A PRELIMINARY REPORT ON
THE EFFECTS OF ATMOSPHERIC EFFLUENTS FROM
MINING AND SMELTING INDUSTRIES
ON FOREST VEGETATION AND SOILS

(Note: This is a scanned copy of the original report. The format may vary from the original, but the content remains the same.)

BY

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ABSTRACT

Analysis of soils and vegetation from plots in the Flin Flon area has demonstrated the existence of a steep gradient of soil metal levels. The principal metals involved are arsenic, cadmium, copper, iron, lead and zinc. Soils close to the stack contain up to 8000 mg/kg Zn compared to a normal background level of less than 100. The metal levels in the soils at the closest sites are in excess of those shown to inhibit the decomposition of organic matter a process which will ultimately lead to a decrease in site productivity. The high levels are restricted mostly to the surface layers of the soil and only infiltrate into the mineral soil at the most heavily contaminated sites.

The evidence presented suggests that metals are being deposited as much as 30 km from the source. These levels have not affected the composition of the stands with respect to vascular plants, but, do appear to have restricted the growth of lichens and mosses.

There is no evidence to indicate that soil acidity has increased as a result of smelter emissions at sites that are further than 5 km distance from the smelter stack. Acidification may have taken place at sites which are closer to the source.
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INTRODUCTION

The Hudson Bay Mining and Smelting Company Limited (H.B.M. & S.) has operated a copper-zinc smelter in Flin Flon, Manitoba for over fifty years. As in any non-ferrous smelting complex, emissions of heavy metal particulates are released to the atmosphere in considerable quantity. The primary source of the emissions from the H.B.M. & S. complex is the 825 foot stack while secondary sources include the copper smelter dryers, the converter aisle roof monitors, the anode casting stack, the zinc casting furnaces and the general plant ventilation.

On January 8, 1973, the Clean Environment Commission issued the H.B.M. & S. company with C.E.G. Ordinary Licence No. 195, as amended by Order No. 18/72 of the Municipal Board. Following issuance of this licence and pursuant to its efforts to preserve the quality of the environment, the Province of Manitoba sought to increase its data base specific to soils and vegetation in the Flin Flon area. The information required included; present levels of contaminants on forest soils and vegetation, rates of accumulation, and the resulting effects of these contaminants on the forest ecosystem. It was anticipated that such information could be utilized by the Environmental Management Division to assist in the administration of the Clean Environment Act, as it applied to the control of atmospheric emissions form the operations of the H.B.M. & S. smelting complex.

To this end, the Environmental Research and Development Branch of the Environmental Management Division entered into a joint Federal/Provincial Forest Study with the Northern Forest Research Centre of the Canadian Forestry Service on April 1, 1977. This forest study was designed to determine and evaluate the environmental impact of airborne sulphur dioxide and heavy metal particulates emitted from mining smelters in Northern Manitoba on forest systems. The research program is a fully co-operative endeavor between research staff of both the federal and provincial governments. All facets of the program, including planning, methodology, site selection, soil and vegetation sampling, technical procedures and analytical techniques have been co-operatively planned and implemented.

The initial phases of the program have been benchmarking studies initiated in both Thompson and Flin Flon. In 1977, preliminary surveys were conducted in the Flin Flon area and in May of 1978, a network of eight study sites was established to the south and southeast of the
H.B.M. & S. smelting complex in the primary pollutant dispersion area. The initial studies sought to determine the extent pollutant deposition to quantify the resultant damage to forest vegetation and soils. The research program was designed using best practicable methods, and is continually evolving through review of data and techniques by research staff of both agencies.

This submission to the Clean Environment Commission will outline the research program objectives, procedures, progress and results to date. As responsibility for individual parts was divided between both federal and provincial agencies according to scientific expertise and laboratory facilities, the reporting of results will be divided along these same lines.

This submission of the joint Federal/Provincial Forest Study in the Flin Flon area is comprised of the following three sections.

**SECTION A**  A federal/provincial report outlining the objectives and program procedures of the principle study elements.

**SECTION B**  A provincial report summarizing the results of the vegetation inventory and the influence of coniferous tree reproduction.

**SECTION C**  A federal/provincial summarizing the results of the benchmark and biomonitoring systems.

**PROGRAM OBJECTIVES**

This research program was designed to evaluate the degree and extent of environmental impact of air pollutants, primarily sulphur dioxide and heavy metals, emitted from the H.B.M. & S. smelting complex on the forest system in the Flin Flon area. To satisfy this objective, the following objectives were defined at the commencement of the program:

1. To carry out a vegetation inventory for baseline information on suitable forested areas around the smelter operation.
2. To study the influence of airborne pollutants on the reproductive capacity of coniferous forests in the area.
3. To establish benchmark and biomonitoring systems utilizing vegetation within the forest communities.
4. To determine the impact of airborne pollutants, heavy metal and sulphur gases, on forest soil chemistry.
STUDY SITE SELECTION:

In the Flin Flon area, eight benchmark and biomonitoring study sites were selected following a detailed review of meteorological data, patterns of pollutant dispersal, forest inventory records and documented areas of forest decline. As indicated in Figure 1, the sampling plots fall along two transects, to the south east and to the south, in a gradient away from the smelter.

Four study plots are located along the southeastern transect at distances of 5.1, 8.9, 15.5, and 38.1 km and three plots were located in the southern transect at distances of 5.8, 14.6, and 35.7 km from the smelter stack. A background or control site, plot # 8, was established at a distance of 68.2 km to the east at Elbow Lake (Table 1).

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Direction From Stack</th>
<th>Distance From Stack (km)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Legal Description</th>
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<td>101°48'48&quot;</td>
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<td>2</td>
<td>S.E.</td>
<td>8.9</td>
<td>54°43'24&quot;</td>
<td>101°46'30&quot;</td>
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<tr>
<td>3</td>
<td>E.S.E.</td>
<td>15.5</td>
<td>54°43'24&quot;</td>
<td>101°39'48&quot;</td>
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<tr>
<td>4</td>
<td>S.E.</td>
<td>38.1</td>
<td>54°33'00&quot;</td>
<td>101°26'06&quot;</td>
<td>Sec 23-64-27</td>
</tr>
<tr>
<td>5</td>
<td>S.</td>
<td>5.8</td>
<td>54°43'30&quot;</td>
<td>101°50'18&quot;</td>
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<tr>
<td>6</td>
<td>S.</td>
<td>14.6</td>
<td>54°38'18&quot;</td>
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<td>E.</td>
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A review of forest inventory records and maps for the Flin Flon area reveal that the most productive and frequent forest stands suitable for benchmark study were mixed coniferous-deciduous. Study plots were established on mixed sites with each plot chosen to include elements of *Pinus banksiana* Lamb. (Jack Pine), *Picea mariana* (Mill.) B.S.P. (Black Spruce), *Picea glauca* (Moench) Voss (White Spruce), *Populus tremuloides* Michx. (Trembling Aspen), and *Populus balsamifera* L. (Balsam poplar). These sites were carefully selected to duplicate as closely as possible features of stand composition, structure, age, aspect, understory and soil characteristics.
Figure 1  Map showing location of study plots in the Flin Flon area.
**Vegetation Inventory**

A description of the existing plant communities within each study site is critical to detect and benchmark present environmental impact from air pollutants and to conduct long-term biomonitoring of the Flin Flon area. The natural forest vegetation of the eight study sites is stratified into tree-shrubs, low shrub, herbs and cryptogams. Two complimentary sampling networks were designed to satisfy this objective, one for the larger tree/high shrubs and the second for the lower shrub-herb species.

**Tree and High Shrub**

A 1/10 hectare circular macroplot was established in each of the eight study sites to describe the plant communities present within jack pine and black spruce stands. Vegetation within the macroplot was stratified into the two major communities of tree cover and tall shrubs. Shrubs were defined as woody plants taller than 50 cm.

All trees within each macroplot were identified and estimates of physical condition, abundance and size were taken. Each tree was tagged, measured for diameter at breast height and mapped within the macroplot. Three representatives were selected from each study site for measurement of age and height.

All shrubs within each macroplot were identified; physical condition was determined and abundance and size, to provide details of species composition and distribution. Each tall shrub clone within the macroplot was identified, mapped as to location within the macroplot, and subjected to a stem count. The density of shrub clones within the macroplots was used as a measure of abundance and measurements of height and crown width were taken for calculations of cover.

**Low Shrub-Herb**

To sample the low shrub-herbs a series of five one m² microplots were established in a linear transect with a distance of ten metres between microplots. In each microplot the vascular cover was further stratified into the following:
1. Low Shrubs: woody plants less than 50 cm high with an indefinite number of stems arising from a single rootstock.
2. Tall Herb: non-woody species between 15 to 50 cm in height
3. Low Herb: non-woody species less than 15 cm in height
4. Cryptograms: the common ground and moss, lichen, and fern layer

The above stratum was sampled for species composition density, frequency and percent cover in each of the five microplots per study site. Individual species members were examined for foliar condition concurrently with sampling procedures. Only the most common ground lichens and mosses were included in the vegetation descriptions largely because of the degree of competence required to do a detailed investigation of these groups.

