

This manuscript has been prepared for the
Canadian National Committee International Peat
Society - Symposium '87
and the contents are subject to change.

This copy is to provide information
prior to publication.

ORGANIC GEOCHEMISTRY OF
BOG DRAINAGE WATERS
by
Richard A. Bourbonniere

Rivers Research Branch
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario, L7R 4A6
September 1987
NWRI Contribution #87-133

MANAGEMENT PERSPECTIVE

This paper summarizes our research related to the impact of peatland drainage for fuel peat carried out from July, 1984 through December, 1986. Research of this type was called for under the Peat component of the Federal Panel on Energy R&D (PERD). The present report is a summary of the major impacts determined at two sites in eastern Canada. Detailed reports are in progress which can lead to specific application of these results. The potential effects of amended bog drainage to the organic character of the drainage waters and receiving water courses include possible increases in biochemical oxygen demand, changes in organic contribution to acidity, and changes in metal complexation capacity. The severity of these potential impacts depends upon the relative discharge or capacity of the local receiving waters compared to the discharge of the amended bog drainage.

PERSPECTIVES DE GESTION

La présente communication résume nos travaux de recherche sur les conséquences du drainage de tourbières pour la tourbe combustible, effectués à partir de juillet 1984 jusqu'en décembre 1986. Ces recherches ont été entreprises dans le cadre des travaux sur la tourbe de la Commission fédérale sur la recherche et le développement énergétiques (PERD). Le présent rapport est un résumé des principaux effets mesurés à deux endroits dans l'est du Canada. On est en train de préparer des rapports détaillés qui pourront conduire à des applications spéciales de ces résultats. Les conséquences possibles de la transformation mécanique du drainage d'une tourbière pour le caractère organique des eaux de drainage et des eaux réceptrices en aval pourraient être les suivantes : augmentation de la demande biochimique en oxygène; variations de la contribution organique à l'acidité; variations de la capacité de complexation des métaux. L'importance de ces effets possibles est fonction du débit relatif ou de la capacité des eaux réceptrices locales, comparativement au débit des eaux de drainage de la tourbière après modification.

GÉOCHIMIE ORGANIQUES DES EAUX DE DRAINAGE

Richard A. Bourbonnière
Environnement Canada
Institut national de recherche sur les eau
C.P. 5050, 867 Lakeshore Road
Burlington (Ontario) L7R 4A6

RÉSUMÉ

La présente communication traite, du point de vue géochimique et environnemental, des effets de matières organiques dissoutes dans les eaux de drainage de tourbières à deux endroits de l'est du Canada. Les variations dans l'abondance de trois fractions organiques acides et de deux fractions organiques neutres sont utilisées pour évaluer les changements qui peuvent se produire si le drainage naturel des zones étudiées est modifié par des moyens mécaniques. Les effets possibles décelés comprennent une augmentation éventuelle de la demande biochimique en oxygène, des variations au niveau de la contribution organique à l'acidité, et des changements dans la capacité de complexation de métaux. L'importance de ces effets est fonction, dans chaque cas, du débit relatif ou de la capacité des eaux en aval, comparativement au débit de drainage d'une tourbière après modification.

ORGANIC GEOCHEMISTRY OF BOG DRAINAGE WATERS

Richard A. Bourbonniere
Environment Canada
National Water Research Institute
P.O. Box 5050, 867 Lakeshore Road
Burlington, Ontario, L7R 4A6

ABSTRACT

This paper deals with the potential impact of dissolved organic materials in bog drainage waters from two sites in eastern Canada, as viewed from a geochemical and environmental perspective. Variations in abundance of three acidic and two neutral organic fractions are used to propose the changes which may occur if the natural drainage of the study sites were mechanically amended. Potential effects identified include possible increases in biochemical oxygen demand, changes in organic contribution to acidity, and changes in metal complexation capacity. The severity of these potential impacts depends in each case on the relative discharge or capacity of the receiving waters compared to the discharge of amended bog drainage.

INTRODUCTION

The potential impact of drainage from peatlands on the quality of receiving waters is a matter of concern especially when focused on projects which involve the development of bogs for harvesting fuel or horticultural peat. We have reviewed briefly some of the major concerns; acidity, organic matter, metals, and nutrients (Glooschenko *et al.*, 1985). This paper deals more specifically with the dissolved organic materials (DOM) which drain from undisturbed and drained bogs at two sites in eastern Canada.

