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PERFORMANCE OF A PILOT SCALE WETLAND FOR NITROGEN REMOVAL FROM COAL MINE DRAINAGE

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ABSTRACT

Nitrate releases from blasting residues at open pit coal mines can be an environmental concern because of potential eutrophication of receiving waters. Cost effective methods have not yet been identified to remove nitrate from large discharges such as occur at surface mines. Earlier studies in Canada and elsewhere have shown that wetlands may be a low-cost option for nutrient and metals removal from mine drainage. As a result of these studies, Environment Canada commissioned a 3-year study to investigate treatment efficiency, wastewater effects on vegetation, and wetland maintenance requirements. The selected study site was an operating coal mine on Vancouver Island, British Columbia. Effluent from the mine's settling pond was dosed with KNO_3 to simulate nitrate enrichment.

This paper presents the results of the third year of wetland operation, from December 1989 to March 1991. Mass removal efficiencies of total-N and NO_3-N averaged 96.7 % and 90.2 %, respectively. Peak nitrogen removals occurred during the warm season, although removal in excess of 72 % continued in winter. NH_3-N and NO_2-N often increased through the wetland, although wetland effluent concentrations were within Canadian water quality guidelines. The results support the hypothesis that wetland systems can be effective in mitigating environmental impacts of mining.

Key words: wetlands, nitrogen removal, coal mining, pilot scale, Canada.

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Utilisation de terres humides pour l'élimination de l'azote des écoulements des mines de charbon

par

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Dans les exploitations minières de charbon à ciel ouvert, les écoulements d'azote provenant des résidus de dynamitage représentent un problème sérieux pour l'environnement, car ils peuvent causer l'eutrophisation plans d'eau qui les reçoivent. Aucune technique, ou approche peu dispendieuse, n'a encore pu être identifiée pour l'élimination des nitrates des gros volumes de décharge que produisent les mines de charbon à ciel ouvert. Cependant, plusieurs études, effectuées au Canada et ailleurs, montrent que les terres humides pourraient représenter une solution pour éliminer à peu de frais les substances nutritives et les métaux, des écoulements miniers, pendant l'exploitation minière ainsi qu'après la fermeture de la mine. Pour donner suite à ces études, Environnement Canada *a* commandé une étude-pilote de trois ans sur les terres humides visant à étudier l'efficacité de l'élimination des éléments nutritifs, l'influence des caractéristiques des eaux usées sur la survie et la croissance de la végétation, ainsi que les besoins requis pour le maintien de terres humides. Une mine de charbon située sur l'île de Vancouver en Colombie-Britannique fut choisie comme site pour l'étude. L'effluent, provenant du bassin de sédimentation de la mine, fut dosé au moyen d'une solution de KNO_3 afin de stimuler l'enrichissement en nitrates des résidus de dynamitage.

Cette communication présente les résultats des deux premières années de l'étude, d'août 1988 à septembre 1990. La végétation a connu une croissance spectaculaire sous l'influence de concentrations en nitrates de 118 mg/1, présentes dans l'effluent. L'efficacité de l'élimination d'azote total et d'azote sous forme de NO_3 ont respectivement été de 90% et de 97%. Les éliminations d'azote les plus élevées se sont produites durant la saison chaude, se poursuivant l'hiver, avant et après le gel. Le NH_3-N et le NO_2-N ont eu tendance à augmenter dans les terres humides même si les niveaux présents dans l'effluent final n'ont pas causé d'inquiétudes. Les résultats supportent l'hypothèse que les systèmes de terres humides peuvent être efficaces pour amoindrir l'impact environnemental de l'exploitation minière.

Mots-clés: terres humides, élimination de l'azote, mines de charbon, échelle-pilote.

INTRODUCTION

Nitrogen content of drainage from surface coal mines has been identified as a potentially significant environmental concern. Discharges and seepage from open pits, stockpiles, and waste rock dumps can contain large amounts of nitrate. The main sources of nitrogen are blasting agents such as ammonium nitrate and fuel oil (ANFO) or slurry gel. From 1 to 6 percent of the total nitrogen in such explosives has been shown to enter the receiving environment from operating mines (Pommen 1983; K. Ferguson, pers. comm.). These nutrients can, under certain conditions, potentially degrade water quality and aquatic habitat through eutrophication (Nordin 1982). As a result, regulatory agencies are increasingly requiring additional monitoring and treatment of mine wastewaters at existing mines. Permitting of proposed mines is becoming more difficult for similar reasons. Cost effective methods to remove nitrate from large wastewater streams have not been identified, especially at the scale necessary for a surface mine. There is a need, therefore, to identify and evaluate low cost alternatives to conventional treatment approaches.

