THE EFFECT ON WATER QUALITY OF
EXPLOSIVES USE IN SURFACE MINING

VOLUME 3:   NITROGEN RELEASE FROM COAL AND
MINE WASTE

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ABSTRACT

Spoil and coal samples were collected at the Fording Coal Limited minesite near Elkford, British Columbia. The samples were analysed for their physical (particle size distribution) and chemical (carbon, NO_3-N, NO_2-N, and NH_4-N) characteristics. The high proportion of coarse material (>= 2mm in size) suggests spoil piles to be highly permeable. The high inorganic nitrogen, $(NO_2+NO_3+NH_4)$-N, content of the spoil was attributed to explosives used at the minesite to blast overburden. Nitrogen losses from loading wet holes with slurry explosives and 'Other Sources' (e.g., nitrogen oxides, spillage etc.) collectively, were recognized to be the major contributors to spoil nitrogen. Waste coal was a minor source of nitrogen.

Leaching of inorganic nitrogen due to explosives was modelled, based on spoil nitrogen content and water flow characteristics of the spoil. The flow rates through spoil piles were determined from measurements of streamflow rates and area of watershed above the point of discharge measurement. High flow conditions were conducive to high nitrogen leaching rates. The impact of spoil nitrogen, due to explosives, on the Fording River water quality was predicted to be short lived, following the cessation of mining. Recommendations are made to reduce the impact of explosives nitrogen on water quality.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

(v)

INTRODUCTION

Large quantities of nitrogen-based explosives are used in surface mining. For instance, Urso (1980) estimated that an average blast at the Fording Coal operations in the East Kootenays involved about 362 900 kg of explosives to break 420 500 bm^3 (bank cubic metres) of overburden material. Most of the nitrogen in explosives is believed to be lost to the atmosphere in gaseous form following the blast (SME Handbook, 1973). Although small in quantity, the residual nitrogen in the spoil is subject to leaching and may pollute surface and ground water (Rudd, 1978).

An increase in ammonium (NH_4-N), nitrite (NO_2-N), and nitrate (NO_3-N) nitrogen was observed in the Fording River, and was believed to be a result of explosives used at the Fording Coal Ltd. surface coal mine. Maximum NO_3-N and NH_4-N concentrations of 10.8 and 0.12 mg/L respectively, were recorded in the river at the minesite during low flows, as opposed to the concentrations of 0.05 and 0.01 mg/L upstream from the minesite (Kootenay Air and Water Quality Study, Phase II, 1978). Elevated nitrate concentrations in coal mine spoil drainage from the use of ammonium nitrate explosives were also observed elsewhere (Hackbarth, 1979; and Van Voast, 1974).

Surface mining activities are on the increase throughout the province of British Columbia. A study was therefore initiated to determine the impact of explosives-associated nitrogen on water quality. The Fording Coal Ltd. surface coal minesite was chosen for the study because of observed high nitrogen concentration in the Fording River (Kootenay Air and Water Quality Study, Phase II, 1978). Several aspects of the impact of explosives were investigated. These included identification and quantification of various sources of nitrogen at the minesite, and their effect on water quality and algal productivity; and prediction and mitigation of impacts. The results of these investigations will be discussed in two separate reports:
   Volume 1: Nitrogen Sources, Water Quality, and Prediction and Management of Impacts by L.W. Pommen (1982).
   Volume 2: Effects on Algal growth by R.N. Nordin (1982).

The objectives of this portion of the study were to determine (i) nitrogen content of the coal and spoil at the Fording Coal Ltd. minesite, and (ii) leaching characteristics of spoil nitrogen in response to precipitation under laboratory conditions. Attempts were also made to model in situ leaching of spoil nitrogen, based on spoil characteristics and the hydrology of the area. Several advantages of this approach were recognized; (i) the parameters used in the model are easily measurable in the laboratory (i.e. spoil nitrogen content), (ii) streamflow data are often available from the Water Survey of Canada, and (iii) the model can be applied to other mine sites.

STUDY AREA

The Fording Coal Ltd. (FCL) mining operation is located in southeastern British Columbia, approximately 29 km north of Elkford, at the headwaters of the Fording River. The actual mining area is situated on both sides of the river valley at elevations ranging from 1700 to 2200 metres. Currently, all coal is produced by surface mining. A plan view of the minesite is shown in Figure 1.

Nitrogen-based explosives (ammonium nitrate, sodium nitrate, calcium nitrate) are used at the minesite to blast the overburden, which consists predominantly of siltstones, sandstones, mudstones, and shales. An ammonium nitrate-fuel oil mixture (AN/FO) is used at drier sites, whereas water-resistant slurry explosives are used in water-bearing rock formations. Urso (1980) estimated that an average blast would involve the use of 362 900 kg of explosives to break 420 500 bm^3, at a powder factor of about 0.86 kg/bm^3. Also, the overall average raw coal stripping ratio (bm^3 of overburden/bm^3 of raw coal) during the mining operation was estimated to be 5.52:1. The actual powder factor and stripping ratio at the time of sampling was determined by the FCL personnel to be 0.8 and and 5.7:1 respectively. The nitrogen content of explosives used ranged from 0.14 to 0.25, with an average value of 0.2 kg N/bm^3.

The mean annual precipitation at the minesite, based on ten years of data, is 713.5 mm. Nearly one half of this precipitation falls as snow during the winter months. The mean monthly temperature ranges from -11.5°C in January to over 20°C in August. A summary of the climate data is shown in Figure 2.

The mining area is drained by a number of creeks, which are tributaries of the Fording River. The Water Survey of Canada has established a gauging station (08NK021) below Clode Creek to monitor river flow. The station receives flow from both disturbed (mined) and undisturbed areas of the watershed. The monthly averages of the streamflow below Clode Creek are indicated in Table 5.

MATERIALS AND METHODS

Spoil Sampling and Analysis

The explosives-based nitrogen that is not lost to the atmosphere at the time of blasting, or to groundwater by dissolution, must become a part of the spoil. Spoil samples were collected to determine their nitrogen content due to explosives used at the minesite.

Thirteen surface spoil samples (0 to 15 cm deep) were collected at random locations at the minesite (Figure 1). Most of the samples were gathered from side slopes of spoil piles, where they were loose, undisturbed, and easily accessible from the haul roads. One of the samples (#12) was obtained from a recently exposed pit floor. The samples were stored in plastic bags and shipped to the laboratory for analysis.

The spoil was analysed for particle size distribution by dry sieving and the hydrometer method (Day, 1965), total carbon by dry combustion (Allison et al., 1965), total and ammonium nitrogen by the Kjeldahl method using an auto analyser (Bremner, 1965a, b), and nitrate nitrogen by the colorimetric method (Bremner, 1965b). Chemical and hydrometer analyses were carried out on the less than 2 mm size fraction.

The readily soluble inorganic nitrogen in the spoil, $(NH_4 + NO_3 + NO_2)-N$, was also determined by a dissolution method using bulk samples. The method involved saturating a known amount of spoil with water for a period of 24 hours. The sample was contained in a column constructed from PVC pipe 30 cm long and 20 cm in diameter. At the end of the soaking period, the water was

allowed to drain through perforated acrylic tubing (or drain pipe) fitted at the bottom of the column. The leachate was collected and its volume and inorganic nitrogen content were measured (McQuaker, 1976). The water used in the dissolution column was also analysed for nitrogen content and a correction was applied to the leachate concentration. The process was repeated several times, to extract all of the soluble nitrogen. The cumulative volume and nitrogen concentration (corrected) of the leachate were plotted on a linear scale to calculate spoil inorganic nitrogen content.

Coal Sampling and Analysis

During field investigations, Pommen (1982) found that an artesian well, located upstream from the minesite, had a much higher inorganic nitrogen concentration (about 4.0 mg/L of mostly NH_4-N) than upstream Fording River water. The source of this nitrogen was believed to be the coal seams intersected by the well which may release nitrogen to groundwater. Also, a certain amount of waste coal is mixed with the spoil, which may contribute to spoil nitrogen content. Coal samples were thus collected and analysed to determine their nitrogen content.

Coal samples, that were not contaminated with explosives, were obtained from diamond drill core samples with the help of Fording Coal Ltd. personnel. These samples were analysed for inorganic nitrogen released in an oxygen deficient atmosphere for two reasons; (i) anaerobic conditions are most likely predominant in water-bearing coal seams, and (ii) mineralization of nitrogen in high C/N materials is much greater under anaerobic conditions than under aerobic conditions (Cameron and Posner, 1979). The oxygen deficient condition, therefore, allowed study of the most pronounced case of nitrogen release. The core samples were ground to pass through a 2 mm sieve, and 125 g of each sample was added to a 250 ml plastic bottle half full of water. The mixture was shaken vigorously to eliminate any trapped air, topped with water, and capped tightly. The amount of water added to the sample was noted (the ratio of water to coal, by weight, ranged from about 1.4:1 to 1.5:1). The coal-water mixture was kept at room temperature ($\approx 25°C$) and shaken occasionally. Six bottles were prepared for each coal sample. At the end of each of one, two, three, four, six

and eight weeks of reaction time, water was decanted off the top of one of the oal samples and analysed for $(NO_3 + NO_2)$-N and NH_4-N (McQuaker, 1976). The amount of nitrogen released from each sample was computed on the basis of the nitrogen concentration in the decanted water and total volume of water in the mixture. The results were corrected for initial nitrogen concentration in water.