For the purpose of this study, an individual plant was defined as one being rooted within the quadrat and having a distinct and single root origin. This system was difficult to apply in the case of species in the Ericaceae family where creeping stems were often rooted in the nodes. In such cases, a decision was made to count each rooted segment as an individual. The cover of each species was also difficult to determine accurately with a one-metre square quadrat. To increase the accuracy of cover estimates the large quadrat was subdivided into four equal units and measures of density and cover taken in each quadrat and then totaled. In each plot, all microplots were photographed so that a permanent record of 1978 vegetation was made for future reference.

The vegetation data collected from each microplot was used to calculate density, relative density, dominance, relative dominance, frequency and relative frequency for each species in the shrub/herb stratum of each study plot. These data were used to calculate an Association Table of Understory species for comparison between study sites. The formulae used in the above calculations are listed below:

\[
\text{Density} = \frac{\text{Number of individuals}}{\text{Area sampled}}
\]

\[
\text{Relative Density} = \frac{\text{Density for a species}}{\text{Total density for all species}} \times 100
\]

\[
\text{Dominance} = \frac{\text{Total basal area for aerial coverage values}}{\text{Area sampled}}
\]
Relative Dominance  = \frac{\text{Dominance for a species}}{\text{Total dominance for all species}} \times 100

Frequency  = \frac{\text{Number of plots in which species occurs}}{\text{Total number of plots sampled}}

Relative Frequency  = \frac{\text{Frequency value for a species}}{\text{Total of frequency values for all species}} \times 100

Association Table  = \frac{\text{Cover & Frequency}}{2}

REPRODUCTIVE CAPACITY OF CONIFEROUS FORESTS

Coniferous trees are a dominant part of the forest community in the Flin Flon area. The reproduction of these trees is vital to the maintenance of the stand as we know it, today. Tree reproduction is thought to be sensitive to air pollution effects and as such should be a good indicator of early pollutant damage. Since black spruce and jack pine are dominant in the community they were selected to be the subjects of investigations on the effect of air pollutants on reproductive organs and potential.

The study was divided into two phases. The first was designed to study cone and seed development up to the germination stage and the second to study seedling growth and development beyond the germination stage. Due to time and staff restraints over the past two years, the study did not go beyond the initial phase and this submission will only contain methods and results for the studies of cone and seed development. It is anticipated that the second phase of this program will be initiated in 1980/81.

Cone and Seed Development

This study was initiated to investigate the effect of air contaminants on cone and seed development up to the stage of seed germination. In each of the eight sample plots, five trees representative were selected from the jack pine and black spruce communities. All mature cones were collected from these trees and in the case of jack pine; a collection of immature first year cones was also made.
The cones were taken to the laboratory, and kiln dried at 55°C for 24 hours to induce cone opening. The open cones were vigorously shaken in paper bags to extract the seeds. Seeds were then separated from the cones. Mature cones and immature jack pine cones were submitted to the Technical Services Laboratory of the Province of Manitoba for chemical analysis. The following elements: lead, copper, zinc, cadmium, and iron were analyzed by atomic absorption spectrophotometry.

The seed germination experiments involved both jack pine and black spruce. The seed from each tree was cleaned and divided into four replicates of 100 seeds each per tree. Each replicate was weighed to determine weight per 100 seeds and was replaced in a Petri plate for germination testing. The plates were placed in a growth chamber and were arranged in a randomized block design within the shelves of the growth chamber to standardize treatment as closely as possible. The seeds were exposed to temperatures of 25°C, relative humidity 95%, for a 16 hour daylight period over a 10 day duration. Daily seed counts were made for each replicate group until germination ceased.

At the termination of the experiment, measurements of germinant mass and length were made in addition to calculations of percent germination. The remaining ungerminated seeds were evaluated for percent hollow, dormant, and rancid. The germinants from each of the replicates were collected and submitted to the Technical Services Laboratory for chemical analysis of lead, copper, zinc, cadmium and iron by the same procedure which was used for the cones.

BENCHMARK AND BIOMONITORING SYSTEMS

In the collection of benchmark data, selected vegetation and soils are analyzed for their existing pollutant content and subsequently sampled over time to provide information on rate of pollutant accumulation. A biomonitoring system utilizes biological species as both indicators of air pollution impingement and as a measure of air pollution impact. Several plant groups, particularly mosses and lichens, have been shown to be very efficient in absorbing and retaining airborne pollutants. The various parts of this study attempt to use the native vegetation on soils on an area as reliable and consistent measure of both contaminant impingement and impact.

Four distinct facets of the research program are classed as benchmarking and biomonitoring activities: (1) foliage analysis of selected species; (2) soil description and analysis; (3)
establishment of a physical network of moss traps; and (4) precipitation sampling.

Foliage Analysis

Foliar samples were taken from both permanently marked tree species and dominant shrubs within each of the study plots. Six replicate samples of black spruce, jack pine, alder (*Alnus rugosa* (DuRoi) Spreng), and Labrador tea (*Ledum groenlandicum* Oeder), were collected. These species were chosen to provide a comparison between coniferous and deciduous species and because they contribute, in a major way, to the formation of the forest litter.

To sample tree foliage, several large branches were collected from each of the permanently marked trees with pole pruners. The branches were divided, and 1 year-old foliage was collected and stored in paper bags. The foliage was oven-dried and ground to pass through a 20 mesh sieve. Two g of foliage was weighed into an acid washed dried crucible. The crucible was placed in a cool muffle furnace and the temperature was increased gradually to 450°C. The material was ashed at this temperature for 16 h. The crucibles were allowed to cool and the ash was moistened with 10 drops of glass distilled water. To the ash was added 3 mL of 5 N HCl and 250 mL of Conc. hydrochloric acid (5 N, 3 mL) was again added to the crucible, it was warmed and 5 mL of glass distilled water was added, the ash solution was transferred quantitatively through a Whatman # 50 filter paper to a 50 mL volumetric flask.

Six random samples of shrub foliage were taken from each area of alder and Labrador tea. The foliage was collected by manually stripping the leaves from the branches and placing them in paper bags. The foliage was dried, ground and ashed according to the previously described method.

Both shrub and tree samples were analyzed for copper lead, zinc, potassium, calcium, magnesium, and iron by atomic absorption spectrophotometry. Phosphorus was determined by the Auto Analyzer using the vanadomolybdate method.

Soil Analysis

A soil pit was dug to a 60 - 100 cm depth at each study plot. The soil profile was photographed, described in relation to soil type, and sampled by profile. The samples of each
profile were taken with a plastic trowel, placed in plastic bags, sealed and stored at field moisture. When the samples were returned to the laboratory, they were stored in a cold room at 30 until required for analysis. Subsamples of the soils were collected, air dried, ground, and passed through a 60 mesh sieve. The samples were analyzed for pH, total organic nitrogen, total cations. The following procedures were used in the soil analysis:

- **pH Measurement:** 10 g of field moist soil was placed in a 30 mL plastic beaker. Twenty mL of .01M CaCl$_2$ was added to the beaker and mixed with the soil to form a slurry. The mixture was allowed to stand for 30 min. and the pH was measured with a glass electrode.

- **Total Metals & Sulphur:** Approximately .6 g of soil was placed in a Teflon beaker, 10 mL of HNO$_3$ and 2 mL of HClO$_4$ were added and the beakers placed in a block digester. The tubes were heated at 70°C for 1.5 hours, the digest was cooled and 20 ml of HF were added. The mixture was heated to dryness 1 ml of Cone. HCl and 5 ml of distilled water were added. The sample was filtered and transferred quantitatively to a 50 ml volumetric flask. Total metals were determined on the acid digests by means of atomic absorption spectrophotometry. Total sulphur was determined on the digests by using the Johnson and Nishita (1952) technique with the Deans (1966) modification.

- **Extractable Metals & Sulphur:** Mineral soils and LFH materials were extracted by similar procedures. One g of LFH material or 10 g of mineral soil was shaken with 20 mL of 1N NH$_4$0Ac (pH 4.8) for 1 hour in a 125 mL flask. The suspension was filtered through a Whatman # 50 filter and analyzed for zinc and copper by atomic absorption spectrophotometry and for extractable sulphur by the Johnson-Nishita (1952) technique with Deans (1966) modification.

**Physical Moss Traps**

Moss traps have been shown to be an effective method of absorbing and trapping airborne pollutants by a passive ion-exchange process. Sphagnum sp. was selected for use in this study as the receptor for airborne contaminants because of its wide distribution and availability in
Manitoba. Samples were selected from the Belair Provincial Forest in Southern Manitoba, a relatively clean area with regard to air pollutant influence.