Wetlands have been identified as a promising treatment option for a variety of wastewaters, including sewage (Herskowitz et al. 1987; Nichols 1988; Steiner et al. 1987), food processing (Seidel 1976; Anon. 1988; Dawson 1989) and mine drainage (Hedin 1988; Kleinmann and Girts 1987). Following promising results of laboratory studies aimed specifically at nitrate removal (Norecol 1987a, 1987b), Environment Canada commissioned a three-year pilot wetland study to construct and test the treatment efficiency of a field scale wetland at an operating coal mine. This study is also intended to provide information on wetlands operation and maintenance requirements as well as wastewater effects on vegetation survival and growth. Results obtained during Years 1 and 2 have been reported previously (Norecol 1989, 1990; Whitehead et al. 1989a, 1989b). This paper reports the findings of Year 3 of the pilot wetland study, with particular reference to nitrogen removal.

METHODS

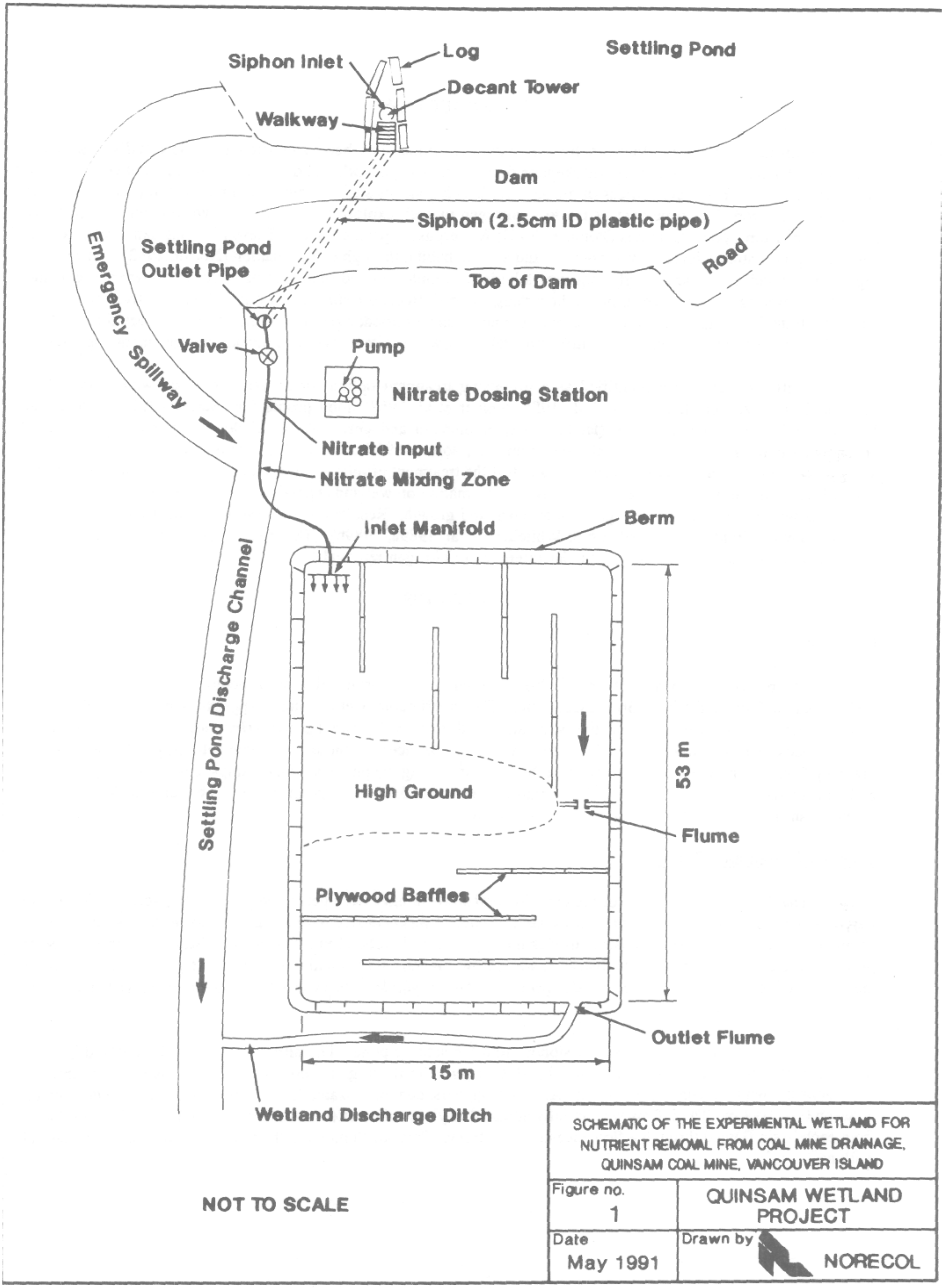
Study Site

The project was located at Brinco Coal Corporation's Quinsam Mine on Vancouver Island, approximately 30 km west of Campbell River, British Columbia. The experimental wetland lies at approximately 290 m above sea level, within a natural wetland. Existing vegetation is dominated by sweetgale *(Myrica gale),* sedges *(Carex* spp.) and hardhack *(Spiraea douglassi).* The natural wetland is adjacent to the mine's main settling pond, that receives drainage from a number of disturbed areas of the mine, including the pit, waste rock dumps, coal processing facilities and haul roads. The natural wetland drains into a tributary of Middle Quinsam Lake. The Quinsam River system supports an important sport fishery and salmon hatchery.

Wetland Design and Operation

The design and operation of the experimental wetland have been described previously (Norecol 1990). An approximately 800 m^2 area of the natural wetland (Figure *1)* was enclosed with a plastic lined earthen berm. A ridge of higher ground within the enclosure divides the experimental wetland into two distinct basins. Baffles made of plywood and earth were installed to distribute water flow. Woody shrubs within the enclosure were cleared to favour the growth of sedges and other non-woody species. Cattail *(Typha latifolia)* was interplanted to increase the diversity of marsh species.