Spoil Nitrogen Leaching Characteristics

Four spoil samples, (#3, 5, 9 and 13) were used to study nitrogen leaching as a function of precipitation rate. These samples were chosen because of their relatively high nitrogen content. Leaching columns were prepared from 10 cm diameter buchner funnels with perforated bottoms. The spoil samples were placed in the columns to heights of about 15 cm. To prevent washout of the finer fraction, the perforated bottom of the funnel was lined with a fine-mesh nylon cloth. A rainfall simulator was used to control the precipitation rate at the spoil surface during leaching. The rainfall simulator consisted of an open top acrylic box, with the bottom plate fitted with a number of syringe needles. The needles were arranged to obtain uniform rainfall distribution at the spoil surface. The precipitation/flow rate was a function of the needle size and water level in the box, which was held constant with a mariotte device during leaching. The leachate at the outflow was collected at certain intervals of time and analysed for inorganic nitrogen content (McQuaker, 1976). A minimum of 80 ml of leachate was collected at each interval. The components of the leaching experiment are shown in Figure 3.

During leaching, inorganic nitrogen present in the spoil, N_{i+1} (mg/100 g) was determined by

$$N_{(i+1)} = N_i - (\frac{VC}{W}) \times 100$$

where N_i (mg/100 g) is the amount of nitrogen present in the spoil at the beginning of the leaching interval i, V (L) and C (mg/L) are the volume and concen-

tration of the leachate collected in the given interval, and W (g) is the over dry weight of the spoil. It is, however, difficult to determine N_i during the process of leaching. The knowledge of initial spoil nitrogen content (N_o, at $i=0$) is, therefore, necessary. The N_o for each leaching run was determined at the end of the experiment by calculating area under the curve of plots between cumulative flow and the leachate nitrogen concentration. For each flow rate condition, the rate of nitrogen loss,

$$100 \left(\frac{VC}{TW}\right)$$

(mg/100 g-h) in any leaching interval of 'T' hours duration, and the spoil nitrogen content at the beginning of the interval was plotted as shown in Figures 4 through 7. These data were then used to draw a relationship between the nitrogen leaching and water flow rates for a spoil of known nitrogen content (Figure 8).

The family of curves shown in Figure 8 was used to predict N leaching from spoil in the field. To achieve this objective, the inorganic nitrogen content and water flow conditions of the spoil pile must be known. The determination of spoil nitrogen content has been explained above. The average monthly flow rate, q (cm/d), through the spoil was computed from the Water Survey of Canada data and is given by

$$q = 8.64 \left(\frac{Q}{A}\right)$$

where Q (m^3/s) is the mean monthly discharge, and A (km^2) is the watershed area above the point of discharge measurement. The factor 8.64 converts flow rate q into units of cm/d.

RESULTS AND DISCUSSION

Physical Characteristics

The results of particle size analyses of the spoil are shown in Table 1. In general, the spoil was coarse and angular in nature. The coarse fraction (>=2 mm diameter in size) constituted a large portion of the spoil samples and ranged from about 48 to 79%.

It should be noted that the actual proportion of the coarse fraction was higher than shown in Table 1, because spoil samples were collected mostly near the top of the spoil pile, and did not include larger cobble/boulder size fragments, which tend to accumulate at the base of the pile during dumping. Also, some large rocks found at the sampling sites were not sampled.

The coarse and angular nature of the spoil suggests low water retention, abundance of large pores, and high water permeability. No attempt was made to measure these properties in the laboratory. It should be recognized that the water flow characteristics of the spoil piles may differ from those inferred from the unconsolidated spoil samples. The compaction caused by the vehicular traffic during the formation of a spoil pile and crusting of the finer fraction (Pedersen et al., 1980) may cause reduction in infiltration and surface ponding. Such situations are also conducive to non-uniform infiltration and surface runoff, the effects of which will be discussed in a later section. Occasional ponding of free water at the surface of a spoil pile was observed during sampling at the mine-site. No attempt was made to quantify surface ponding, because access to spoil piles was restricted.

Chemical Characteristics

A. Diamond Drillhole Coal Samples.

The quantity of nitrogen released (mineralized) from the coal samples is shown in Table 2. The results show that the total inorganic nitrogen released

- 7 -

varied with the sample. The maximum amount was determined to be 0.22 mg/100 g for the DDH-1659-1 sample after a 3-week reaction time, with an overall average value of about 0.10 mg/100 g. The data also show that most of the inorganic nitrogen released was in the form of NH_4-N. This behaviour was expected because the coal-water mixture was kept saturated and devoid of free oxygen at all times during the experiment.

In most cases, the maximum amount of nitrogen was released within the first 3 weeks, beyond which nitrogen mineralization decreased with time (Table 2). These trends are similar to those found by Stanford and Smith (1972), who observed that mineralization rates of nitrogen tended to decrease with time in soils with low N mineralization rates. Reeder and Berg (1977), however, reported that N mineralization in fresh spoil increased with time. It must be emphasized that these studies (Reeder and Berg, 1977; Stanford and Smith, 1972) were conducted under aerobic conditions, and a direct comparison with the results in Table 2 would be questionable.

B. Spoil Samples.

Table 3 shows the results of the chemical analyses for the spoil samples. Both the soil and dissolution analyses indicate that NH_4-N and NO_3-N contents of the spoil samples were highly variable. The average total inorganic nitrogen content of the spoil samples determined with the dissolution technique was about 21.6% higher than that found using the soil analysis technique. It should be noted that in the soil analysis technique (a) NO_2-N content was assumed to be insignificant, (b) spoil particles larger than 4.76 mm were excluded from the analyses, and (c) spoil samples were air dried before chemical analyses were performed. On the other hand, unmodified bulk samples were used to extract soluble inorganic nitrogen content in dissolution analyses. However, a statistical analysis ('t' test for paired plots) indicated that the observed difference between the two means was not significant. The spoil N content in the following discussion is, therefore, an average value based on the two techniques of measurement.

In the spoil, unlike the diamond drill coal samples, NO_3-N constitutes a larger proportion of the inorganic nitrogen content (Table 3). The results in Tables 2 and 3 show that the amount of total inorganic nitrogen recovered from spoil (≈ 0.6 mg/100g) was about six times as large as that released from coal samples (≈ 0.1 mg/100g). The higher nitrogen content of the spoil was attributed to the nitrogen-based explosives used in the mining. It is believed to be true because the bedrock in the mining area has low available nitrogen (NO_3-N) content, ranging from <0.1 to 0.3 mg/100g as in the Line Creek (B.C. Research, 1976) and Sage Creek (B.C. Research, 1979) coal development areas. The Fording Coal, Line Creek, and the Sage Creek areas are similar in their bedrock geology and represent the Kootenay Group (sandstone, siltstone, shale, coal conglomerate) of the Mist Mountain Formation of the Jurassic-Cretaceous period. The fact that (a) nitrogen present in the bedrock is largely in the forms that are not readily available, and (b) high carbon/nitrogen ratios and low microbial activity in spoil make indigenous N mostly unavailable (Reeder and Berg, 1977; Hesman and Temple, 1978), would limit contribution of geologic materials to spoil inorganic nitrogen content. The unconsolidated soil in the area may contain ($NO_3 + NH_4$)-N ranging from 0.4 mg/100 g (8 lb/ac) to 2.4 mg/100 g (48 lb/ac) (Gardiner, 1971). However, the soils in the area form a thin veneer, and their influence on spoil nitrogen content was considered to be minimal. Also, unconsolidated soil material is dumped in the middle of the spoil pile (Lane, 1981), and therefore spoil samples taken were not contaminated by soil (see 'Materials and Methods' section).

It was recognized that explosives could contribute to spoil nitrogen in several ways (Pommen, 1982). First, high levels of inorganic nitrogen were measured in the groundwater from blast holes following injection of slurry-explosives mixture. The slurry explosives are water-resistant and, therefore, commonly used at the Fording Coal mining operation at sites where water is present. Some loss of nitrogen from the slurry explosives to groundwater, however, is inevitable because a short period of time is required for the water-proofing to occur after injection of the slurry into the blast hole. Field observations indi-

cated that some of the nitrogen-enriched groundwater was likely to remain as a part of the spoil material after the blast. Second, detonation of nitrogen-based explosives results in the production of nitrogenous gases, which consist mainly of nitrogen gas (N_2), and relatively small proportions of ammonia (NH_3) and oxides of nitrogen (N_2O, NO, NO_2). Whereas most of the relatively insoluble N_2 is lost to the atmosphere, the more soluble NH_3, N_2O, NO, and NO_2 could become part of the spoil system by dissolution in soil water. Third, incomplete reaction and/or misfiring of explosives during detonation is another probable source of spoil nitrogen. This usually occurs only when dry, hyrophilic AN/FO explosives are used in wet areas. No misfiring was reported by Fording Coal Ltd. when water resistant slurry explosives were used at wet sites. However, there is some evidence that slurry explosives are somewhat susceptible to water attack and that slurry-explosives mixtures immersed in water for one week detonated with reduced velocity (Bauer et al., 1979).