Samples were air dried in the laboratory and exposed to a series of washes and rinses in alternating solutions of hydrochloric acid and distilled water in order to empty existing materials from ion-exchange sites. Following a final distilled water rinse, the moss was air dried. The moss was arranged as a thin mat between two layers of mesh. The mesh and the moss was then stretched across a plastic embroidery hoop (15 cm in diameter) and clamped tight. In this way the moss formed a uniformly thick layer across the surface of the mesh. The complete traps were stored in plastic bags until they were required. At the field site the traps were suspended (in replicates of 5) from a plastic crossbar (3 m in height). The moss traps were exchanged at monthly intervals with the exposed traps being returned to the laboratory and analyzed.

The moss traps were designed to collect particulates from rainfall and dry deposition. Once collected, the exposed moss traps were dried and transferred to crucibles for dry ashing. The ashing procedure was similar to that described for the foliar samples. After the samples were ashed and made up to volume, they were analyzed for copper, zinc and lead. It is anticipated that the moss trap will provide an estimate of deposition of particulates on a surface area basis and allow for a determination of the present area of impingement of metals.

Precipitation Sampling

Air pollutants were readily scavenged from the air shed by rain and snow. Rainfall samples were taken throughout the summer field season of 1978 using a special collector designed and built by C.F.S. staff at N.F.R.C. The collectors were established in the field in early May and collected rainfall all season with samples removed in late September. The results of the study have been discarded because of problems with the collectors under field conditions.

Snow sampling, like moss exposure, assists in determining the identity, quantity and extent of particulate contaminants near industrial sources of air pollution. A snow survey was conducted in early March 1979 and in January 1980 at each sample plot in Flin Flon network. The Mount Rose sampler was used to obtain information on snow depth and moisture content. An acrylic tube of similar dimension was used to collect a representative snow sample for chemical analysis. The core sampled the snow pack from top to bottom and the sample was
transferred into 4 plastic bottles. Duplicate samples were taken at each point with one bottle being reserved for sulphate analysis and the other acidified so that the sample could be used for metal analysis. The snow was kept frozen until ready to process for analysis of cadmium, copper, lead, nickel, zinc and iron by Atomic Absorption Spectrophotometry and sulphate by the Auto Analyzer.

**IMPACT ON FOREST SOIL CHEMISTRY**

The impact of pollutants on forest soil chemistry is being assessed by two studies.

**Leaching and Acidification**

Six sites were chosen at each plot to study the movement of metal and sulphur from the soil organic layer (LFH) into the mineral soil. A shallow pit was dug at each location and samples were taken from the organic layer, the 0 - 5, 5 - 10 and 10 - 15 cm layers of the mineral soil. The samples were taken with a trowel, placed in plastic bags and kept at field moisture. The samples were then stored in a cold room at 30°C until required. Subsamples of the soil and LFH material were taken for pH determinations and the remaining material was air dried and ground for chemical analysis.

For pH measurements, ten g of field moist soil was placed in a 30 mL plastic beaker. Twenty mL of .01M CaCl$_2$ was added to the beaker and mixed with the soil to form a slurry. The mixture was allowed to stand for 30 minutes and the pH was measured with a glass electrode.

**Effect on Metal Contaminated Soil on Jack Pine**

This phase of the study will be initiated during the 1980 field season in an attempt to determine what effects metal contaminated soils have on the germination and growth of jack pine.
SECTION B

FOREST VEGETATION INVENTORY

Eight study sites were chosen in the Flin Flon area based on the environmental criteria discussed in section A. A description of the existing plant communities was undertaken to determine what vegetational changes may have occurred, or are likely to occur in response to pollutant deposition. It is recognized that any conclusions reached from this initial survey would be tentative, and must await a confirmation of vegetational change from studies which will be conducted in the future.

The results of the forest vegetation surveys are shown in the following tables.

Tables 2 - 4 shows the species distribution of the various plots, these results show that community composition of the trees, shrub, tall-herbs, low herb-grand shrubs and pteridophytes is not affected by the distance from the pollutant source at present. This is reflected in the total species found at each site (Table 2, 3) and also in the data on mortality and basal area shown in Table 5. The plots are very variable with respect to species present but there is no clear indication that this is related to pollutant deposition. The data obtained on bryophytes and lichens appears to indicate that the presence of the sensitive species has been affected by the pollutant source. The plots which are closer to the smelter (1, 2, and 5) have fewer species than the less contaminated sites, whether this is due to an environmental gradient other that that of air pollutants cannot be determined at this time.
Table 2. Distribution of Understory in Flin Flon Sample Plots 1 to 8

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<td>Populus tremuloides</td>
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<tr>
<td>Shrubs</td>
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<td>Cornus stolonifera</td>
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<td>Epilobium angustifolium</td>
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<tr>
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<td>Rosa acicularis</td>
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<td>Shepherdia canadensis</td>
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<td>Low Herb/Ground Shrubs</td>
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Table 3. Moss and Liverwort Distribution, Flin Flon 1978

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*Total Species Present: 2 3 7 13 2 8 19 18*

*Nomenclature from: Conard 1956, How to Know the Mosses and Liverworts, and Crum 1973, Mosses of the Great Lakes Forest*

**Nomenclature from: Hale 1969, How to Know the Lichens*
<table>
<thead>
<tr>
<th>Cover</th>
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<th>Plot 3</th>
<th>Plot 4</th>
<th>Plot 5</th>
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Table 5: Summary of data on shrub stratum from phytomonitoring sites in Plan Pyon, 1978.
### Table 6. Community description information for understory species found at Plot 1, 1978

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<thead>
<tr>
<th>Species</th>
<th>Density</th>
<th>Relative Density (%)</th>
<th>Dominance</th>
<th>Relative Dominance (%)</th>
<th>Frequency</th>
<th>Relative Frequency (%)</th>
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<td>3.3</td>
<td>13.27</td>
<td>0.17</td>
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### Table 7. Community description information for understory species found at Plot 2, 1978

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Table 8. Community description information for understory species found at Plot 3, 1978

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<th>Relative Frequency (%)</th>
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Table 9. Community description information for understory species found at Plot 4, 1978

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<th>Relative Frequency (%)</th>
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Table 10. Community description information for understory species found at Plot 5, 1978

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Table 11. Community description information for understory species found at Plot 6, 1978

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<td>3.33</td>
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</table>
Table 12. Community description information for understory species found at Plot 7, 1978

<table>
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<th>Species</th>
<th>Density</th>
<th>Relative Density (%)</th>
<th>Dominance</th>
<th>Relative Dominance (%)</th>
<th>Frequency</th>
<th>Relative Frequency (%)</th>
</tr>
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<tbody>
<tr>
<td>Tall Herb</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Aralia nudicaulis</td>
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<td>0.83</td>
<td>13.47</td>
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<tr>
<td>Low Herb/Ground Shrubs</td>
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<tr>
<td>Cornus canadensis</td>
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<td>Goodyera repens</td>
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Table 13. Community description information for understory species found at Plot 8, 1978

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<th>Frequency</th>
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<td>7.26</td>
<td>0.17</td>
<td>14.41</td>
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<td>Low Herb/Ground Shrubs</td>
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<td>Pteridophytes</td>
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<td>Lycopodium lucidum</td>
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<td>70.94</td>
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REPRODUCTIVE CAPACITY - SEED GERMINATION TESTS

In the Flin Flon area coniferous trees are important members of the forest community. Since the maintenance of the community is dependent on the reproductive capacity of existing trees an examination of seeds and seed germination was made on seed collected from the plots. This study sought to determine if there was any effect of existing levels of air pollutants on forest reproduction as measured by these seed characters at the biomonitoring plots.

Seed Germination Tests

Jack pine has been shown to be more sensitive to air pollutants than black spruce. Because of this sensitivity jack pine seed was used in conducting germination tests. The results of germination tests are only applicable to jack pine but chemical analysis results for both jack pine and black spruce cones and seeds are presented.
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<thead>
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<th>Species</th>
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<td>13.34</td>
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</table>

In Table 15, a summary of all the germination related duties is presented. When sampling seed mass prior to germination, it was found that seeds from plot locations closest to the smelter were marginally lighter than those further away. Seed mass is positively correlated (not
significantly) with distance from the smelter, this is clearly shown in plots 5, 6 and 7 (i.e. 0.92, 1.09, 1.19 g/400 seeds respectively). Seeds from plot 1 at 5.1 km from the stack are 16% lighter than those found 38.1 km from the smelter (plot 4) in the southeastern transect.

The results of seed germination is shown in table 15, they indicate that there is no significant difference in germination capacity between sample plots. Seeds sampled from plot 1 (5.1 km from the smelter) germinated equally as well as those at plot 4 (38.1 km) and percent germination is higher at plot 1 than at the plot control, 78% and 75.0% respectively. In general, jack pine seed germination in 1978 for the Flin Flon area ranged between 64.2% and 79.0% and distance from the smelter does not appear to be a determining factor in reducing germination.