Peat is composed almost exclusively of organic matter, the bulk of which is humic matter, generally considered to be a complex mixture of degradation products of plant material (Mathur and Farnham, 1985). The DOM in bogs are derived predominantly from humic matter. Indeed Thurman (1985) suggests that the DOM in water from wetlands are 90% fulvic acid (FA).

In this investigation DOM are examined from geochemical and environmental viewpoints. For simplicity the total DOM in bog, creek,

river, and ditch samples are considered to be humic substances, and are fractionated into humic acid (HA) and FA by methods which have been in use for many years (Stevenson, 1982). Using methods recently developed for fractionation of DOM into chemically definable sub-fractions (Leenheer, 1981, 1985; Richmond and Bourbonniere, 1987), the FA fraction from water samples in this study was further fractionated into six sub-fractions: hydrophobic acid, base and neutral (HPOA, HPOB, and HPON), and hydrophilic acid, base and neutral (HPIA, HPIB, and HPIN). Variations in the abundances of these FA fractions and HA with climatic changes and bog development indicate the types of reactions which occur and the potential for environmental impact.

STUDY AREAS

The two areas studied contain bogs representative of many in eastern Canada (Fig. 1). Both sites are coastal, but differ in local climate. The Nova Scotia site (Barrington Bog) experiences a maritime climate: moderate winters; snowfall melts quickly; wet periods occur in spring and autumn; and summers are usually dry. The Quebec site (Sept-Iles) has a more continental climate with heavy winter snowfalls, spring melting period and "normal" summer and autumn weather with wet and dry periods intermixed. Barrington Bog was never ditched, so only pre-development data exists from this site. Ditching had occurred at some of the Sept-Iles sites before our sampling, so we have post-ditching and unditched sites for comparison among themselves and with Barrington Bog. Only brief descriptions of the sites follow and the reader is referred to Shotyk (1986) and Bourbonniere *et al.* (1987) for more detailed information.

The primary natural drain of Barrington Bog is Judas Ck. which drops 22 m from the highest point of the bog to the mouth of the