The significance of various sources contributing to spoil N is shown in Table 4. All nitrogen values are expressed in kg N/bm^3 (A multiplication factor of 0.0265 was used to convert mg $N/100g$ to kg N/bm^3). The quantities of nitrogen from slurryhole groundwater and explosives per se were based on data gathered by Pommen (1982), whereas the values for spoil and waste coal are derived from Tables 2 and 3. The total nitrogen from the 'Other Sources' was estimated by subtracting slurryhole nitrogen and readily soluble coal nitrogen from spoil N content. It represents that fraction of spoil nitrogen which could not be accounted for by the measured sources (i.e. 'slurryhole' and waste coal mixed with the spoil). The results clearly indicate that the average spoil nitrogen content was a small proportion ($\approx 8\%$) of that present in the explosives before detonation. For an explosion to be efficient and complete, one would expect that most of the explosive nitrogen, 92% in this case, would be lost to the atmosphere during blasting. The residual explosive nitrogen in spoils, albeit small, has been known to affect surface and groundwater quality (Hackbarth, 1979; Kootenay Air and Water Quality Study, 1978; Pommen, 1982). Note that the nitrogen content of the total spoil will be lower than 8%, since the coarser (cobbles, boulder, etc.) fraction of spoil was disregarded due to difficulty in sampling it, and the coarse fraction would contain less nitrogen.

The dissolved nitrogen in slurryhole groundwater appears to contribute a significant proportion to spoil N content (Table 4). On the average this contribution is about 34%. These calculations assume that (a) chemical analyses represented conditions of a fresh spoil, and (b) no loss of slurryhole nitrogen occurred during blasting. It should be noted that the spoil samples were collected from spoil piles two to eight months old (Table 1) and nitrogen losses from spoil piles due to leaching in situ is a real possibility. Also, the quantity of nitrogen originating from the slurryholes could be higher than indicated in Table 4 (Pommen, 1982). The influence of these factors on spoil N content is difficult to determine at this time due to lack of extensive field data.

Comparison of spoil and coal analyses suggest that pure coal samples had 16% as much inorganic N as spoil. The actual contribution of coal to spoil N will, however, be far less than this value for the following reasons: (i) the proportion of waste coal in spoil samples is expected to be very small. For instance, the volume of extractable raw coal/volume of overburden for the Fording Coal minesite was estimated to be about 0.18. As most of the coal is extracted and shipped away, the waste coal/overburden ratio in the spoil is expected to be much lower than 18% as indicated above. (ii) The nitrogen released from coal was measured under anaerobic and saturated, rather than aerobic and unsaturated, conditions. The anaerobic conditions are conducive to higher nitrogen mineralization from coarse materials with high C/N ratios (Cameron and Posner, 1979) such as coal. The physical characteristics and field observations, however, indicate that the spoil was very coarse (Table 1) and spoil piles to be unsaturated and aerobic, especially near the surface. The actual contribution of spoil nitrogen in Table 4 was calculated to be about 0.1×10^{-3} kg N/bank m^3, assuming waste coal to spoil and extractable coal to overburden ratios of 0.20 and 0.18, respectively. Note that the waste coal/overburden ratio of 0.20 is a conservative estimate and represents the higher end of the scale. The calculations show that nitrogen released from waste coal was less than one percent of the measured spoil N content (Table 4.)

The 'Other Sources' fraction appears to be another major source of spoil nitrogen, which on the average, could contribute up to 65% of spoil N. The

individual sources in this category include (a) nitrogenous gases (mostly NH and oxides of nitrogen) produced during blasting, (b) partial misfiring, (c) spillage during blasthole loading with explosives, etc. In the case of nitrogen oxides (N_2O, NO, and NO_2), a production rate of 0.6 - 2% of the nitrogen content of the explosives was estimated (Pommen, 1982) depending upon the type of explosives used. Assuming that all of the nitrogen from nitrogen oxides produced during a blast was retained by the spoil, these gases could contribute between 8 and 25% to spoil N (Note that most of nitrogen oxides produced during a blast are prone to escape to the atmosphere, unless returned to spoil by precipitation). The remaining 40 to 57% coming from partial misfiring and spillage seems unlikely since no misfiring was reported during blasting, and spillage did not seem to be significant during field observations.

It is apparent from the above discussion that the individual sources of nitrogen are difficult to quantify due to uncertainty in the measurement of these sources (e.g. Slurryhole) and lack of field data. In general, it appears that waste coal in spoil is an insignificant source, whereas slurryhole groundwater and 'Other Sources' collectively are the major contributors to spoil nitrogen.

Leaching and Impact of Spoil N on Water Quality

The leaching of explosives nitrogen in spoil as a function of spoil nitrogen content and precipitation/water flow rate through spoil is shown in Figures 4 through 7. The results show that the rate at which nitrogen was leached increased with spoil nitrogen content and water flow rates. It may be concluded that for a given spoil nitrogen concentration, nitrogen loading to streams and groundwater draining the area will be much greater during high flow conditions. On the other hand, high nitrogen concentration in leachate during low flow rates (not shown) suggest that stream water nitrogen concentration will be higher during low flow conditions. These observations are in agreement with those made in the field (Pommen, 1982).

The in situ leaching of spoil nitrogen from the use of explosives was assessed based on data presented in Figures 4 through 7. The estimates of in situ water

flow through spoil piles was obtained from the river flow data and the area of the watershed above the stream gauging station (see 'Materials and Methods' section). The average monthly flow rates through the spoil, thus calculated, are shown in Table 5. The average spoil nitrogen content, on April 16, was taken to be 0.60 mg/100 g as given in Table 3. Using the above information, a family of curves indicating water flow rate and nitrogen leaching/loading rate for spoil nitrogen content at the beginning of the month (except in April) was drawn as outlined in the 'Materials and Methods' section, and shown in Figure 8. For instance, the curve with 0.60 mg/100 g spoil N represents April conditions, whereas the curve with spoil N equal to 0.51 mg/100 g is for the month of May. The amount of nitrogen leached per month is shown in Table 5.

The results indicate that all the spoil nitrogen would be lost after just over one month of leaching, provided no more nitrogen is added to the system during that period. It should be noted that May and June are high flow months and that nitrogen losses will be maximum during this period. On the other hand, nitrogen added to the spoil during winter months of low flows will be leached out slowly. One may, therefore, safely conclude that spoil nitrogen from explosives would not be expected to remain in the system for more than one year; in other words, the impact of explosives nitrogen from spoils on stream water quality is short lived. High nitrogen losses during high water flow conditions are in general agreement with Pommen (1982) field measurements. However, it must be emphasized that the model calculations were qualitative. The rate at which explosives nitrogen is added to a spoil pile during continual mining operations was not considered because of lack of such data. Also, non-uniform flow conditions in spoil piles, which may occur due to surface compaction by vehicular traffic and surface crusting, were not considered (Pedersen et al., 1980). The latter condition will result in a decrease in the rate at which spoil nitrogen may leach.

CONCLUSIONS AND RECOMMENDATIONS

Spoil at the Fording coal mine was coarse textured and highly permeable. The average inorganic (NO_3 + NH_4) nitrogen content of the spoil (0.6 mg/100g) was much higher than that of uncontaminated coal (0.1 mg/100g) and bedrock (<0.1 to 0.3 mg/100g) in the area. The high spoil nitrogen content was

attributed to explosives used at the mine. The true contribution of explosives t
spoil nitrogen was difficult to assess because (a) the coarse fraction of spoil was
not sampled, and (b) samples were collected from spoil piles which were 2 to 8
months old and subject to nitrogen loss due to leaching. The knowledge of
actual spoil nitrogen contents is essential in determination of nitrogen leaching
rates and its impact on water quality. It is recommended that:

1. *Uncontaminated and freshly blasted spoil be analysed to determine true
   explosives contribution to spoil nitrogen.*

The model used in the report suggested that the inorganic nitrogen in spoil
would be leached out within one year. The model was developed in the laboratory
assuming uniform distribution and flow conditions in spoil piles. Gradual and
prolonged leaching of explosives nitrogen from spoil has been observed at a
minesite elsewhere (Hackbarth, 1979), most probably from non-uniform flow
conditions in spoil resulting from surface ponding (Pedersen et al., 1980). On
site measurements of water distribution, water flow, and accumulation of explo-
sives nitrogen in spoil are essential in determining validity of the model. It is
recommended that:

2. *Laboratory development and study of leaching models be done in conjunc-
   tion with on site monitoring of spoil moisture conditions, e.g. distribution
   and flow, and leaching of explosives nitrogen from spoil.*

The amount of explosives nitrogen leached from spoil was predicted to be at a
maximum at high flow rates and vice versa. Nitrogen loadings in the Fording
River (Pommen, 1982) support this conclusion. Ensuring poor hydraulic contact
of spoil with surrounding areas and slow water movement through spoil will
reduce but prolong the effect of explosives on water quality. It is recommended
that:

3. *Spoil piles be isolated hydrologically by diverting upslope water away from
   them.*

One possible way of reducing flow rate in spoil is to cover the spoil pile, as it is formed, with finer, relatively slowly permeable material (e.g. fine waste coal fraction), followed by surface compaction. The feasibility of such an action would, however, require a study of the cost and ease with which it can be carried out in the field.