The water supply was piped by siphon from the settling pond. The nitrate content of the wetland influent was increased to nominal 10 to 20 mg/1 by dosing with fertilizer grade potassium nitrate (KNO_3) to simulate conditions known to occur at other mines (K. Ferguson, pers. comm.). Water depth varied with micro-relief, ranging between O and 0.4 m. The inflow was initially adjusted to yield a theoretical retention time of 4 days. The discharge from each basin flowed through a flow measurement flume (Parshall flume) and the final effluent entered the natural wetland.


Siphon Inlet
Log
Settling Pond
Decant Tower
Walkway
Dam
Siphon (2.5cm ID plastic pipe)
Road
Settling Pond
Outlet Pipe
Toe of Dam
Emergency Spillway
Valve
Pump
Nitrate Dosing Station
Nitrate Input
Nitrate Mixing Zone
Inlet Manifold
Berm
Settling Pond Discharge Channel
53 m
High Ground
Flume
Plywood Baffles
Outlet Flume
15 m
Wetland Discharge Ditch
NOT TO SCALE
SCHEMATIC OF THE EXPERIMENTAL WETLAND FOR NUTRIENT REMOVAL FROM COAL MINE DRAINAGE, QUINSAM COAL MINE, VANCOUVER ISLAND
Figure no.
1
QUINSAM WETLAND PROJECT
Date
May 1991
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Sampling and Analyses

Triplicate grab samples of water were collected weekly or biweekly at the inlet of each basin and at the final outlet. The samples were iced and shipped within 24 hours to the laboratory for determination of nitrogen species (NO_3, NO_2, NH_3, Total N), pH, conductivity, and other parameters. Water quality analyses were carried out according to standard methods (A.P.H.A. 1985). Temperature was measured in the field at the time of sampling. Flows were measured at each sampling location. Flows; at the wetland midpoint (outlet of the upper basin) were measured only after June 1990, when a Parshall flume was installed. Precipitation data were obtained from a rain gauge at the minesite.

Calculations

The water balance was calculated from flow measurements and precipitation. Evapotranspiration was estimated using the Thorththwaite equation (Chow 1964, in Mitsch and Gosselink 1986). Exfiltration was estimated by subtraction. Mass loadings were calculated by multiplying average concentrations and cumulative flows over each sampling interval (usually weekly). Mass removal efficiency was estimated over each sampling interval and over the entire reporting period.