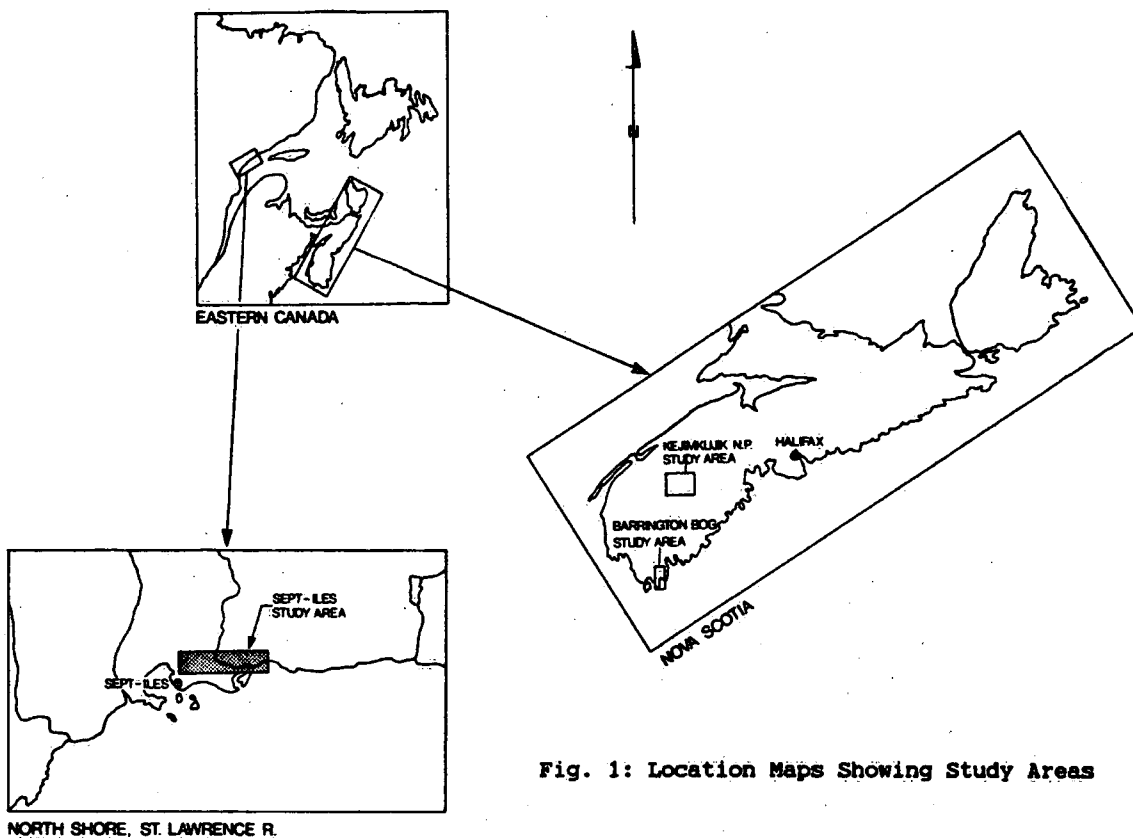


Fig. 1: Location Maps Showing Study Areas

creek at Lyles Bay, five km from its source. Lyles Bay is in an intertidal zone at the head of Negro Hbr. which is the estuary of the Clyde R. The lower reach of Judas Ck. flows through a salt marsh and consequently experiences tidal influence.

The sites from which water samples were collected for this study represent bog pore water, drainage water from Judas Ck., some of which was affected by tidal fluctuations, and water from the Clyde R. sampled from a point near the mouth above the level of tidal fluctuation. The river makes a good comparison site for this study; the potential environmental impact of Barrington Bog drainage upon Lyles Bay and Negro Hbr. will be in proportion to the difference in water quality and quantity between the drainage water and the Clyde R. water.

The sampling sites in the Sept-Iles area (Fig. 1) were chosen for us by Prof. T.R. Moore from McGill University. Three bogs which have undergone differing degrees of development for horticultural peat (undisturbed, recently drained, and drained and harvested for several years) were chosen, and two sites in each bog were

sampled under varying seasonal conditions. One site represents bog pore water, one represents a natural drain, and four sites represent mechanically amended drainage.

CHARACTER OF DOM

DOM fractionations were completed on 85 samples. Statistical data for this set appears in Tab. 1 as well as the calculated average distribution of DOC among the seven organic fractions. On average 62% of the DOC resides in acidic fractions and 34% in neutral fractions. The basic fractions together contain only a small portion of the DOC (ca. 4% on average) and will be ignored from here on.

For most of these parameters the ranges determined are rather broad and quite variable as indicated by the RSD values. To some extent this is attributable to the variety of sample types, and seasonal fluctuations, as will be seen later; but variability can also be induced by the derived nature of some of the data. For instance HA, HPIA, HPIB, and HPON are determined by the difference of at least two

Tab. 1: pH and DOC Distribution for all Samples with Complete DOM Fractionations (Concentrations in mgC/L, n=85)

	pH	DOC	HA	HPOA	HPIA	HPOB	HPIB	HPON	HPIN
Min	3.4	16.0	0.00	3.52	0.00	0.00	0.00	0.00	0.13
Max	6.2	71.9	25.6	31.2	14.4	0.88	11.4	18.2	15.8
Mean	4.42	33.1	5.16	11.3	3.97	0.15	1.19	5.73	5.62
S.D.	0.59	12.7	5.04	5.53	3.49	0.20	1.93	3.95	3.57
RSD	13.3%	38.2%	97.6%	49.0%	88.0%	132%	161%	69.0%	63.5%
Frac-C (% of DOC)			15.6	34.1	12.0	0.40	3.60	17.3	17.0
Cum-C (% of DOC)			15.6	49.7	61.7	62.1	65.7	83.0	100.

S.D. - \pm Sample standard deviation (n-1 d.f.)
RSD - (S.D. / Mean) x 100%
Frac-C - Mean Fraction (mgC/L) / Mean DOC (mgC/L) x 100%
Cum-C - Cumulation of Frac-C

DOC determinations, whereas the carbon measurements for DOC, HPOA, HPOB, and HPIN are more direct (Richmond and Bourbonniere, 1987).

In this paper the chemical character of DOM in samples is described by the relative distribution of DOM fractions, normalized to DOC. The properties of water which contains DOM result from the absolute concentrations of DOM fractions expressed in mgC/L.