REFERENCES

Allison, L.E., W.B. Bollen, and C.D. Moodie. 1965. Total carbon. In C.A. Black (ed.), Methods of Soil Analysis, Part 2. Agronomy 9:1346-1366. Am. Soc. of Agronomy, Madison, Wisconsin.

B.C. Research. 1976. Environmental Study of the Line Creek Project, Stage 2, Volumes I, II, and III.

B.C. Research. 1979. Sage Creek Coal Ltd., Sage Creek Coal, Stage 2. Environmental Assessment, Volumes I, II and III.

Bauer, A., P.N. Calder, W.A. Crosby, and L. Workman. 1979. Drilling and blasting in open pits and quarries. June 4-8, 1979. Donald Gordon Centre, Queens University.

Bremner, J.M. 1965a. Total nitrogen. In C.A. Black (ed.), Methods of Soil Analysis, Part 2. Agronomy 9:1149-1178. Am. Soc. of Agronomy, Madison, Wisconsin.

Bremner, J.M. 1965b. Inorganic forms of nitrogen. In C.A. Black (ed.), Methods of Soil Analysis, Part 2. Agronomy 9:1179-1237. Am. Soc. of Agronomy, Madison, Wisconsin.

Cameron, R.S. and A.M. Posner. 1979. Mineralisable organic nitrogen in soil fractionated according to particle size. J. of Soil Sci. 30:565-577.

Cornwell, S.M. and E.L. Stone. 1968. Availability of nitrogen to plants in acid coal mine spoil. Nature (London) 217:768-769.

Day, P.R. 1965. Particle fractionation and particle-size analysis. p. 545-567. In C.A. Black (ed.), Methods of Soil Analysis, Part 1. Am. Soc. of Agronomy, Madison, Wisconsin.

Gardiner, R.T. 1971. Report on Fording Coal Limited reclamation research, 1971.

Hackbarth, D.A. 1979. The effects of surface mining of coal on water quality near Grande Cache, Alberta. Canadian J. Earth Sci. 16:1242-1253.

Hesman, L.E. and K.L. Temple. 1978. ATA as a parameter for characterizing coal strip mine spoils. Soil Sci. 126: 350-352.

Kootenay Air and Water Quality Study. Phase II. 1978. Water Quality in the Elk and Flathead River basins. Water Investigations Branch, Ministry of Environment. Victoria, B.C. 289 p.

Lane, D. 1981. Fording Coal Ltd. Personal Communications.

McQuaker, N.R. 1976. A laboratory manual for the chemical analysis of water, wastewaters, sediments and biological tissues (Second Edition). Dept. of Environment, Water Resources Services, 3650 Wesbrook Cres. Vancouver, B.C. 389 p.

Nordin, R.N. 1982. The effect on water quality of explosives use in surface mixing. Volume 2: Effects on algal growth. APD Bulletin No. -. Ministry of Environment, Victoria, B.C.

Pedersen, T.A. A.S. Rogowski, and R. Pennock, Jr. 1980. Physical characteristics of some minesoils. Soil Sci. Soc. Am. J. 44:321-328.

Pommen, L. 1982. The effect on water quality of explosives use in surface mining. Volume 1: Nitrogen sources, water quality and prediction and management of impacts. APD Bulletin No. -. Ministry of Environment, Victoria, B.C.

Reeder, J.D. and W.A. Berg. 1977. Nitrogen mineralization and nitrification in cretaceous shale and coal mine spoils. Soil Sci. Soc. Am. J. 41:922-927.

Rudd, R.T. 1978. Pollution Control in the mining industry in South Africa. In Water Management and Development, Proceedings of the U.N. water conference; Mar Del Plata, Argentina, March 1977. 1(4):2583-2600.

SME Mining Engineering Handbook. 1973. A.B. Cummins and I.A. Given Ed. The American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., Port City Press, Baltimore, MD. Vols. I and II.

Stanford, G. and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Urso, P.J. 1980. The Fording River mine - an overview. C.I.M. Bulletin. P:82-88.

Van Voast, W.A. 1974. Hydrologic effects of strip coal mining in south eastern Montana - Emphasis: One year of mining near Decker. Montana College of Mineral Science and Technology, Butte. Bulletin 93. 24 p.

Wilson, H.A., and G. Stewart. 1955. Ammonification and nitrification in a strip mine spoil. W. Va. Univ. Agric. Exp. Stn. Bulletin 379 T. 16 p.

Table 1: Particle Size Distribution of Fording Coal Spoil Samples

Spoil Sample		Particle Size Analysis				
No	Description	Gravel (>2 mm)	Sand (<2 mm->0.05 mm)	Silt (<0.05 mm->0.002 mm)	Clay <0.002 mm	Textural* Classification
		%				
1	8-Spoil; west side haul road; possibly washed, reject Coal	62.7	30.3	5.9	1.1	gls+
2	As above	48.7	38.3	11.4	1.5	gls
3	8-Spoil; west side haul road; 6 to 8 months old	76.8	16.7	4.5	2.0	gsl++
4	8-Spoil; runaway lane north side	59.6	29.1	9.3	2.0	gsl
5	As above	79.4	15.5	4.1	0.9	gls
6	8-Spoil; runaway lane west side; ≈ 2 months old	61.6	29.6	7.1	1.7	gls
7	As Above	60.4	34.3	13.1	2.2	gsl
8	8-Spoil; east side haul road; 6 to 8 months old	55.4	39.5	3.7	1.3	gs+++
9	As above	75.3	20.4	3.1	1.1	gsl
10	8-Spoil; runaway lane east side; ≈ 2 months old	50.1	33.9	13.8	2.2	gsl
11	As above	67.1	23.6	7.8	1.5	gsl
12	Clode pit; coaly waste on pit floor exposed for 2 months	62.0	39.7	6.1	2.2	gls
13	8-Spoil along haul road 6 to 8 months old	76.1	18.7	4.1	1.1	gls

* U.S.D.A. classification system   ++ gravelly sandy loam
+ gravelly loamy sand   +++ gravelly sand

Table 2: Inorganic Nitrogen Released From Diamond Drillhole Coal Samples

Diamond Drillhole Sample			Reaction Time (Weeks)						
No	Description		1	2	3	4	6	8	Av.
			mg/100 g						
DDH-1658	Coal-Mudstone mixture; Composite of 1099' and 1154' depths	(NO_2+NO_3)-N	-	-	0.031	-	0.017	0.030	0.013
		NH_4-N	0.183	0.158	0.074	0.210	0	0	0.104
		Total	0.183	0.158	0.105	0.210	0.017	0.030	0.117
DDH-1659-1	Coal-Mudstone mixture; Composite of 1248', 1417' and 1916' depths	(NO_2+NO_3)-N	-	-	-	-	-	*	-
		NH_4-N	0.207	0.189	0.220	0.177	0.182	*	0.195
		Total	0.207	0.189	0.220	0.177	0.182	*	0.195
DDH-1658/ 1659	Coal; 925' and 1350' depths	(NO_2+NO_3)-N	-	-	-	-	-	*	-
		NH_4-N	0.025	0.004	0.024	-	-	*	0.011
		Total	0.025	0.004	0.024	-	-	*	0.011
DDH-1659-2	Coal; 390', 1810' and 2020' depths	(NO_2+NO_3)-N	-	-	-	-	-	-	-
		NH_4-N	0.134	0.145	0.171	0.112	0.156	0.129	0.141
		Total	0.134	0.145	0.171	0.112	0.156	0.129	0.141
DDH-1660	Coal; 302', 371' and 500' depths	(NO_2+NO_3)-N	-	-	-	-	-	-	-
		NH_4-N	0.018	-	0.043	-	-	-	0.010
		Total	0.018	-	0.043	-	-	-	0.010
	Overall Average, Total Inorganic-N								≈ 0.10

* Sample destroyed.
- Not detectable.