All seeds which germinated during the experiment were collected and allowed to continue growth in the environmentally controlled chamber until the termination of the experiment. At this time, the germinants were measured for radicle length and weighed to determine germinant mass. The measurement of germinant length did not show any significant difference between sample plots. The radicle length of seed germinants from the south transect were consistently longer than those of the southeastern transect by approximately 10% (table 15). However, seeds from plot 4 with lengths of 57.4 mm were similar to those of plot 2 (57.0 mm) in the southeastern transect and seeds from the plot 8 control (61.2 mm) were similar to those at plot 5 and 6, (60.7 and 61.7 mm respectively). In general, radicle length does not appear to be influenced by distance from the smelter.

Table 15. The germination characteristics of jack pine seeds from the study sites as related to distance from the smelter. Flin Flon, 1978

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Stack Distance (km)</th>
<th>Seed Mass (g/400)</th>
<th>Germination (%)</th>
<th>Germinant Length (mm)</th>
<th>Mass (g/400)*</th>
<th>Hollow (%)</th>
<th>Dormant (%)</th>
<th>Rancid (%)</th>
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<td>1.00</td>
<td>78.0</td>
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<td>6.54</td>
<td>15.0</td>
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<tr>
<td>2</td>
<td>8.9</td>
<td>1.08</td>
<td>72.8</td>
<td>57.0</td>
<td>7.35</td>
<td>18.0</td>
<td>6.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>1.02</td>
<td>64.2</td>
<td>61.2</td>
<td>8.01</td>
<td>30.0</td>
<td>5.0</td>
<td>1.0</td>
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<tr>
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<td>77.6</td>
<td>57.4</td>
<td>7.82</td>
<td>18.0</td>
<td>5.0</td>
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</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>0.92</td>
<td>68.2</td>
<td>60.7</td>
<td>8.50</td>
<td>25.2</td>
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<td>61.6</td>
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<td>10.6</td>
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<td>78.0</td>
<td>68.4</td>
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<td>75.0</td>
<td>61.2</td>
<td>9.15</td>
<td>17.2</td>
<td>1.6</td>
<td>4.8</td>
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</tbody>
</table>

*Germinant mass standardized to 100% germination.
An examination of germinant mass of seeds from plots located on the southeast transect showed a similar gradient, of increasing mass as distance from the smelter increases, table 15. For example, plots 1, 2 and 3 are located at distances of 5.1, 8.9 and 15.5 km respectively and germinant mass was 6.54, 7.35 and 8.01 gm/400 seeds. In table 15, a similar relationship between plots of the southern transect is shown. Seed germinant mass from sample plots in both the south and southeastern transects were consistently less than those taken from the plot 8 control. In addition, the relationship of seed mass is similar to that of germinant mass, where mass increased as distance from the smelter increased.

Seeds which failed to germinate were subjected to further study. Each seed was dissected to determine if it was hollow, dormant or rancid. In each case, no significant relationships could be found between plots. Sample plot 1 at 5.1 km from the stack showed only 15% hollow which was lower than the 17.2% found in plot 8 at 68.2 km distance. Seeds from plot 3 (30%) and plot 5 (25.2%) had the highest percentage of hollow seeds, but in both transects, plots closer to the smelter had much reduced values (Table 15).

Plots in the southeastern transect had considerably more dormant seeds than those in the south transect (i.e. plot 1 at 4.0% and plot 5 at 2.6%). In the south transect, the closest plot to the stack had the greatest percentage of dormant seed whereas in the southeastern transect, the closest plot had the lowest percentage. In the control plot, 1.6% were found to be dormant and this was considerably less than all other plots except 6 and 7 in the south transect at 1.0 and 1.8 respectively.

The number of seeds found to be rancid is a reversal of the results found in the % hollow and % dormant categories. In this category, the control had the highest value (4.8%) in all cases except plot 6 which was almost double at 8.4%. In the southeastern transect plots 1 and 2 were twice the value of plot 3 and in the south transect plot 5, the closest to the smelter, had a lower percentage than the other two plots (table 15). In general, no distinct patterns appear to exist in terms of distance or direction from the smelter.

Summary

Jack pine seed germination from trees in the Flin Flon sampling network ranged between 64.2% and 79%. Germination varied between plots and no relationship between percent
germination and distance from the smelter was apparent. Similarly, there was no effect of distance on germinant length; % hollow, % dormant and % rancid of seed which did not germinate.

Seed mass and germinant mass were shown to be a function of distance from the stack, as distance increased so did the mass of the seeds or germinants. This effect was not, however, statistically significant (<.059).

CONE AND SEED CHEMICAL ANALYSIS

Jack pine and black spruce cones were analyzed to determine what effect distance from the smelter has on pollutant content.

Jack pine cones take two years to develop for this reason an analysis was carried out on both mature and immature cones. Only mature black spruce cones were analyzed for pollutant elements. All samples were processed by the previously described methods.

All samples were submitted to the technical services laboratory for chemical analysis of cadmium, copper, iron, lead, zinc, by atomic absorption spectrophotometry.

Jack Pine Immature Cone

Chemical analysis results of jack pine immature cones are presented in table 16. Results of copper and nickel were found to be inconsistent with the patterns of accumulation found from the other four metals and for this reason they were not graphically illustrated in figure 2. The values found for copper ranged between 6.59 ug/gm at plot 6 to 13 at plot 1, however, the mean value for immature cones from the plot 8 control was 12.6.

In figure 2 (a-d), values for lead, zinc, cadmium and iron found in the immature cone samples are illustrated. Lead values shown range between 0.53 ug/gm (plot 8) to 4.27 at plot 5. A distinct gradient of decreasing lead concentration as distance increases from the smelter is evident in both transects from (figure 2 (a)). In the southeastern transect values decrease from plots 1 to 4 (3.99 and 1.3) and in the southern transect from plots 5 to 7 (4.2 and 1.2 respectively). (Table 16).

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
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</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>1.52</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>1.34</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>4.27</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>1.35</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>1.23</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>0.53</td>
</tr>
</tbody>
</table>

The zinc concentrations shown in figure 2 (b) indicate similar patterns of accumulation as those of lead. The highest concentrations are found at plot 5 (233 ug/gm) and range down to the lowest at plot 8 (45). A distinct gradient is evident in both the southeastern and southern transects (figure 2 (b)). In the southeastern transect values are: 175, 122, 89 and 61 for plots 1-4 and in the southern transect they are 233, 75 and 76 (table 16) for plots 5-7 (table 16).

The cadmium and iron concentrations followed identical pattern to lead and zinc as shown in figure 2 (c) and (d). In both cases metal levels were highest in trees from the plots closest to the smelter and decreased as distance increased. Cadmium values ranged from 1.12 at plot 5 to 0.1 ug/gm in cones from the plot 8 control site. Iron levels were highest in cones from plots 1, 93 ug/gm and lowest at plot 8, 31. Cadmium and iron were substantially higher in cones from plots 1 and 5 than from other areas (Table B2.2).

**Jack Pine Mature Cone**

The chemical analysis results of mature jack pine cones are shown in table 17. As in the analysis of immature cones, the results found for lead and nickel were inconsistent with those of the copper, zinc, cadmium and iron. Copper values were found to be highest in cones from plot 1 and decreased to the lowest level at plot 4. In the southern gradient, copper values at plot 5 (5.8 km) were highest and decreased to the levels found at plot 6 and 7.
Figure 2: Mean metal concentrations found in immature jack pine cones, Flin Flon, 1979.
The mean concentrations of lead, zinc, cadmium and iron found in plots 1 to 8 are shown in figure 3. The results show that the second highest heavy metal concentrations found for zinc, cadmium and iron are in samples from plot 2. The highest values for lead in jack pine cones come from plot 2.

### Table 17. Metal content of mature jack pine cones from Flin Flon, 1978

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
<th>Mean Heavy Metal Concentration in ug/gm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pb</td>
</tr>
<tr>
<td>1</td>
<td>5.1</td>
<td>0.79</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>0.85</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>0.66</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>0.52</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>0.76</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>0.52</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The highest values found for lead concentrations were 0.85 ug/gm in samples from plot 2 and the lowest 0.5 were found at plot 8. Background levels found at plot 8 are equal to those of cone samples from plot 7. As indicated in figure 3, lead levels in cones were found to exhibit a distinct gradient with concentration decreasing as distance increased from the smelter in the southern direction. In the southeastern transect, plot 2 at (8.9 km) from the smelter was the highest at 0.85 ug/gm and although both plots 1, 3 and 4 were lower, the values at plot 1 were very close to those at plot 2 while 3 and 4 were much less (table 17).

The highest values for zinc concentration were found in mature cones from plot 5 in the southern transect and a distinct gradient of zinc accumulation was found in the southern transect as shown in figure 3. Values for plots 5, 6 and 7 decreased with increased distance from the smelter (i.e. 32.88, 16.88 and 16.34 ug/gm). In the southeast gradient, zinc values for plot 2 were similar to plot 1 but values for plots 3 and 4 were considerably less and showing a decrease in proportion to distance from the smelter. Background levels of zinc determined from plot 8 samples were 6.62 ug/gm.
Results for cadmium were found to be in a similar pattern as zinc with highest cadmium values found in samples from plot 5 and the second highest at plot 2. In the southern gradient, the closest plot to the smelter had the highest concentration of cadmium and all other values were
not significantly different from the background value. In the southern transect, plot 2 was the highest, however, values found at plot 1 were similar. Plot 3 and 4 cadmium values were lower in proportion to their increased distance from the smelter.