RESULTS

Hydrology

The wetland hydrology is summarized in Table 1. Inflow averaged 14.6 m^3/d, but was variable due to changes in hydraulic head as a result of varying water levels in the settling pond. Precipitation ranged from 10 mm/mo in August to 336 mm/mo in November. Outflows; from both basins during dry weather were significantly less than inflows. During rainy weather, outflows approximated the piped inflows, reflecting precipitation inputs. During the spring thaw, outflows exceeded inflows by up to 212%, as snow and ice accumulated in the wetland melted. Water losses to evapotranspiration ranged from an estimated 6 tu 85 mm/mo ("average 49 mm/mo), which represented 0.02% to 0.21% (average 0.11%) of the piped inflow. Exfiltration through the wetland soi! and berm accounted for an average of 24.3% of the inflows.

Water Quality

Table 2 summarizes the changes in water quality through the wetland. The pH decreased slightly through the wetland, from an average of 7.7 in the influent to 7.5 and 7.4 in the upper and lower basin effluents, respectively. The decline in pH probably reflects acidification by organic acids released from decaying organic matter in the wetland sediments. Suspended solids (TSS) tended to increase through the upper basin from an average of 9 mg/1 to 13 mg/1, and decreased to 7 mg/1 in the lower effluent. The higher average TSS values in the upper basin effluent probably reflects sediment re-suspension during sampling in the shallow outlet channel. Conductivity declined through the wetland, from an average of 1601 umhos/cm in the influent, to 1471 umhos/cm and 1346 umhos/cm in the upper and lower basin effluents, respectively.

Average total nitrogen (TN) concentrations declined from 16.4 mg/1 in the influent (dominated by NO_3), to 5.3 mg/1 in the midpoint (dominated by NO_3 and organic-N) and to 2.9 mg/1 in the effluent (dominated by NO_3 and organic-N). Influent TN and NO_3 concentrations were usually between 12 and 16 mg/1; however, higher and lower values occurred occasionally due to dosing problems, as reflected in the high standard deviation values shown in Table 2. Nitrate exhibited marked decreases from an average of 14.8 mg/1 in the influent (90% of TN), to 5.0 mg/1 (94% of TN) and 2.6 mg/1 (90% of TN) at the outlets of the upper and lower basins, respectively. Removal of total ammonia (NH_3-N) occurred primarily in the upper basin; NH_3-N declined in the upper basin from 0.155 mg/1 to 0.097 mg/1, and to 0.095 mg/1 in the lower basin. Nitrite-N declined from an average of 0.025 mg/1 in the influent

TABLE 1

MONTHLY WATER BALANCE FOR THE EXPERIMENTAL WETLAND AT QUINSAM MINE, CAMPBELL RIVER, B.C. (DECEMBER 1989-MARCH 1991)

MONTH	INFLOW m^3/d	PRECIPITATION		EVAPOTRANSPIRATION[a]		EXFILTRATION[b]		OUTFLOW	
		mm	%[c]	mm	%	m^3/d	%	m^3/d	%
January	9.1	114	0.4	6	0.02	2.1	23.5	7.0	76.9
February[d]	15.9	172	0.4	24	0.005	12.1	76.4	3.8	23.9
March[e]	17.6	41	0.1	31	0.06	-19.7	-112.0	37.3	212.0
April[e]	18.0	51	0.1	47	0.09	7.6	42.4	10.4	57.6
May	16.4	67	0.1	63	0.12	8.3	50.6	8.1	49.4
June[f]	15.3	86	0.2	75	0.16	-2.8	-18.6	18.1	118.6
July	13.0	11	<0.05	85	0.21	7.3	56.1	5.7	43.7
August	15.1	10	<0.05	84	0.18	10.1	66.5	5.0	33.3
September	15.2	23	0.1	71	0.16	6.1	40.4	9.1	59.5
October	18.5	201	0.3	51	0.09	7.2	38.7	11.4	61.6
November	11.5	335	1.0	31	0.09	-	-	-[g]	-
December	9.7	103	0.3	17	0.06	2.7	27.7	7.1	72.6
Average	14.6	101	0.3	49	0.11	3.7	24.3	11.2	73.5

[a] Potential evapotranspiration estimated using the Thornthwaite method (see text).
[b] Exfiltration calculated by subtraction.
[c] Values represent percent of inflow.
[d] Freezing conditions; inflow and precipitation accumulated in wetland as ice and snow.
[e] Spring freshet: melt-down of ice and snow accumulated in wetland.
[f] Difficulties measuring outflow due to high water levels outside of experimental wetland.
[g] Outflow not measured.