Table 3: Chemical Analysis of Spoil Samples

Spoil No.	Soil Analysis						Dissolution Analysis		
	Carbon	Nitrogen	C/N	NO₃-N	NH₄-N	Total** Inorganic-N	(NO₃+NO₂)-N	NH₄-N	Total** Inorganic-N
	$\%$			mg/100 g			mg/100 g		
1	50.5	0.763	66.2	*	*	*	0.199	*	0.199
2	70.4	1.072	65.6	0.084	*	0.084	*	*	
3	14.1	0.215	65.6	0.148	0.400	0.548	2.854	0.002	2.856
4	54.4	0.668	81.5	0.074	0.100	0.174	0.020	0.015	0.035
5	12.6	0.198	63.6	1.884	0.400	2.284	0.699	0.217	0.916
6	54.3	0.674	80.5	0.055	0.100	0.155	0.147	0.132	0.279
7	46.8	0.634	73.9	0.155	0.200	0.355	0.082	0.105	0.187
8	61.9	0.765	81.0	0.023	*	0.023	0.014	*	0.014
9	25.5	0.414	61.5	2.793	*	2.793	1.187	0.003	1.190
10	50.8	0.644	78.9	*	0.100	0.700	0.033	0.114	0.147
11	47.9	0.658	72.8	*	*	*	0.260	0.059	0.319
12	63.0	0.935	67.4	0.049	0.100	0.149	0.222	0.229	0.451
13	26.1	0.373	70.0	0.092	0.400	0.492	1.903	0.208	2.111
Average ($\bar{x}$)			71.4	0.412	0.138	0.551	0.586	0.083	0.670
Standard Error ($S\bar{x}$)				0.243	0.045	0.251	0.245	0.025	0.247
95% Confidence Limit				±0.529	±0.098	±0.547	±0.534	±0.055	±0.538

* Not detectable
** The average total Inorganic-N, based on Soil and Dissolution Analyses, was taken to be ≈ 0.60 mg/100g for discussions in the text.

Table 4: Inorganic Nitrogen Associated With Explosives, Spoil and Various Sources Contributing to Spoil Nitrogen.

Source	Range	Average	Amount of Nitrogen Relative to Explosive	Amount of Nitrogen Relative to Spoil
	——— kgN/bank m^{3*} ———		- % -	
Explosives	0.14-0.25	0.20#	100	
Spoil	$0 - 75.7 \times 10^{-3}$	16.1×10^{-3}	8	100
Waste Coal**		0.09×10^{-3}		0.6
Slurryholes	$0.31 \times 10^{-3} - 35.5 \times 10^{-3}$	5.48×10^{-3}		34.0
'Other Sources'***		10.53×10^{-3}		65.4
Nitrogen Oxides		$1.2 \times 10^{-3} - 4.0 \times 10^{-3}$		7.5-24.8
Unaccounted for		$6.53 \times 10^{-3} - 9.33 \times 10^{-3}$		40.6-57.9

*   1 bank m^3 = 2650 kg.

**   Waste Coal = 2.52×10^{-3} x 0.18 (Extractable Coal/Overburden) x 0.2 (Waste Coal/ Spoil).

***   'Other Sources' = Spoil N - Waste Coal N - Slurryhole N.

\#   Explosives Nitrogen Content x Powder Factor (kg of explosives/bank m^3)

Table 5: Predicted Inorganic Nitrogen, $(NH_4+NO_3+NO_2)$-N, Leaching From Spoil

Month	Mean Monthly† Streamflow		Spoil Nitrogen Content	Leaching Rate	Amount of Nitrogen Leached	
					Monthly	Total
	m^3/s	cm/d	mg/100 g	mg/100 g-hr	—mg/100 g—	
Jan.	0.29	0.0261				
Feb.	0.26	0.0234				
Mar.	0.28	0.0252				
*Apr.	1.05	0.0945	0.60	0.00025	0.090	0.090
May	5.68	0.5112	0.51	0.00100	0.744** (0.51)	0.834** (0.60)
June	8.00	0.7200				
July	3.28	0.2952				
Aug.	1.71	0.1539				
Sept.	1.05	0.0945				
Oct.	0.69	0.0621				
Nov.	0.46	0.0414				
Dec.	0.35	0.0315				

* Amount of inorganic nitrogen leached for April is shown to be half as much, since spoil was sampled at mid month.
** Indicates potentially leachable amounts; when these values exceed the spoil nitrogen content for the month, the amounts of nitrogen leached is given by the amount present in spoil as shown in the parenthesis.
† Fording River below Clode Creek (08NK021).