The iron results showed a very distinct gradient of decreasing concentration with distance in the southeastern transect as indicated in figure. The highest iron values were found at plot 1 and decreased to plot 4 (table 17). In the southern transect, the highest values were found at plot 5 (12.3) which is the closest plot to the smelter, however, iron values found at plot 7 (11.5) were higher than those found at plot 6 (7). Analysis of mature cone samples from plot 8 revealed background levels of 7.7 ug/gm for iron.

Jack pine germinant analysis

The results of chemical analysis for jack pine seed germinants are presented in table 18. The lead values were found to be highest in samples from plot 5 with 3.95 ug/gm and second highest at plot 1 with 2.49 ug/gm. These are the two closest plots to the smelter in both transects. Background levels of lead found at plot 8 were 1.92 indicating that seeds at most plots were not significantly enriched by atmospheric lead (table 18).

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
<th>Pb</th>
<th>Cu</th>
<th>Zn</th>
<th>Cd</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.1</td>
<td>2.49</td>
<td>17.15</td>
<td>194</td>
<td>1.46</td>
<td>364.5</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>1.59</td>
<td>19.8</td>
<td>152</td>
<td>1.61</td>
<td>443</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>1.35</td>
<td>19.7</td>
<td>143</td>
<td>1.06</td>
<td>431</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>1.45</td>
<td>17.4</td>
<td>126</td>
<td>0.71</td>
<td>390</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>3.95</td>
<td>16.8</td>
<td>235</td>
<td>1.92</td>
<td>316</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>1.67</td>
<td>15.5</td>
<td>151.5</td>
<td>0.88</td>
<td>299.5</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>1.88</td>
<td>22.1</td>
<td>177</td>
<td>1.06</td>
<td>496</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>1.92</td>
<td>19.85</td>
<td>124</td>
<td>0.7</td>
<td>358.5</td>
</tr>
</tbody>
</table>

The copper analysis results indicated that there was no significant increase of seed levels of copper. Values were the highest at plot 7 (22.1 ug/gm) well within the expected range for vegetation. No relationship of copper concentration and distance from the smelter was evident (table 18).
The mean iron concentration in background samples was 458.5 ug/gm which was higher than those found at plot 5 (316.0), plot 6 (299.5) and less than those found in samples from plot 7, at 496.0. Values at plots 2, 3, 4 decreased as distance increased.

The analysis results for zinc and cadmium are graphically illustrated in figure 4 (a, b). Samples from plot 5 had the highest concentration of zinc at 235.0 ug/gm and values ranged down to 124.0 at the plot 8 control. A gradient of zinc concentration in seed germinants was found in samples from the southeastern transect with levels ranging from 194.0 to 126.0 ug/gm from plots 1 to 4 as illustrated in figure 4 (a). In figure 4 (b), cadmium values are shown to be higher in the plots closest to the smelter, but do not form a smooth gradient of concentration as distance increases. There appears to be elevated levels of Cd at the closest sites but no significant effect on Cd levels at the other sites. In the southeastern transect, the greatest amount of cadmium was found in sample plot 2 with 1.61 ug/gm and plot 1 was second highest at 1.46. There was no significant relationship between distance and cadmium levels at the other plots.

Jack Pine Cone and Seed Analysis

The results of lead, zinc, cadmium and iron analysis in the immature and mature cones of jack pine and results of zinc and cadmium in seed germinants demonstrated a distinct relationship between element concentrations and distance from the smelter stack. The highest levels of concentration in the southeastern and southern transects were found in samples located closest to the smelter complex and a gradient of decreasing concentration was found as distance increased.

The results of copper and nickel analysis were not consistent with the other metals. Levels of copper in cones close to the stack were similar to background levels.

The levels of metals found in immature cones was higher than those levels found in mature cones. The values found in seed germinants were consistently higher than those found in mature cones and generally higher than those found in immature cones. A relationship does appear to exist between the accumulation of metals in the various reproductive structures and their stages of development. However, a full understanding of the implications of this relationship will require further more intensified study.
Figure 4 (a,b): Heavy metal concentrations found in P. seed germinants, Flin Flon, 1979.
Results of Black Spruce Cone Analysis

A summary of chemical analysis of the heavy metals lead, copper, zinc, nickel, cadmium and iron in black spruce cones is found in table 19. The results found for nickel and iron analysis were varied from those of the other four metals and as such, only lead, copper, zinc and cadmium values are graphically illustrated in figure 5 (a-d).

The highest iron concentrations were found in plot 5 (19.82 ug/gm) with a gradient of decreasing concentration in the other southern plots ranging from 8.74 to 7.20 (table 19). In the southeastern transect, values were found to be more erratic ranging from 8.5, 11.3, 7.6 and 11.3 for plots 1, 2, 3 and 4 respectively.

Table 19. Levels of metals in black spruce cones at the various study plots, Flin Flon 1978

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
<th>Mean Heavy Metal Concentration in ug/gm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pb</td>
<td>Cu</td>
</tr>
<tr>
<td>1</td>
<td>5.1</td>
<td>0.50</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>0.69</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>0.50</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>0.50</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>1.32</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>0.52</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>0.50</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Plot 5, the closest plot to the smelter in the transect was found to have the highest lead levels at 1.32 ug/gm (figure 5). Plot 2, the second closest to the smelter in the southeastern transect had the second highest level at 0.69. Lead concentrations found in all other plots were not different from the background levels found in plot 8 (table 19).

Zinc levels were found to be highest in samples from plot 5 (46.12 ug/gm). A gradient of decreasing zinc concentration with increasing distance from the smelter was found in plots 1, 2, 3 and 4 of the southeastern transect and plots 5, 6 and 7 of the southern transect (figure 5). Samples from plot 8 had background levels of 12.86 ug/gm for zinc (table 19).
Cadmium concentrations from plot 5 samples were the highest with a mean value of 0.19 ug/gm. Samples from plot 7 which were considerably further from the smelter than those at plot 5 (i.e. 35.7 km as compared to 5.8 km) were found to be very close to those of plot 5 at 0.17 (table 19). The mean value found in samples from the plot 8 control were 0.10 and this level was also found in samples from plots 1, 3 and 4 (table B2.5). There does not appear to be a significant relationship between cadmium levels found in black spruce cones and distance from the stack.

Samples from plot 5 had the highest copper levels of all (3.83 ug/gm). Copper values found in black spruce cones at all plots of both transects followed a similar pattern as those found in zinc (figure 5). A distinct gradient of decreasing copper concentration with increased distance from the smelter was found in plots 1, 2, 3 and 4 of the southeastern transect and in plots 5, 6 and 7 of the southern transect (table 19).

In summary, it is evident from figures B2.4 (a-d) that the highest concentrations of lead, zinc, cadmium and copper in black spruce cones are found in samples from plot 5 located 5.8 km south of the smelter. A gradient of decreasing zinc and copper concentration as distance increased from the smelter was found in plots located on both the southeastern and southern transects.

SECTION C

SOIL ANALYSIS

Metal Levels in Soils

The zinc content of the LFH level of the soil as a function of distance from the smelter stack is shown in Figure 6. These results demonstrate that large increases in zinc have occurred in the surface layers of soils that are close to the smelter stack. Zinc levels of sites closer than 5 km to the stack are in excess at 6000 ug/g. The levels of zinc in decline in an exponential fashion to a background level of about 300 ug/g, which appears to be fairly consistent for these boreal forest litter samples (indicated by the dotted line). Metal dispersal in a south east direction is shown to be up to a distance of 20 km from the stack. At distances in excess at 20 km the level of zinc in these surface layers of the soil does not differ significantly from background. This distribution is similar to that shown by Frazin and McFarlane (1976) following their snow
sampling study conducted during the period of Nov. 75 - Feb. 76. They showed that during the winter months at least, dispersal of most particulates was skewed in southeast direction. If this is the case then the 15-20 km radius of metal accumulation shown in Fig. 6 represents a maximum detectable range for the particulate dispersal. A log/log plot of the same data is shown in Figure 7. The linear relationship between log 10 of LFH zinc concentration and log 10 of the distance from the stack (<0.001) suggests that there is a direct relationship between the two and that the zinc levels on the LFH are as a direct result of atmospheric fallout of metal particulates being released by the stack. The levels of zinc which are present in the LFH layers close to the stack are very high and are in excess of those shown to be prohibitive to a number of biological processes. Tyler (1974) demonstrated that levels of copper and zinc in excess at 2000 mg/kg had a significant effect on the respiration and enzymatic activity (urease and acid phosphatase) of a number of soils associated with a brass foundry. Workers in the United States (Spalding 1979) have been able to demonstrate that 1000 mg/kg Zn added to Douglas fir needle litter inhibited respiration of these samples. The samples examined from the Flin Flon area, are clearly in excess of the levels reported to inhibit respiration and enzymatic activity by both of these authors. The implication is that sites which possess levels of zinc in excess at 2000 mg/kg may be rendered less productive because decomposition has been inhibited. If decomposition of litter is inhibited then release of nutrients from this pool will be reduced, this reduction of nutrient availability would ultimately lead to reduced productivity. The presence of the metal within the soil will reduce not only the size of nutrient pool within the various compartments (litter layer, mineral soil, plants) but will also restrict the ability of plants to obtain nutrients. Zinc has been shown to inhibit root growth (Hogan 1978), when the growth of roots is inhibited the ability of the plant to take up nutrient is impaired. This would also lead to a reduction in productivity.