Variations Among Sample Types

Samples in this study may be classified according to six types based upon their sampling environment. The particular sites in Barrington Bog or Sept-Iles which correspond to each of the sample types identified are described in Bourbonniere et al. (1987). Thus bog interstitial water may be either "upper" (BUP, read bog upper pore water) or "lower" (BLP). Bog drainage may be either "natural" (BND, read bog natural drainage) or "mechanically amended" (BAD), or in some cases it may undergo saline influence (BSL) due to tidal fluctuations. The Clyde R. mouth (CLY) is considered as a distinct sample type for this study because of the integrative effects of its many tributaries.

Sorting by sample type was done without consideration for season or hydrologic condition. Tab. 2 shows the distribution of DOC for the three acidic and two neutral fractions of DOM as well as pH and DOC. As was seen for the entire data set, there is a considerable amount of variability even among samples of the same type. To some extent this is explained by the lesser sample populations tested after sorting, but it may also indicate that other processes,

such as seasonal variations may be important.

Bog related sample types seem to contain the highest concentrations of DOC, with decreases apparent in the more integrated samples, BND, BSL, and CLY. HA appears to be a more significant proportion of the DOC in the more integrated samples such as CLY and BSL, and occurs to the least extent in the most localized samples (BUP). An increase in HA contribution to DOC in the lower layers of bogs (BLP) and in bog drainage (BND), relative to shallow bog pore water (BUP), suggests that on average the deeper waters are contributing to the drainage, and that bog drainage is not simply surface runoff. On average the highest relative HPIC content occurs in the BUP samples, suggesting that the acids which make up this fraction are closer to their biochemical sources. For all sample types the HPOA fraction dominates. This material is the most similar to the "traditional" FA by the operational definitions most often used.

The HPON fraction contains molecules like hydrocarbons and amorphous polymers with little peripheral functionality. These materials are relatively unreactive and stable and could be diagenetic products which would be expected to accumulate in the deeper layers of peat and in integrated systems. Thus higher absolute and relative concentrations of this fraction appear in the BLP and BAD samples, and to a lesser extent in the BND and CLY samples (Tab. 2). The HPIN fraction seems to be associated more with bog sources; BUP, BLP, and BAD, and less with integrated samples, BND and CLY. This suggests that HPIN contains

Tab. 2: pH and DOC Distribution for Samples Sorted by Type

	pH	DOC	HA	HPOA	HPIA	HPON	HPIN
Bog pore water, upper (BUP), n=12							
Mean	4.19	38.5	4.05	13.1	5.91	5.14	7.56
S.D.	0.50	15.4	4.31	5.32	4.59	5.55	4.45
Frac-C (% of DOC)			10.5	34.0	15.4	13.4	19.6
Bog pore water, lower (BLP), n=3							
Mean	3.90	49.0	7.54	15.2	6.26	10.8	9.00
S.D.	0.46	5.90	6.76	3.64	2.83	9.44	4.38
Frac-C (% of DOC)			15.4	31.0	12.8	22.0	18.4
Bog natural drainage (BND), n=36							
Mean	4.30	34.5	5.69	12.4	3.98	6.02	5.13
S.D.	0.40	13.2	5.74	6.18	3.76	3.49	3.36
Frac-C (% of DOC)			16.5	35.9	11.5	17.4	14.9
Bog amended drainage (BAD), n=11							
Mean	4.35	29.0	3.92	8.43	2.83	6.49	6.62
S.D.	0.59	8.70	3.23	4.00	1.95	3.66	2.95
Frac-C (% of DOC)			13.5	29.1	9.76	22.4	22.8
Bog drainage, saline influence (BSL), n=7							
Mean	5.71	32.1	6.00	10.6	3.26	4.57	6.03
S.D.	0.53	13.8	5.91	5.37	2.17	1.25	3.43
Frac-C (% of DOC)			18.7	33.0	10.2	14.2	18.8
Clyde R., near mouth (CLY), n=16							
Mean	4.43	26.4	4.84	9.06	3.16	4.58	3.78
S.D.	0.32	7.16	4.51	4.18	2.90	2.65	2.70
Frac-C (% of DOC)			18.3	34.3	12.0	17.3	14.3

biogeochemically "young" molecules. The BSL samples are integrated, but their character may be influenced by ionic strength, thus anomalous compared to the other sample types.