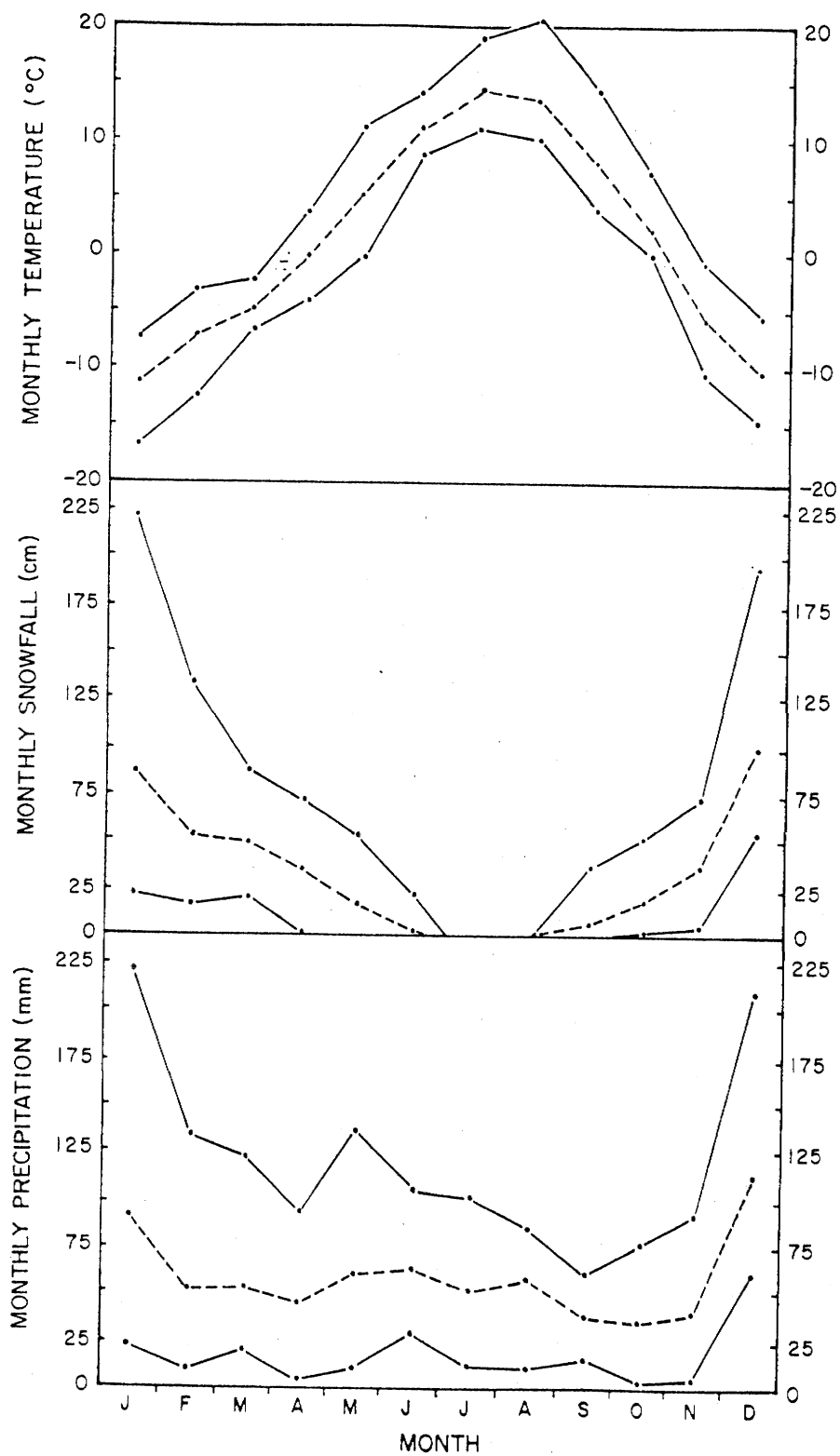Figure I. Fording Coal Limited Mine
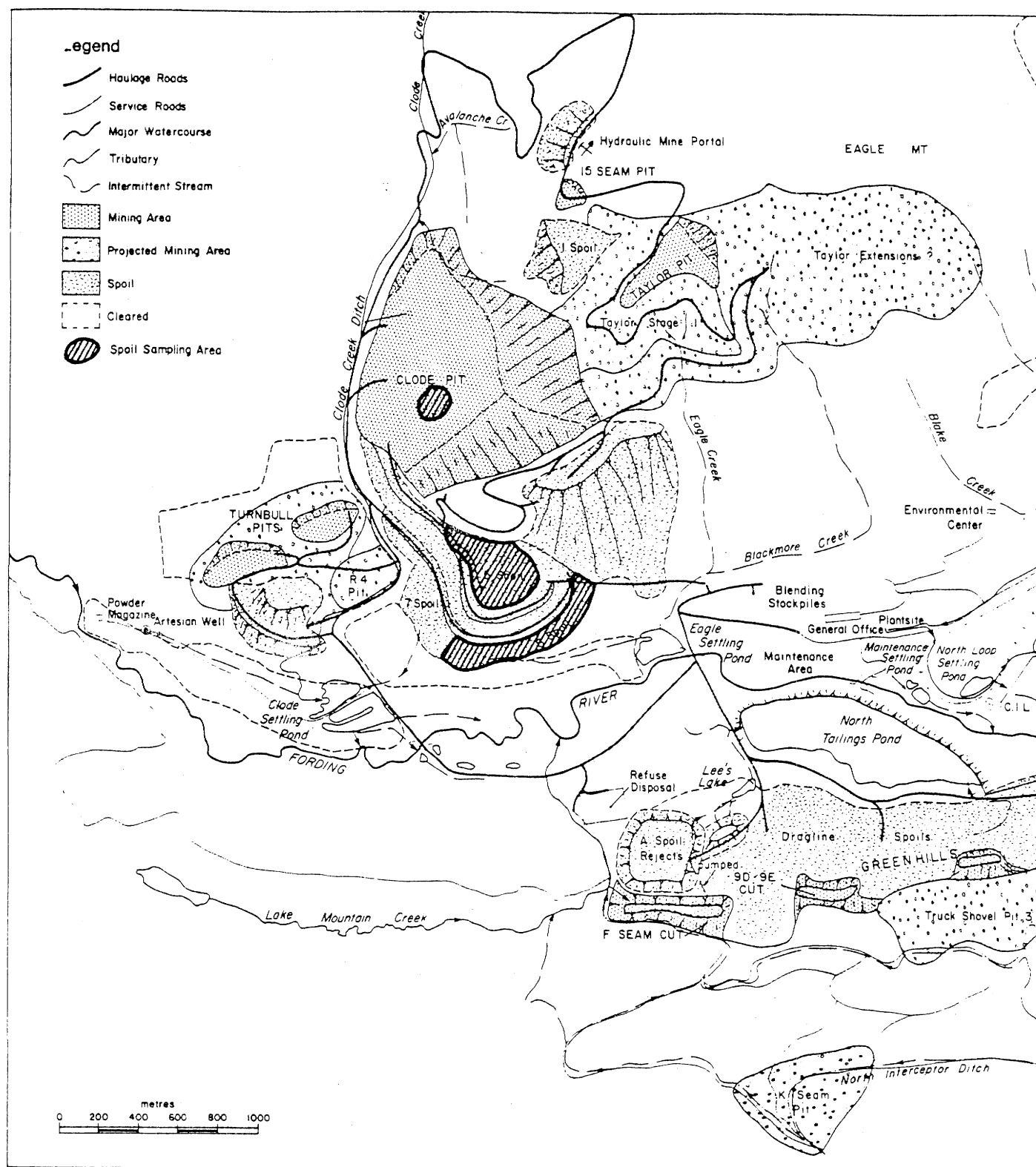
Figure 2. Monthly Precipitation, Snowfall, and Temperature
at Fording Coal Limited, 1970-79. (Fording River
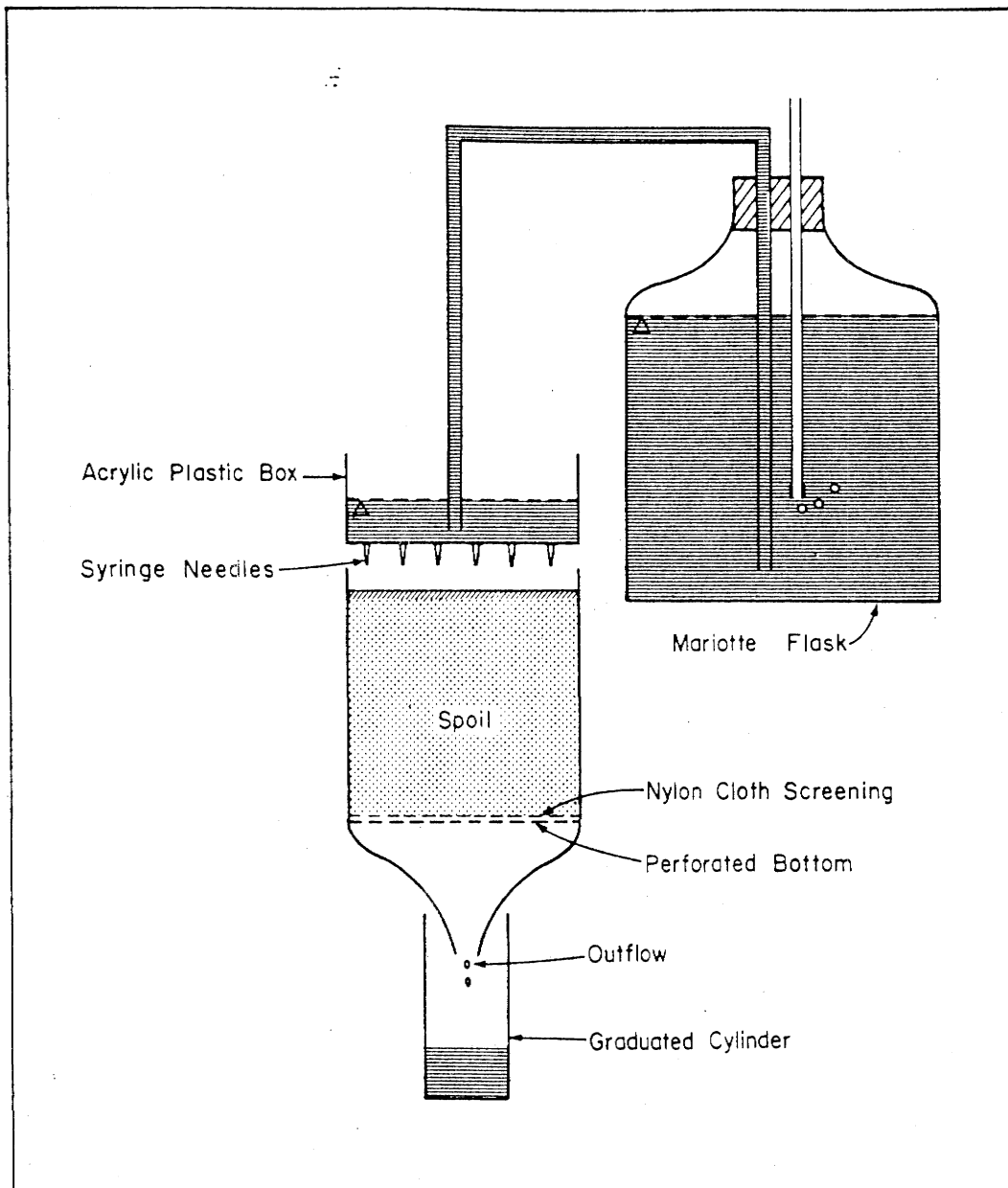Cominco Station, 50°11', 114°52', 1658-1702 m).

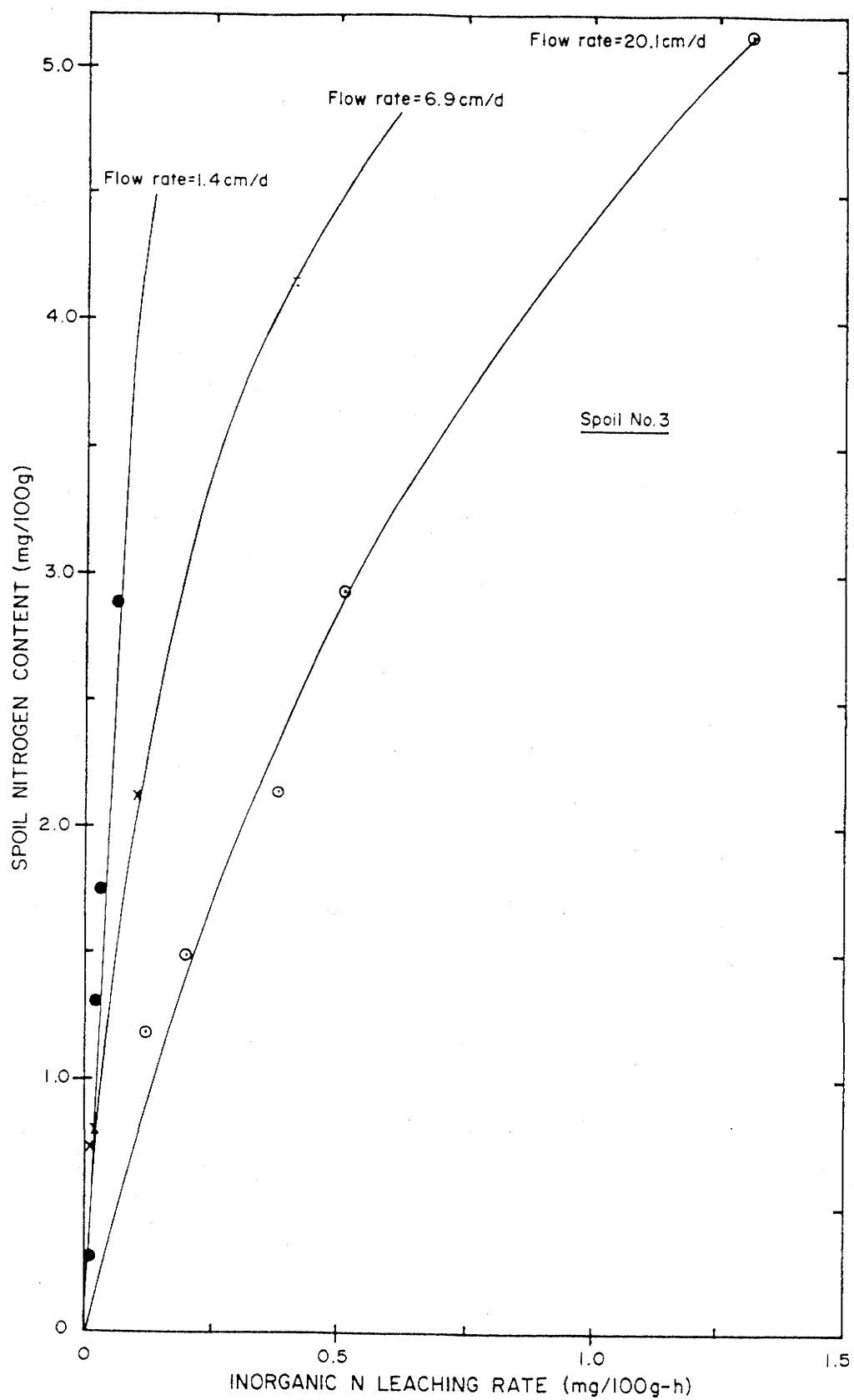Figure 3. Experimental Set-Up for Leaching Studies.