The deposition pattern of copper and lead is similar to that shown for zinc. High levels of these metals are found in the soils close to the stack with a exponential decline in a gradient away from the stack. The concentrations of lead and copper are not as high as those of zinc but are sufficiently high at sites close to the stack to be of concern. Levels of lead and copper in the surface organic layer are well in excess of 1000 mg/kg. These levels are 10+20 times the background levels reported from plot 8 in table 20. The levels of copper and lead found at plots 1-7 differ significantly from the level found at plot 8, indicating that significant deposition of metals is occurring at distances of 35 km from the source.
Figure 6. The pattern of accumulation of zinc in the LFH layer of the soil in a southeast direction. The dashed line indicates the background level of zinc for the area.
Figure 7. A log/log plot of the data presented in Figure 6. The linear relationship between the transformed data and distance is apparent.
Table 20. The total elemental content of soils from the permanent study sites in Flin Flon. Values are the means of six replicates.

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from Stack (km)</th>
<th>Copper</th>
<th>Lead</th>
<th>Zinc</th>
<th>Potassium</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Manganese</th>
<th>Iron</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil LFH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.1</td>
<td>1538 g</td>
<td>808 e</td>
<td>7399 e</td>
<td>4111 a</td>
<td>14292 a</td>
<td>2178 ab</td>
<td>456 b</td>
<td>13884 ed</td>
<td>1120 b</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>1143 f</td>
<td>3052 f</td>
<td>4636 e</td>
<td>5758 a</td>
<td>21384 ab</td>
<td>2469 abc</td>
<td>916 d</td>
<td>12012 bcd</td>
<td>1051 b</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>334 d</td>
<td>392 d</td>
<td>1346 d</td>
<td>5082 a</td>
<td>19624 ab</td>
<td>2474 abc</td>
<td>730 c</td>
<td>6931 abc</td>
<td>1079 b</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>77 b</td>
<td>107 b</td>
<td>282 b</td>
<td>5757 a</td>
<td>15194 a</td>
<td>3925 bc</td>
<td>227 ab</td>
<td>5781 ab</td>
<td>726 a</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>1204 f</td>
<td>502 dc</td>
<td>6216 e</td>
<td>3519 a</td>
<td>37376 c</td>
<td>3490 bc</td>
<td>116 c</td>
<td>10982 bcd</td>
<td>895 ab</td>
</tr>
<tr>
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<td>14.6</td>
<td>493 d</td>
<td>585 dc</td>
<td>1484 d</td>
<td>11416 b</td>
<td>15718 ab</td>
<td>4364 c</td>
<td>826 cd</td>
<td>18971 d</td>
<td>945 ab</td>
</tr>
<tr>
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<td>35.7</td>
<td>109 c</td>
<td>197 c</td>
<td>527 c</td>
<td>6206 a</td>
<td>22741 b</td>
<td>2476 abc</td>
<td>866 ed</td>
<td>7978 bc</td>
<td>1101 b</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>26 a</td>
<td>28 a</td>
<td>98 a</td>
<td>3868 a</td>
<td>14907 a</td>
<td>1747 a</td>
<td>326 bc</td>
<td>4262 a</td>
<td>1053 b</td>
</tr>
<tr>
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<td>378 d</td>
<td>1153 c</td>
<td>18561 b</td>
<td>15129 ab</td>
<td>9790 b</td>
<td>686 de</td>
<td>37966 bc</td>
<td>751 e</td>
</tr>
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<td>8.9</td>
<td>116 e</td>
<td>52 e</td>
<td>312 b</td>
<td>20109 bc</td>
<td>16372 abc</td>
<td>7805 b</td>
<td>915 c</td>
<td>37497 bc</td>
<td>663 e</td>
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<td>20 a</td>
<td>9 a</td>
<td>70 a</td>
<td>23642 bc</td>
<td>19028 c</td>
<td>10354 b</td>
<td>361 abcd</td>
<td>41039 b</td>
<td>369 b</td>
</tr>
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<td>28445 c</td>
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<td>15878 c</td>
<td>477 bcde</td>
<td>49739 b</td>
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<td>3242 d</td>
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<td>43202 d</td>
<td>4005 a</td>
<td>192 a</td>
<td>11550 a</td>
<td>784 e</td>
</tr>
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<td>25 bc</td>
<td>229 b</td>
<td>19395 b</td>
<td>17254 abc</td>
<td>8945 b</td>
<td>615 cde</td>
<td>40120 b</td>
<td>534 bc</td>
</tr>
<tr>
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<td>35.7</td>
<td>55 bc</td>
<td>6 a</td>
<td>79 a</td>
<td>21652 bc</td>
<td>19151 c</td>
<td>14788 c</td>
<td>342 abc</td>
<td>61759 b</td>
<td>411 b</td>
</tr>
<tr>
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<td>68.2</td>
<td>42 b</td>
<td>11 ab</td>
<td>102 a</td>
<td>27944 c</td>
<td>18030 bc</td>
<td>15977 c</td>
<td>300 ab</td>
<td>55796 b</td>
<td>652 e</td>
</tr>
<tr>
<td>Soil 5-10 cm depth</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>5.1</td>
<td>148 d</td>
<td>75 d</td>
<td>419 b</td>
<td>21169 b</td>
<td>21091 ab</td>
<td>11967 bc</td>
<td>473 bc</td>
<td>59896 bc</td>
<td>522 ab</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>52 bc</td>
<td>10 bc</td>
<td>179 a</td>
<td>23856 bc</td>
<td>15011 a</td>
<td>9904 b</td>
<td>679 c</td>
<td>47468 b</td>
<td>502 ab</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
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<td>27473 b</td>
<td>19302 b</td>
<td>11636 bc</td>
<td>345 abc</td>
<td>42953 b</td>
<td>410 ab</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>62 bc</td>
<td>6 ab</td>
<td>83 a</td>
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<td>13690 a</td>
<td>16749 d</td>
<td>441 bc</td>
<td>55847 bc</td>
<td>333 a</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>490 c</td>
<td>391 e</td>
<td>1877 b</td>
<td>3982 a</td>
<td>31871 b</td>
<td>3891 a</td>
<td>215 a</td>
<td>7549 a</td>
<td>887 c</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>52 bc</td>
<td>17 c</td>
<td>131 a</td>
<td>23966 b</td>
<td>16297 a</td>
<td>11521 bc</td>
<td>433 bc</td>
<td>47098 b</td>
<td>547 ab</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>84 c</td>
<td>3 a</td>
<td>83 a</td>
<td>22449 b</td>
<td>18647 ab</td>
<td>17454 d</td>
<td>346 abc</td>
<td>75041 c</td>
<td>470 ab</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>37 ab</td>
<td>12 bc</td>
<td>82 a</td>
<td>29519 b</td>
<td>19258 ab</td>
<td>15517 cd</td>
<td>265 ab</td>
<td>51511 bc</td>
<td>567 b</td>
</tr>
<tr>
<td>Soil 10-15 cm depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.1</td>
<td>94 cd</td>
<td>25 b</td>
<td>262 b</td>
<td>22075 b</td>
<td>16897 bc</td>
<td>12740 b</td>
<td>515 b</td>
<td>63665 bc</td>
<td>434 bc</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>65 bcd</td>
<td>6 b</td>
<td>144 a</td>
<td>24952 b</td>
<td>14921 ab</td>
<td>11699 b</td>
<td>484 ab</td>
<td>53211 bc</td>
<td>487 bc</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>23 a</td>
<td>11 ab</td>
<td>86 a</td>
<td>26767 b</td>
<td>18374 bc</td>
<td>11790 b</td>
<td>310 ab</td>
<td>41333 bc</td>
<td>391 ab</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>47 bc</td>
<td>6 ab</td>
<td>80 a</td>
<td>31623 b</td>
<td>12451 a</td>
<td>17010 bc</td>
<td>374 ab</td>
<td>57016 bc</td>
<td>308 a</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>304 a</td>
<td>213 c</td>
<td>1349 c</td>
<td>7677 a</td>
<td>42865 d</td>
<td>5483 a</td>
<td>314 ab</td>
<td>12788 a</td>
<td>793 d</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>86 bcd</td>
<td>9 ab</td>
<td>99 a</td>
<td>24457 b</td>
<td>15707 bc</td>
<td>13344 b</td>
<td>364 ab</td>
<td>55386 bc</td>
<td>563 c</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>120 d</td>
<td>2 a</td>
<td>79 a</td>
<td>23142 b</td>
<td>19593 c</td>
<td>21414 c</td>
<td>214 ab</td>
<td>81433 c</td>
<td>537 bc</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>41 b</td>
<td>11 ab</td>
<td>87 a</td>
<td>29546 b</td>
<td>19834 c</td>
<td>17290 bc</td>
<td>259 a</td>
<td>52638 bc</td>
<td>580 c</td>
</tr>
</tbody>
</table>

Means followed by the same letter are not significantly different at the 0.05 level according to the Student-Neuman-Keuls procedure.