TABLE 2

AVERAGE CONCENTRATIONS ± STANDARD DEVIATION OF WATER QUALITY PARAMETERS IN THE INFLUENT AND EFFLUENTS OF THE TWO EXPERIMENTAL WETLAND BASINS AT QUINSAM MINE BETWEEN NOVEMBER 20, 1989 AND MARCH 31, 1991[a]

PARAMETER	UNITS	INFLUENT	UPPER BASIN EFFLUENT	LOWER BASIN EFFLUENT
pH	-	7.7±0.4 (n=135)[b]	7.5±0.4 (n=135)	7.4±0.4 (n=133)
Suspended Solids	mg/l	9±9 (n=133)	13±24 (n=133)	7±2 (n=132)
Conductivity	μmhos/cm	1601±638 (n=135)	1471±612 (n=135)	1346±603 (n=135)
NO_3-N	mg/l	14.806 ± 10.896 (n=138)	5.000 ± 4.047 (n=138)	2.613 ± 3.490 (n=137)
NO_2-N	mg/l	0.025 ± 0.024 (n=138)	0.017 ± 0.015 (n=138)	0.020 ± 0.022 (n=138)
NH_3-N	mg/l	0.155 ± 0.127 (n=135)	0.097 ± 0.098 (n=135)	0.093 ± 0.112 (n=135)
Organic-N[c]	mg/l	1.394	0.232	0.168
Total N	mg/l	16.380 ± 12.964 (n=135)	5.346 ± 3.778 (n=135)	2.894 ± 3.291 (n=135)

a Upper basin effluent is lower basin influent.
b n = number of samples
c Calculated as Total-N minus (NO_3-N + NO_2-N + NH_3-N).

to 0.017 mg/1 at the outlet of the upper basin outlet, and increased to 0.020 mg/1 at the outlet of the lower basin. Organic nitrogen decreased through the wetland, from an average of 1.39 mg/1 in the influent to 0.232 mg/1 and 0.168 mg/1 in the upper and lower basin effluents, respectively.

Nitrogen Mass Removal

Table 3 and Figure 2 show the N mass removals over the November 1898 to March 1991 sampling period. Approximately 75.2 kg of the estimated 76.3 kg of total nitrogen added to the wetland (both basins) were removed from the wastewater. This represents a net total nitrogen removal efficiency of 98.6%, at an average removal rate of 1.9 kg/ha/d. Highest removal efficiencies were obtained in summer, although removal remained high throughout the year. Seasonal nitrogen removals ranged from an average of 94.5 % and 2.3 kg/ha/d in winter (December through March), to 95.7 % and 2.4 kg/ha/d in spring (April through June), 99.6 % and 2.6 kg/ha/d in summer (July through September), and 96.8 % and 5.9 kg/ha/d in fall (October 1990 data only available). Negative removal efficiencies shown for NH_3-N and NO_2-N in Table 3 indicate export of these compounds from the wetland, especially in January and September. The corresponding concentrations, however, were below the guidelines for protection of aquatic life (Canadian Council of Resource and Environment Ministers 1987).

DISCUSSION

Water loss through leaking berms is a recognized problem with constructed wetlands (Kadlec 1983), which causes some difficulty in estimating the significance of the various mineral removal pathways in a wetland ecosystem. It is likely, however, that nitrate lost from the experimental system through the berms is subject to denitrification in the soil pore space, since the necessary conditions for denitrification are probably present (Engler et al. 1976). As part of the present project, measurement of vegetation biomass production and tissue mineral content is being undertaken to assess the relative importance of the macrophyte and microbial pathways of nitrogen removal.

The available data show that significant amounts of nitrogen can be removed in a wetland system through the growing season, including periods of intermittent freezing weather. Inhibition of N removal (especially denitrification) by low temperatures during winter at Quinsam mine appears to occur only during prolonged freezing weather.

The results from the third year of operation are consistent with results obtained during the first two years of the experimental program (Table 4) (Whitehead et al. 1989b). Monthly N removal efficiencies in 1988 generally followed the seasonal pattern expected from the temperature dependence of plant uptake and denitrification, which are the main N removal processes in wetlands (Reed et al. 1988). During 1989 through 1991, the results were more variable, and the temperature effect, while present, appears to have been moderated by variations in water supply, influent nitrate concentrations, wetland ageing, and possibly other factors.