Seasonal Variations

Mean DOC concentrations show the expected seasonal differences with summer levels twice as high as those in spring and winter, and autumn concentrations intermediate (Tab. 3). Dilution by spring rains and snowmelt can explain these differences. The following comparisons are made using the data normalized to mean DOC to facilitate discussion in terms of processes.

Lower average relative proportions of HA occur in the spring and summer probably due to the predominance of saturated surface flow. Relative increases in the autumn and winter may be caused by an increased predominance of deeper water or by a slowdown of biochemical processes which produce the more hydrophilic fractions. HPOA is relatively invariant with season suggesting that it is a conservative component, or a diagenetic intermediate between HA and the hydrophilic fractions. Variations in average HPIA contents may be

explained by biochemical production of soluble acidic components, a process related to decomposition of biomass which is maximal in summer (Auclair *et al.* 1976). Autumn and winter show progressively less HPIA reflecting decreases in biochemical activity and flushing of summer accumulations. Lowest average HPIA levels are seen during spring following the period of lowest microbial activity in winter.

Seasonal variations occur in the proportion of HPON but the average concentration of HPON carbon is more constant (Tab. 3). Dilution of HPON in summer and autumn by increased amounts of other DOM fractions that contain greater functionality explains the lower relative amount of this fraction. The relative proportion of HPIN exhibits a sequential decrease from spring to winter. In wetlands much of the annual export of biomass occurs during spring (Auclair *et al.*, 1976; Bartsch and Moore, 1985). Soluble carbohydrates (part of HPIN) are certainly part of this material, and may have survived further decomposition to HPIA because of decreased microbial activity in winter.

Tab. 3: pH and DOC Distribution for Samples Sorted by Season

	pH	DOC	HA	HPOA	HPIA	HPON	HPIN
Spring (Mar-Apr-May; n=16)							
Mean	4.44	21.7	3.00	6.75	1.63	4.54	4.87
S.D.	0.55	5.70	2.24	2.09	1.38	3.00	2.52
Frac-C (% of DOC)			13.8	31.1	7.51	20.9	22.4
Summer (Jun-Jul-Aug; n=34)							
Mean	4.39	40.7	5.61	14.2	5.39	5.78	7.62
S.D.	0.61	11.8	5.07	5.78	3.79	4.89	4.26
Frac-C (% of DOC)			13.8	34.9	13.2	14.2	18.7
Autumn (Sep-Oct-Nov; n=20)							
Mean	4.53	34.6	6.48	12.2	4.19	6.48	4.79
S.D.	0.70	11.8	5.61	5.28	3.23	3.83	1.97
Frac-C (% of DOC)			18.7	35.3	12.1	18.7	13.8
Winter (Dec-Jan-Feb; n=15)							
Mean	4.31	26.2	4.70	8.44	2.95	5.90	3.02
S.D.	0.41	8.15	5.94	2.88	3.29	2.32	1.75
Frac-C (% of DOC)			17.9	32.2	11.2	22.5	11.5

EFFECT OF AMENDED DRAINAGE

The impact of amended drainage is best illustrated by the Sept-Iles data shown in Tab. 4. On average about 30% more DOC is released by amended drainage than occurs in undisturbed systems. The absolute average concentrations of all DOM fractions also increases for amended drainage but the relative proportions show mixed results. Ditching of a bog to increase drainage requires about two metres of excavation. The pattern of increased DOC for the lower pore water in Sept-Iles would likely be the same as that for the Barrington samples which gave rise to the BLP data in Tab. 2, but of a smaller magnitude as shown in Tab. 4. Thus the amended drainage represents a mixture of both the BUP and BLP types of samples similar to those which appear in Tab. 2.

Differences occurring in the chemical character of the amended drainage can be seen in the average relative proportions of the DOM fractions (Tab. 4). HA and HPPIA show slightly increased proportions, not enough to change the acidic nature of the DOM, and are probably compensated by the decrease in HPOA relative proportion. As the acidic fractions contain the majority of the functionalities which can complex metals, then the relative capacity for metal complexation is likely not changed by the amended drainage. However the absolute capacity of drainage water to complex metals and provide organic acidity is concentration dependent, and will increase by roughly 30%. The impact of this will depend upon the properties of the receiving waters. Increased complexation may sequester metals which are micronutrients, but may have a beneficial impact upon environments where toxic metals are a problem.