Statistical analysis was carried out on log<sub>10</sub> transformed data.

The results presented in table 20 were subjected to a correlation analysis. The results shown in table 21 indicate that there is a strong correlation between distances from the stack and metal level in the LFH.
Table 21. Correlation coefficients for total soil LFH metal levels and distance from the smelter stack. Coefficients were calculated from log$_{10}$ transformed data.

<table>
<thead>
<tr>
<th></th>
<th>Zinc</th>
<th>Copper</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>-0.9757</td>
<td>-0.9717</td>
<td>-0.8215</td>
</tr>
<tr>
<td>Zinc</td>
<td></td>
<td>0.9787</td>
<td>0.8517</td>
</tr>
<tr>
<td>Copper</td>
<td></td>
<td></td>
<td>0.9201</td>
</tr>
</tbody>
</table>

All are significant at the 0.001 level

This correlation is significant at the .001 level. No significant differences have been found from soils on the south or southeast transect, these results suggest that a more or less even distribution of metal particulates occurs over the south southeast sector of the study area. The strong positive correlation between the metals indicates that they are released from the same source.

Metal leaching

The metals which are deposited in the LFH layer are not necessarily restricted to this upper organic layer of the soil. In heavily contaminated sites there is ample evidence that the metal is leaching into the lower mineral soil layers (table 20). Most of the leaching is taking place in sites which are a 10 km or closer to the stack. The metal level is highest in the upper layers of the mineral soil, which would be expected and decreases in magnitude as the depth into the soil increases. This trend is indicative of the atmospheric source of the metal versus an edaphic origin. The eluviation of zinc from the LFH is decreased as distance increases and consequently as the size of the zinc pool in the litter is decreased.

At sites which are closer than 10 km to the stack, the LFH layer appears to have reached its limit with respect to the amount of metal that can be retained. As new metal is added to this layer from the atmospheric source it will ultimately move into the mineral soil. The data shown in table 20 indicates that when zinc levels in the LFH layer are in excess of 4000 mg/kg significant amounts of zinc are released into the mineral soil below. Sites # 1, 2, 5 and 6 show a significant (0.05) release of zinc into the mineral soil. This release is shown to increase the zinc levels of the
lower strata to a depth of 10 cm. At sites # 3 and 4 there was no evidence of the release of zinc from the LFH. While there is no evidence of release of zinc into the mineral soil from the LFH layer at site # 3 there is evidence that these soil sites shows significant accumulations of zinc in the surface layer (table 20). Obviously the amount of zinc trapped within the LFH layer of the soil, at this site, has not exceeded the capacity of that layer to bind and retain zinc.

While the situation is more pronounced with respect to zinc movement a similar situation exists for copper and lead. At the sites most heavily contaminated with metals, there is a significant metal release into the mineral soil, this is demonstrated by the copper and lead values shown for plot 1 and 2 at the 0-5 cm depth. At a greater depth the situation is true for sites 1 and site 5.

Table 22. The pH LFH and mineral soil samples from Flin Flon. The mineral soil samples were taken from three depth intervals. Values shown are means of six determinations +/- 95% confidence limits. Means followed by the same letter are not significantly different at the 0.05% level according to the Student-Nueman-Kuels procedure.

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
<th>LFH 0-5 cm Fraction</th>
<th>10 – 15 cm Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.1</td>
<td>4.64 +/- 0.19 a</td>
<td>4.90 +/- 0.45 ab</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>5.18 +/- 0.36 a</td>
<td>4.76 +/- 0.32 ab</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>4.99 +/- 0.67 a</td>
<td>4.81 +/- 0.23 ab</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>4.78 +/- 0.77 a</td>
<td>5.76 +/- 0.58 c</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>6.96 +/- 0.27 b</td>
<td>7.13 +/- 0.21 d</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>4.46 +/- 0.49 a</td>
<td>5.20 +/- 0.23 b</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>5.34 +/- 0.40 a</td>
<td>4.46 +/- 0.23 a</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>4.57 +/- 0.69 a</td>
<td>4.79 +/- 0.35 ab</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
<th>5 – 10 cm Fraction</th>
<th>10 – 15 cm Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.1</td>
<td>3.45 +/- 1.69 a</td>
<td>4.22 +/- 0.16 a</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>4.16 +/- 0.16 abc</td>
<td>4.16 +/- 0.16 a</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>4.47 +/- 0.07 abc</td>
<td>4.57 +/- 0.15 a</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>5.28 +/- 0.66 c</td>
<td>5.34 +/- 0.82 b</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>6.82 +/- 0.29 d</td>
<td>6.76 +/- 0.19 c</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>4.66 +/- 0.31 bc</td>
<td>4.65 +/- 0.36 a</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>4.06 +/- 0.34 ab</td>
<td>4.22 +/- 0.35 a</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>4.50 +/- 0.20 abc</td>
<td>4.55 +/- 0.20 a</td>
</tr>
</tbody>
</table>
Site 5 which shows elevated levels of copper, lead and zinc at all levels appears to be an anomaly. The high levels of metal in the lower layers are a function of 1) the organic nature of these soils and 2) the horizontal movement of water which occurs at this site. Because these (Plot 5) soils are experiencing a great deal of lateral water movement they may be concentrating metals which would remain in the surface layer of a more typical site. Leaching studies are based on the assumption that water movement will occur downward in the vertical plane because of these results the atypical values obtained for the lower soil layers from plot 5 will be ignored.

Soil Nutrients

An analysis of the various soil macro nutrients was carried out to determine whether all sites were similar. This information is required for later experiments with soils and plant growth experiments. The results which appear in table 20 indicate that differences do exist between sites. There is no consistent relationship with distance from the stack except that site # 5 is the most-atypical for all elements for the reasons which have been discussed. It would appear that the sites are variable with respect to their total elemental composition. This however 'does not mean that plants growing thereon will respond to pollutants in a different manner, but it may be an indication that this could occur. Relationships between extractable metals taken levels total levels of nutrients must be examined before statements can be made concerning the growth response of trees at any affected site.

Soil Acidification

A study was initiated to determine whether or not soil acidification has taken place with respect to distance from the stack. A number of studies have indicated that atmospheric release of SO₂ results in an increase soil and lake acidification. Results of this study are shown in table 22. These results indicate that no significant differences exist with respect to the soil LFH pH as a function of distance from the source. The surface layer would be the layer that would most clearly demonstrate the greatest acidification effect. Hutchinson and Whitby (1974) clearly demonstrated the effect of distance from an SO₂ source on soil acidity in Sudbury, Ontario. In this study sites closer to the stack than 5 km showed increased acidity as a result of acidic rainfall. The soils examined were most acidic at the surface and the effect decreased at deeper
soil depths. The results of the analysis of mineral soils shown in table 22 indicate that there is a significant difference between sites (1, 2, 3) and site # 4, the latter site has a significantly higher pH at all three depths examined. This effect cannot be attributed to distance from the source and is probably due to the nature of the parent material. Since the soils are higher in magnesium at all levels it is not possible to demonstrate a trend in the pH of the surface horizon it would be highly improbable that one would exist in the mineral soil.

The reasons that there has been no change in soil pH (at sites <5 km from the stack) despite considerable emission of SO₂ over a long period of time are not known. However, it is most likely because of the buffering capacity of the mor organic layer. The soils examined by Hutchinson and Whitby (1974) were mainly mineral soils, which had been exposed after removal of the surface organic layer by erosion. It would be expected that these soils would be more subject to changes in pH than the soils which were examined in the present study.

Site 5, is again an anomaly, with a considerably higher pH than all of the other sites. Despite its close proximity to the stack, as shown by its high metal levels this site remains alkaline or only slightly acidic. These results demonstrate the high buffering capacity of certain soils in the Flin Flon area.

FOLIAR ANALYSIS

Foliar Analysis of four species from the Flin Flon area was carried out. The intention was to examine foliar levels of pollutants and nutrients to determine whether significant pollutant induced changes had taken place.

The results of the analysis of jack pine foliage are shown in table 23. They show that there is a significant relationship between copper, iron, lead and zinc content and distance from the smelter stack. There does not appear to be any significant effect on the level of macro nutrients present in the foliage of jack pine. Similar results are found for the other species examined - black spruce (table 24), alder (table 25) and Labrador tea (table 26) with a few exceptions. At the moment these relationships cannot be verified but are being investigated by further sampling.
Table 23  The pollutant and nutrient content of jack pine foliage from the study sites in the Flin Flon area.