CONCLUSIONS

The following conclusions can be made from the results obtained to date:

1. A modified natural wetland system can remove an average of 87 to 97 percent per annum of the total N mass added via simulated surface coal mine drainage water, including 85 to 99 percent during winter in coastal British Columbia.

2. Nitrate removal rates of 1.2 to 5.3 kgN/ha/d can be sustained over at least three years, including 1.2 to 2.8 kg N/ha/d during cold weather (November to April).

3. Ammonia and nitrite can be released from the wetland receiving elevated nitrate concentrations. However, the low concentrations of ammonia and nitrate released pose no threat to the receiving environment.

TABLE 3

NITROGEN MASS REMOVAL EFFICIENCES AND MASS REMOVAL RATES IN THE EXPERIMENTAL WETLAND AT QUINSAM MINE, CAMPBELL RIVER, B.C. (DECEMBER 1989-MARCH 1991)

MONTH	NITRATE-N		AMMONIA-N[a]		TOTAL-N		NITRITE-N	
	%	$g/m^2/d$	%	$mg/m^2/d$	%	$g/m^2/d$	%	$mg/m^2/d$
December 1989	89.4	0.393	-35.0	-0.448	93.8	0.233	-54.3	-0.291
January 1990	76.9	0.179	-338.7	-1.40	96.8	0.316	-288.3	-0.141
February	84.7	0.306	-11.7	-0.036	85.0	0.153	-135.3	-0.082
March	97.1	0.145	34.7	1.71	99.5	0.286	50.7	0.230
April	99.5	0.359	35.5	0.411	99.6	0.354	86.2	0.616
May	95.3	0.385	26.5	0.174	97.7	0.270	94.8	0.350
June	67.6	0.089	-53.1	0.222	89.7	0.108	20.5	0.476
July	100	0.151	97.0	4.04	99.5	0.225	96.4	0.582
August	100	0.251	96.8	5.11	99.8	0.282	84.6	0.091
September	98.4	0.197	41.2	0.822	99.5	0.276	-458.3	-0.256
October	78.4	0.530	91.9	7.12	96.8	0.591	74.4	0.990
November	-[b]	-	-	-	-	-	-	-
December	-	-	-	-	-	-	-	-
January 1991	-	-	-	-	-	-	-	-
February	80.0	0.208	63.5	5.39	97.0	0.218	14.8	0.319
March	72.4	0.282	74.2	3.37	94.7	0.143	-215.9	-0.664
Period Average	90.2	0.261	14.3	2.07	96.7	0.283	-48.8	0.229

[a] Total ammonia-N: (NH_4^+-N plus NH_3-N).
[b] No data obtained.

