.2	16.0*
pH	"	6.4	6.5
Ca	"	24.7	25.6
Mg	"	9.3	9.4
Al	"	0.2	0.2
Fe	"	1.8	1.7
Specific conductivity (μmhos/cm)		198	235*

[1] Mean of five samples, from Martin (1979).

* Denotes consistently significantly higher concentrations over time at the 5% level.

Joula Creek, which largely flows through mineral soil after it leaves the Toivola peatland, was found to increase the pH, dissolved oxygen, and specific conductivity of the peatland runoff (Table 27). The Floodwood River (Sta. 6), after receiving Joula Creek water (Sta. 5), was reduced in pH by 0.2 units, in temperature by 0.5°C, and in specific conductivity by 20 percent or 23 μmhos/cm. Color increased in the Floodwood River by 12 percent or 30 units, and dissolved oxygen increased by almost 30 percent.

Table 27. Water quality values along several points of Joula Creek downstream from the Toivola peatland.[1]

Station	Downstream Distance (km)	pH	Temp. ^{o}C	Color Pl.Co.	Dissolved Oxygen (mg/l)	Specific conductivity μmhos/cm
1	0	5.1	14.0	270	5.2	26
2	2.6	6.1	15.5	320	4.7	58
3	6.0	6.4	15.0	370	7.2	47
4	7.4	6.5	15.5	300	7.4	51
5	--	6.8	17.0	260	5.7	94
6	--	7.0	17.5	230	4.5	117

[1] Conducted July 11, 1978.

6. Water Quality Relationships

The relationships between water quality constituents and both discharge and temperature were investigated. Also, the interrelationships among constituents were evaluated.

a. Discharge

Significant correlations ($\alpha = 0.05$) were found between discharge and concentrations (mg/l) or loadings (kg/ha/yr) of potassium, sodium, and total-nitrogen at Corona (Table 28). Discharge also correlated with total-nitrogen and organic-nitrogen at Fens. All correlations were positive except for sodium. No significant correlations between discharge and constituents were obtained at Toivola or the Tamarac River.

Table 28. Correlation coefficients (R) for significant relationships between discharge and various water quality parameters at Corona and Fens.

Parameter	Corona (n=26)	Fens (n=9)
K	.476*	--
Na	-.557**	--
Total - P	.394*	--
Total - N	.462*	.697*
Organic - N	--	.683*

* $\alpha = 0.05$

** $\alpha = 0.01$

b. Air Temperature

Air temperature was found to be significantly correlated to concentrations of suspended sediment and total phosphorus at Toivola; sodium, total-nitrogen, and ammonia-nitrogen at Corona; and calcium at Fens (Table 29). Correlations were positive except for ammonia-nitrogen and calcium. No significant correlations between air temperature and constituents were obtained at Fens.

Table 29. Correlation coefficients (R) for significant relationships between air temperature and various water quality parameters by study area.

Parameter	R	Location
Suspended sediment	.355*	Toivola
Total - P	.738**	Toivola
Na	.541**	Corona
Total - N	.431*	Corona
NH_4 - N	-.565**	Corona
Ca	-.752*	Fens

* $\alpha = .05$

** $\alpha = .01$

c. Peat Temperature

The peat temperature at 30 cm was found to correlate with more water quality constituents than air temperature (Table 30). All correlations were positive. Peat temperature correlated with all the parameters that air temperature correlated with, as well as with aluminum, iron, and organic-nitrogen but not with total phosphorus or ammonia-nitrogen. No correlation between peat temperature and water quality constituent were obtained at Fens.

Table 30. Correlation coefficients (R) for significant relationships between peat temperature and various water quality parameters at Toivola and Corona.

Parameter	Toivola (n=38)	Corona (n=26)
Suspended sediment	.417**	--
Ca	.431**	--
Al	.343*	.500**
Fe	.446**	--
Total - N	.495**	.634**
Organic - N	.457**	.536**

* $\alpha = 0.05$

** $\alpha = 0.01$

d. Constituent Interrelationship

Correlations exist among many water quality constituents (Figure 40). All correlations were positive except Mg and Ca at Corona. Calcium, magnesium, sodium, and iron were highly related to other cations. Phosphorus and nitrogen were also related to certain cations. The large number of interrelationships may exist because when some constituents are high, other values are also likely to be high. Study watersheds differ in their correlations. Toivola has the greatest number of relationships and Corona the second greatest. The fens

3. Fertilizing a fen for reforestation reclamation appeared to increase potassium and specific conductivity in runoff.

4. pH in runoff from the Toivola peatland appeared to be increased downstream after mixing with waters in contact with mineral soil.

RECOMMENDATIONS

Based upon the results obtained to date, a number of recommendations are given.

1. Studies of the effects of disturbing peatlands by clearing, draining, and cultivating or mining should continue for at least an additional two years.
2. The effects of hydraulic mining and dewatering on water quantity and especially water quality should be evaluated before use of this technology.
3. Sedimentation basins should be used at the outlet of drained and cultivated or mined peatlands to reduce suspended sediment exports, and the effect of sedimentation on other water quality constituents, especially nutrients, should be evaluated.
4. Means should be explored for using peat as a filter to remove nutrients from the runoff from disturbed peatlands.

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