Tab. 4: Selected Comparisons of Mean Fraction Concentration and DOC Distribution

		DOC	HA	HPOA	HPPIA	HPON	HPIN
Sept-Iles (n=6) Undisturbed	Mean	21.98	2.71	7.69	1.65	5.34	3.21
	Frac-C (%)		12.34	35.00	7.50	24.31	14.63
Sept-Iles (n=11) Amended	Mean	29.04	3.92	8.43	2.83	6.49	6.62
	Frac-C (%)		13.49	29.02	9.74	22.36	22.80
Barrington (n=15) Nat. Drn. JC2	Mean	37.79	7.20	13.80	4.45	6.23	5.02
	Frac-C (%)		19.05	36.53	11.78	16.49	13.27
Barrington (n=15) Clyde R. (CLY)	Mean	26.09	4.99	9.13	3.00	4.43	3.48
	Frac-C (%)		19.11	35.01	11.49	16.97	13.33

The HPON relative proportion is also not significantly altered by the drainage, but the HPIN fraction is considerably increased both in absolute concentration and relative proportion. Lower molecular weight carbohydrates (sugars and starches) are included in the HPIN fraction. These materials may be increased in amended drainage because of oxidative degradation of larger polymeric carbohydrates which could occur upon ditching. This hypothesis is supported by the increase in HPIA, which could also be produced by oxidation. The most important potential impact of the HPIN increase, which amounts to about half of the DOC increase, may be an increase in biochemical oxygen demand of amended drainage water relative to undisturbed drainage. Given the labile nature of the HPIN, such an impact would be significant if the amended drainage travelled only a short distance to a receiving lake or river. If the distance is great or the receiving water has a large capacity, the impact would be reduced in severity.

POTENTIAL INFLUENCE OF BARRINGTON BOG DRAINAGE ON THE CLYDE RIVER

The average character of DOM from site JC2, which is at the upper end of Judas Ck. near the edge of the bog, shows a remarkable similarity with that from the Clyde R. near its mouth but upstream from the mouth of Judas Ck. (Tab. 4). The average relative proportions of all five DOM fractions are nearly identical for both of these sites. From the DOC data it appears that the CLY samples are on average a 30% dilution of the JC2 samples. The samples from which the averages were computed are 15 paired samples taken over a 21 month sampling period. Correlation coefficients for the DOM fractions of the paired analyses are ranked in Tab. 5. The best correlation is with DOC which represents an integration of all chemical structures and the HPOA correlation is also strong because it is the most significant fraction and shows little seasonal variation (see Tab. 3). The remaining fractions show lesser correlations and also show more seasonal variations.

As a first approximation the impact of Judas Ck. upon the Clyde R. is simply a matter of dilution, the relative discharges of these two streams being the most important consideration. The Clyde R. is very much larger than Judas Ck. To discuss further applications requires that the probable change in character of DOM in drainage water

be estimated by comparing the various water types. Amended drainage at Barrington Bog would add DOM with character such as BLP (Tab. 2) to Judas Ck., represented by JC2 (Tab. 4). One would expect increases in DOC, but little change in HA concentrations. HPOA, HPIA, HPON, and HPIN would all be expected to increase in absolute concentration relative to JC2. Since HPOA and HPIA tend to contain a greater number of carboxylic functions per unit of carbon (Bourbonniere, 1986), this may have an impact upon the acidity of Judas Ck., possibly reducing pH, under amended drainage, and could also impact the degree of complexation, and the resulting bioavailability, of metals in the creek. HPON and HPIN may also be increased under an amended drainage regime with the potential effect on biochemical oxygen demand, in the case of HPIN, as suggested before for the Sept-Iles sites. Components of the HPON fraction are relatively unreactive and are probably of less concern.