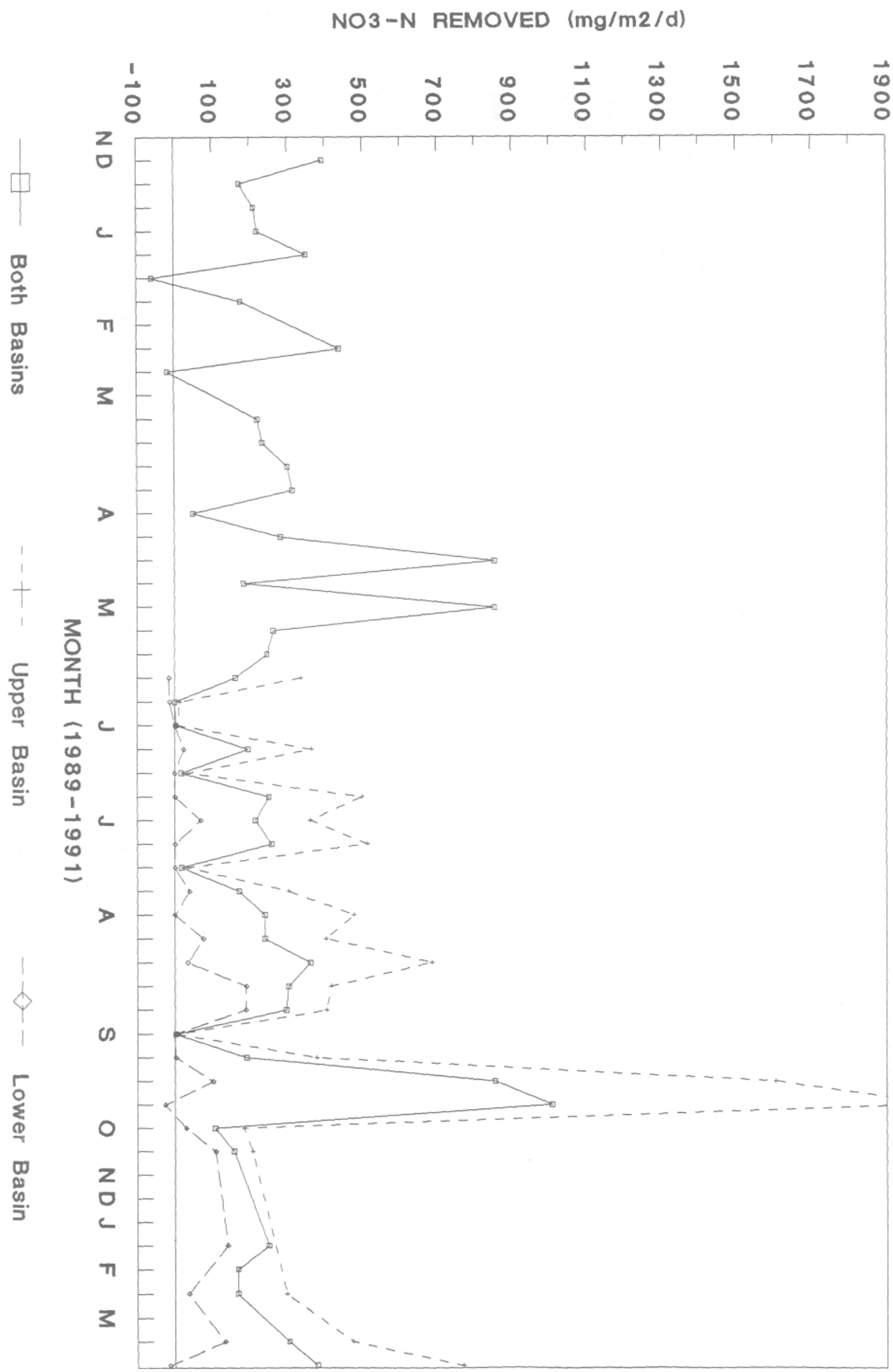

FIGURE 2. NITRATE MASS REMOVAL IN THE EXPERIMENTAL WETLAND AT QUINSAM MINE

TABLE 4

MONTHLY AVERAGE MASS AND PERCENT REMOVALS OF TOTAL NITROGEN, NITRATE, AMMONIA AND NITRITE EXPERIMENTAL WETLAND AT QUINSAM COAL MINE BETWEEN AUGUST 1988 AND JULY 1989

DATE	WEEKS SAMPLED	TOTAL-N		NO_3-N		NH_3-N[a]		NO_2-N	
		$g/m^2/d$	%	$g/m^2/d$	%	$g/m^2/d$	%[b]	$g/m^2/d$	%[b]
1988									
August	2	0.235	88.0	0.251	99.8	-0.017	-	0.001	-
September	4	0.190	84.1	0.208	99.6	-0.017	-	0.001	-
October	4	0.338	87.5	0.349	98.0	-0.014	-	0.054	-
November	2	0.157	84.3	0.158	95.3	-0.010	-	0.137	-
December	1	0.032	87.4	0.032	95.1	-0.006	-	0.007	-
Period 1 Average		0.190	86.3	0.200	97.5	-0.013	-	0.040	-
1989									
March	2	0.280	97.5	0.279	99.4	<-0.001	-	<0.001	-
April	4	0.131	75.6	0.123	74.2	<-0.001	-	<0.001	-
May	5	0.211	81.3	0.256	99.1	<-0.001	-	<0.001	-
June	4	1.072	96.8	0.944	100.0	-0.008	-	<0.001	-
July	5	0.324	90.3	0.304	96.3	-0.004	-	<0.001	-
Period 2 Average		0.404	88.3	0.381	93.8	-0.003	-	<0.001	-
Overall Average		0.297	87.3	0.290	95.7	-0.008	-	0.020	-

a Total ammonia (NH_3-N + NH_4-N); negative values indicate export.

b Percent removals not shown for ammonia and nitrite due to negative or very low mass removal rates.

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