Acrylic Plastic Box

Syringe Needles

Spoil

Nylon Cloth Screening

Perforated Bottom

Mariotte Flask

Outflow

Graduated Cylinder

Figure 4. Inorganic Nitrogen Leaching Rate as a Function of Spoil (NO_2+ NO_3+NH_4) Nitrogen Content and Flow Rate.
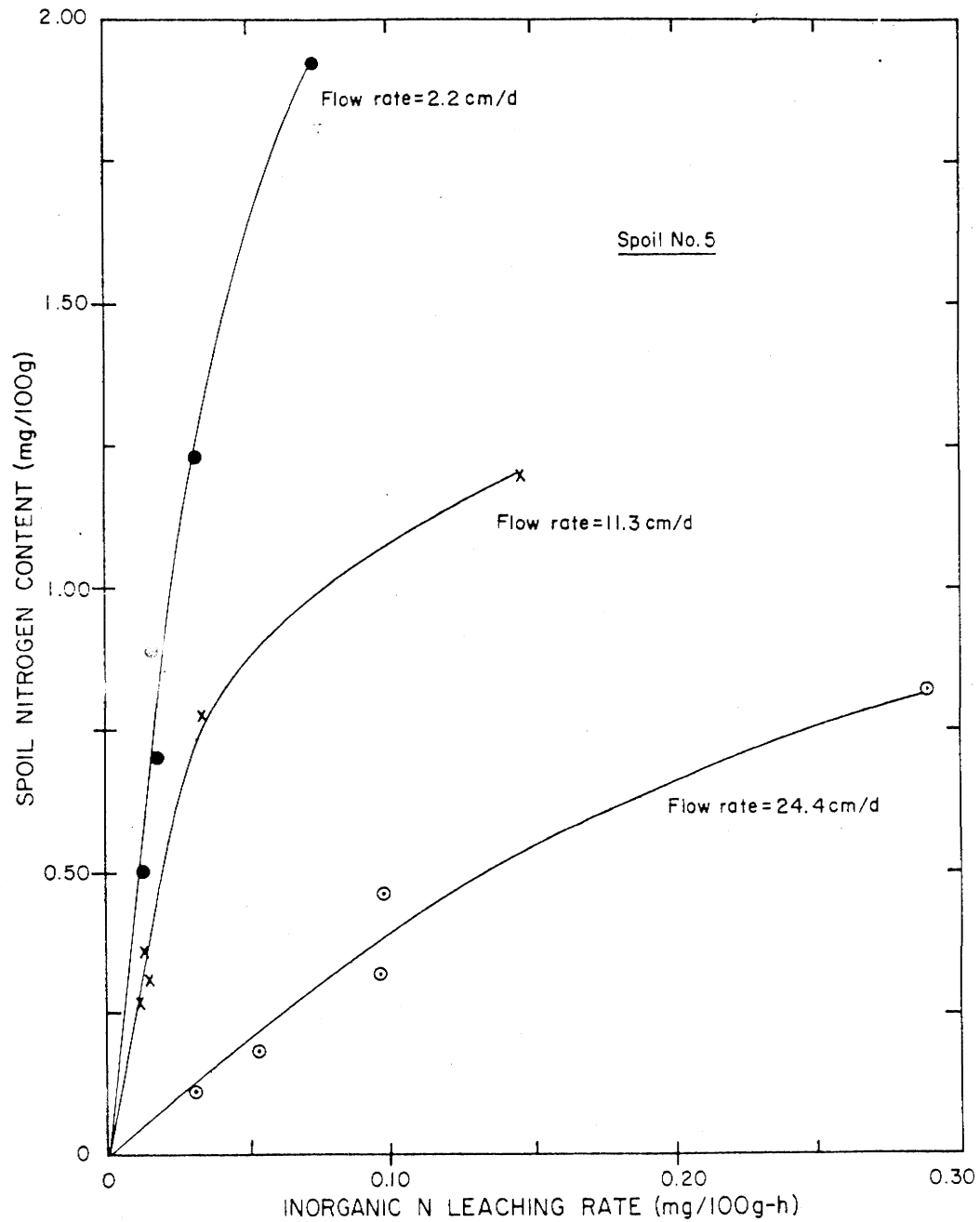
Figure 5. Inorganic Nitrogen Leaching Rate as a Function of Spoil (NO_2+ NO_3+NH_4) Nitrogen Content and Flow Rate.
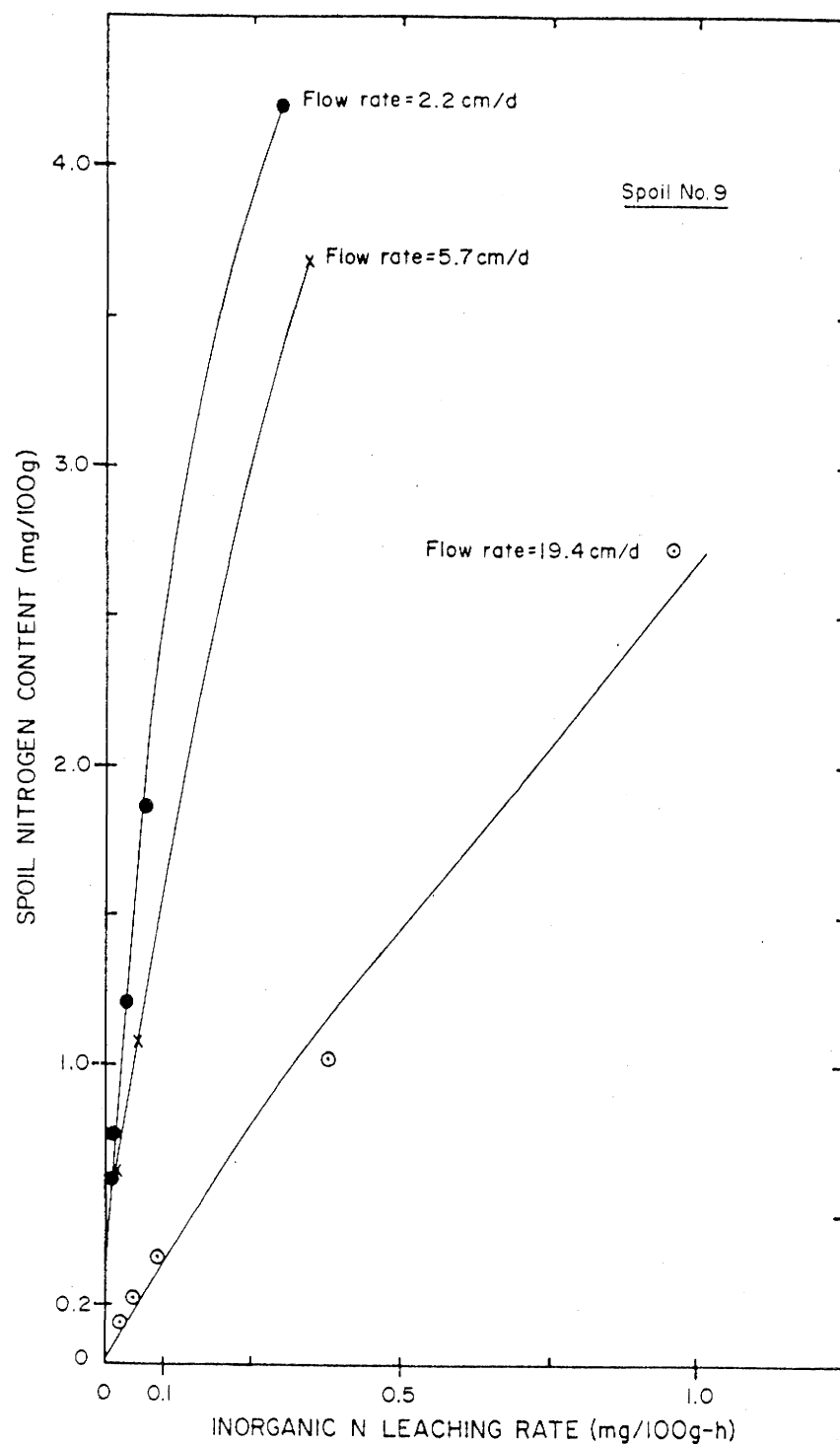
Figure 6. Inorganic Nitrogen Leaching Rate as a Function of Spoil ($NO_2 + NO_3 + NH_4$) Nitrogen Content and Flow Rate.