Tab. 5: Ranked Paired Correlation Coefficients for JC2 and CLY Samples (n=15)

Fraction	Corr. Coeff.
DOC	0.866
HPOA	0.712
HA	0.604
HPIA	0.447
HPIB	0.398
HPIN	0.296
HPOB	0.204
HPON	0.173

CONCLUDING REMARKS

The character of DOM in bog, ditch, creek, and river water in the areas studied varies with sample type and with seasons. These variations, combined with knowledge of the chemistry involved in the fractionation procedure, indicate the composition, origin, and fate of the DOM fractions studied. HA, HPOA, and HPON are more related to diagenetic processes such as polycondensation. HPIA and HPIN are "close" to their biochemical sources.

The main effect of DOM increases in amended drainage at Sept-Iles would be an increase in biochemical oxygen demand. This is expected because of the increase in HPIN concentration of the amended drainage waters.

In the Barrington case, the DOM from natural bog drainage resembles in character that from the Clyde R. If probable changes in drainage water properties can be estimated using the character of DOM from deeper pore water, the impact of amended drainage there might be to decrease the pH, increase the metal complexation capacity, and increase the biochemical oxygen demand.

In both cases the severity of the impact would depend upon the distance which the amended bog drainage must travel to reach the receiving waters, and the capacity of those waters to dilute the increased loads. For the Barrington case the Clyde R. is very much larger than Judas Ck.

REFERENCES

Auclair, A.N.D., A. Bouchard and J. Pajaczkowski. 1976. Plant Standing Crop and Productivity Relations in a Scirpus-Equisetum Wetland. *Ecology* 57: 941-952.

Bartsch, I. and T.R. Moore. 1985. A Preliminary Investigation of Primary Production and Decomposition in Four Peatlands Near Schefferville, Quebec. *Can. J. Bot.* 63: 1241-1248.

Bourbonniere, R.A. 1986. Characterization of Dissolved Organic Matter in Kejikujik Waters. *In: Proceedings Kejikujik Calibrated Catches Program, LRTAP Workshop, J.J. Kerekes, editor. Environment Canada, 6 pp.*

Bourbonniere, R.A., M. Richmond, B.L. VanSickle and W.A. Glooschenko. 1987. Impact of Amended Bog Drainage on the Character of Dissolved Organic Matter: A Preliminary Study. *Environment Canada, NWRI Report, in prep.*

Glooschenko, W.A., R.A. Bourbonniere and W. Shotyk. 1985. Environmental Impact of Peat Harvesting and Combustion upon Aquatic Ecosystems - A Review. *In: Symposium 85: Technical and Scientific Conference on Peat and Peatlands, Riviere-du-Loup, Que., Part 1, pp. 70-90.*

Leenheer, J.A. 1981. Comprehensive Approach to Preparative Isolation and Fractionation of Dissolved Organic Carbon from Natural Waters and Wastewaters. *Environ. Sci. Technol.* 15: 578-587.

Leenheer, J.A. 1985. Fractionation Techniques for Aquatic Humic Substances. *In: Humic Substances in Soil, Sediment, and Water, G.R. Aiken, D.M. McKnight, R.L. Wershaw and P. MacCarthy, editors. John Wiley & Sons, New York. pp. 409-429.*

Mathur, S.P. and R.S. Farnham. 1985. Geochemistry of Humic Substances in Natural and Cultivated Peatlands. *In: Humic Substances in Soil, Sediment, and Water, G.R. Aiken, D.M. McKnight, R.L. Wershaw and P. MacCarthy, editors. John Wiley & Sons, New York. pp. 53-85.*

Richmond, M. and R.A. Bourbonniere. 1987. Manual for the Fractionation of Dissolved Organic Matter in Natural Waters. *Environment Canada, NWRI Report, in prep.*

Shotyk, W. 1986. Geochemistry of Metal-Organic Complexes in Naturally-Acidic Waters from Peatlands. *NRC Peat Energy Series, NRCC No. 27414, 52 pp.*

Stevenson, F.J. 1982. *Humus Chemistry. John Wiley & Sons, New York. 443 pp.*

Thurman, E.M. 1985. *Organic Geochemistry of Natural Waters. Martinus Nijhoff / Dr. W. Junk, Dordrecht. 497 pp.*

ACKNOWLEDGEMENTS

The assistance of M. Richmond, B. VanSickle, D. Piche, L. Bisutti, K. Lawrynuik, R. Tordon, S. Mazzei, E. Tozer, L. Parent, S. Smith, and L. Holloway with field and laboratory work is very much appreciated. This work was supported by the Federal Panel on Energy R&D (PERD).