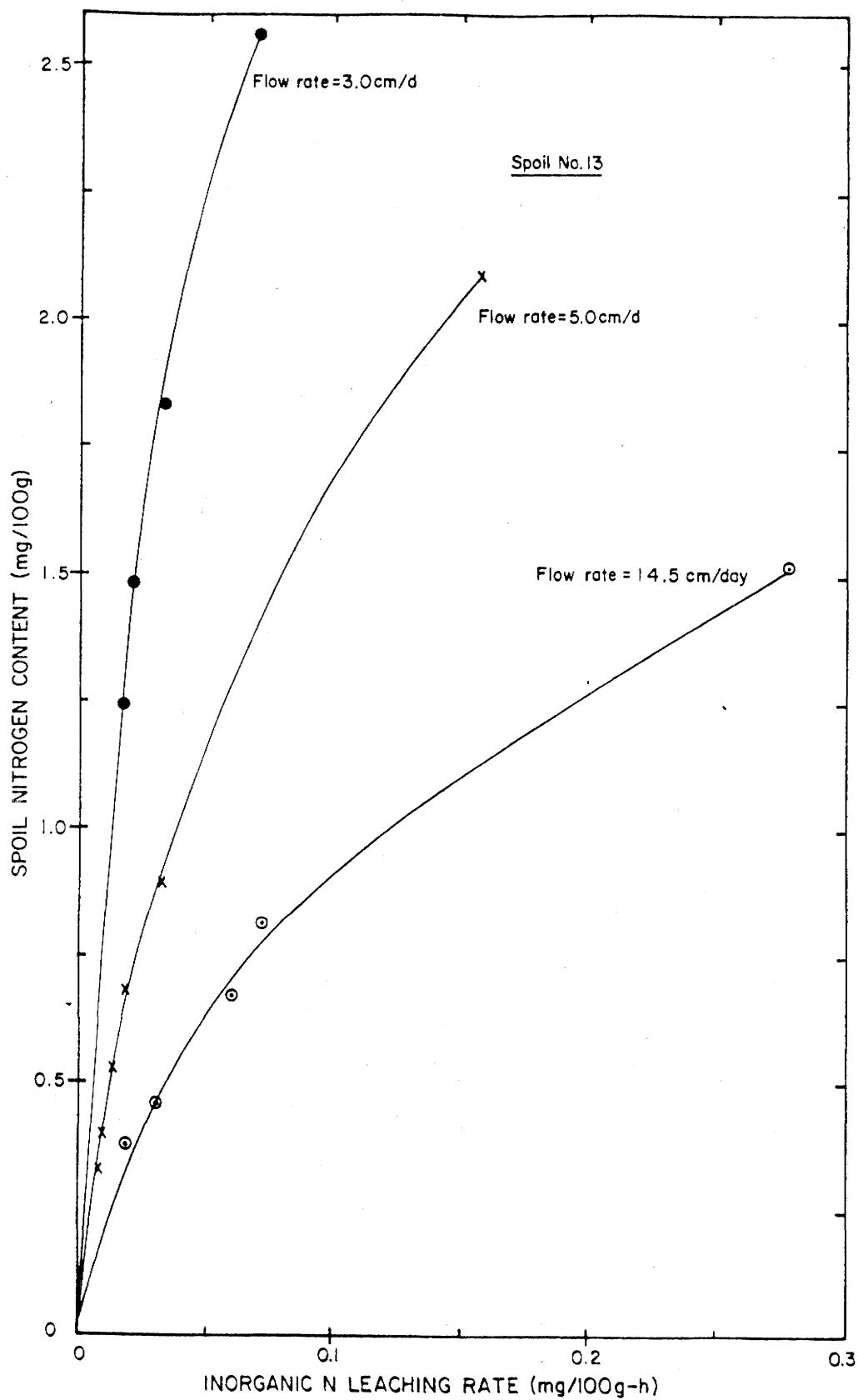Figure 7. Inorganic Nitrogen Leaching Rate as a Function of Spoil $(NO_2+NO_3+NH_4)$ Nitrogen Content and Flow Rate.
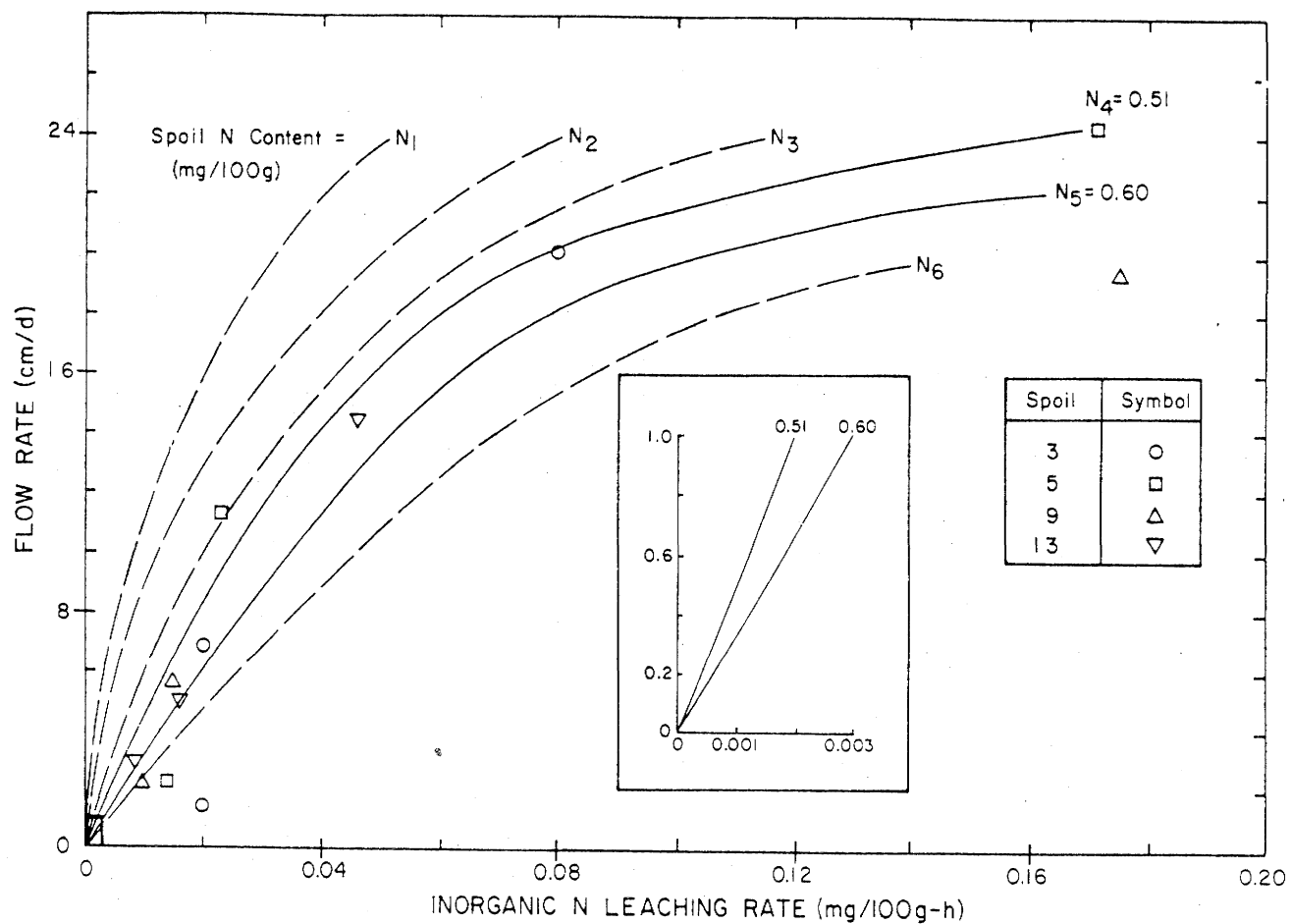
Figure 8. Inorganic Nitrogen Leaching Rate as a Function of Flow Rate for a given Spoil N, derived Figures 4 thru 7. The Dotted Lines are Projected Curves. The Data Points are shown for Spoil N = 0.60 only. The Insert shows Details at the Lower End of the Scale.