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Fe</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.1</td>
<td>27.9 f</td>
<td>37.6 d</td>
<td>363. a</td>
<td>3417. ab</td>
<td>5155. a</td>
<td>967. a</td>
<td>296. a</td>
<td>1107. a</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>32.7 d</td>
<td>32.7 d</td>
<td>294. d</td>
<td>4338. b</td>
<td>5930. a</td>
<td>1146. a</td>
<td>208. e</td>
<td>1208. a</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>12.8 d</td>
<td>15.6 bc</td>
<td>201. c</td>
<td>4160. b</td>
<td>5987. a</td>
<td>1122. a</td>
<td>126. c</td>
<td>1217. a</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>8.3 c</td>
<td>13.8 bc</td>
<td>95. a</td>
<td>3145. a</td>
<td>4100 a</td>
<td>1664. b</td>
<td>155. d</td>
<td>1237. a</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>29.2 f</td>
<td>61.9 e</td>
<td>506. e</td>
<td>4074. b</td>
<td>5470. a</td>
<td>1011. a</td>
<td>298. a</td>
<td>1393. a</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>10.6 c</td>
<td>18.3 c</td>
<td>184. c</td>
<td>3760. a</td>
<td>4484. a</td>
<td>1229. a</td>
<td>184. de</td>
<td>1343. a</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>5.5 b</td>
<td>10.7 b</td>
<td>137. b</td>
<td>4362. b</td>
<td>3883. a</td>
<td>1231. a</td>
<td>102. b</td>
<td>1273. a</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>3.4 a</td>
<td>5.2 a</td>
<td>75. a</td>
<td>3995. b</td>
<td>5880. a</td>
<td>1208. a</td>
<td>61. a</td>
<td>1087. a</td>
</tr>
</tbody>
</table>

Values shown are means of six determinations. Means followed by the same letter are not significantly different at the .05% level according to the Student-Nueman-Kuels procedure.
Table 24  The pollutant and nutrient content of black spruce foliage from the study sites in the Flin Flon area.

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
<th>Copper</th>
<th>Lead</th>
<th>Zinc</th>
<th>Potassium</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Iron</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.1</td>
<td>10.1 e</td>
<td>13.5 d</td>
<td>227. c</td>
<td>6698. a</td>
<td>8527. a</td>
<td>783. a</td>
<td>127. d</td>
<td>1144. a</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>7.9 d</td>
<td>10.9 d</td>
<td>165. b</td>
<td>6296. a</td>
<td>6450. a</td>
<td>797. a</td>
<td>76. cd</td>
<td>1268. ab</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>6.9 d</td>
<td>8.9 bc</td>
<td>163. b</td>
<td>5624. a</td>
<td>6760. a</td>
<td>925. ab</td>
<td>76. cd</td>
<td>1268. ab</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>3.7 b</td>
<td>4.9 a</td>
<td>76. a</td>
<td>5162. a</td>
<td>4668. a</td>
<td>1002. ab</td>
<td>102. d</td>
<td>1446. ab</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>18.1 f</td>
<td>31.4 e</td>
<td>455. d</td>
<td>5937. a</td>
<td>8126. a</td>
<td>1185. a</td>
<td>203. e</td>
<td>1446. ab</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>4.7 c</td>
<td>7.2 ab</td>
<td>132. b</td>
<td>6358. a</td>
<td>6356. a</td>
<td>1230. ab</td>
<td>72. cd</td>
<td>1629. b</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>3.5 b</td>
<td>6.7 ab</td>
<td>120. b</td>
<td>5646. a</td>
<td>7601. a</td>
<td>1009. ab</td>
<td>48. b</td>
<td>1606. b</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>2.1 a</td>
<td>4.9 a</td>
<td>62. a</td>
<td>5255. a</td>
<td>6140. a</td>
<td>1304. b</td>
<td>21. a</td>
<td>1763. b</td>
</tr>
</tbody>
</table>

Values shown are means of six determinations. Means followed by the same letter are not significantly different at the .05% level according to the Student-Nueman-Kuels procedure.
Table 25 The pollutant and nutrient content of alder (*Alnus sp.*) foliage collected from the study sites in the Flin Flon area.

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>Distance from stack (km)</th>
<th>Copper</th>
<th>Lead</th>
<th>Zinc</th>
<th>Potassium</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Iron</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.1</td>
<td>31.9 e</td>
<td>17.1 c</td>
<td>289. c</td>
<td>5428. a</td>
<td>8759. ab</td>
<td>2163. a</td>
<td>200. e</td>
<td>1177. a</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>27.3 de</td>
<td>16.6 c</td>
<td>226. c</td>
<td>6372. ab</td>
<td>8042. a</td>
<td>2067. a</td>
<td>206. de</td>
<td>1417. b</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>24.4 d</td>
<td>16.5 c</td>
<td>145. b</td>
<td>10129. d</td>
<td>10587. b</td>
<td>3640. cd</td>
<td>166. cd</td>
<td>1458. b</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>9.0 a</td>
<td>7.4 a</td>
<td>55. a</td>
<td>8348. bcd</td>
<td>7967. a</td>
<td>4451. d</td>
<td>144. bc</td>
<td>1274. b</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>40.9 f</td>
<td>38.0 d</td>
<td>473. d</td>
<td>8578. bcd</td>
<td>14672. c</td>
<td>2624. b</td>
<td>274. f</td>
<td>982. a</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
<td>16.4 c</td>
<td>11.4 b</td>
<td>145. b</td>
<td>7004. abc</td>
<td>9164. ab</td>
<td>3171. e</td>
<td>229. ef</td>
<td>1384. b</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>9.9 ab</td>
<td>9.7 b</td>
<td>53. a</td>
<td>8064. bcd</td>
<td>10866. b</td>
<td>3664. ed</td>
<td>127. b</td>
<td>1201. b</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>11.1 b</td>
<td>14.7 c</td>
<td>69. a</td>
<td>9141. cd</td>
<td>13636. c</td>
<td>4209. d</td>
<td>87. a</td>
<td>1452. b</td>
</tr>
</tbody>
</table>

Values shown are means of six determinations. Means followed by the same letter are not significantly different at the .05% level according to the Student-Newman-Keuls procedure.
The pollutant and nutrient content of Labrador tea (*Ledum sp.*) foliage collected from the study sites in the Flin Flon area.

<table>
<thead>
<tr>
<th>Distance from stack (km)</th>
<th>Copper</th>
<th>Lead</th>
<th>Zinc</th>
<th>Potassium</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Iron</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>32.6 f</td>
<td>21.2 c</td>
<td>324. d</td>
<td>7854. cd</td>
<td>7832. b</td>
<td>1009. a</td>
<td>191. d</td>
<td>1174. a</td>
</tr>
<tr>
<td>8.9</td>
<td>17.1 d</td>
<td>15.4 bc</td>
<td>166. b</td>
<td>6186. b</td>
<td>6528. ab</td>
<td>1123. a</td>
<td>114. bc</td>
<td>1113. a</td>
</tr>
<tr>
<td>15.5</td>
<td>23.1 e</td>
<td>19.6 bc</td>
<td>223. c</td>
<td>9243. d</td>
<td>6912. ab</td>
<td>1808. b</td>
<td>180. d</td>
<td>1548. b</td>
</tr>
<tr>
<td>38.1</td>
<td>6.6 a</td>
<td>6.6 a</td>
<td>60. a</td>
<td>4435. a</td>
<td>7199. ab</td>
<td>1435. b</td>
<td>90. a</td>
<td>1004. a</td>
</tr>
<tr>
<td>5.8</td>
<td>34.9 f</td>
<td>33.7 d</td>
<td>376. d</td>
<td>6787. bc</td>
<td>6247. a</td>
<td>1627. b</td>
<td>315. e</td>
<td>1082. a</td>
</tr>
<tr>
<td>14.6</td>
<td>12.6 c</td>
<td>14.7 b</td>
<td>150. b</td>
<td>4727. a</td>
<td>6562. ab</td>
<td>1853. b</td>
<td>125. c</td>
<td>1139. a</td>
</tr>
<tr>
<td>35.7</td>
<td>7.1 ab</td>
<td>7.7 a</td>
<td>74. a</td>
<td>5736. b</td>
<td>7734. b</td>
<td>1891. b</td>
<td>98. ab</td>
<td>1224. a</td>
</tr>
<tr>
<td>68.2</td>
<td>7.9 b</td>
<td>6.1 a</td>
<td>61. a</td>
<td>5859. b</td>
<td>7068. ab</td>
<td>1878. b</td>
<td>85. a</td>
<td>1616. b</td>
</tr>
</tbody>
</table>

Values shown are means of six determinations. Means followed by the same letter are not significantly different at the .05% level according to the Student-Newman-Kuels procedure.
The copper, iron, lead and zinc values presented on tables 23-26 represent metal particulates which are on the outside of the leaf and metallic ions and complexes which are an integral part of the leaf. At present it is not possible to divest the leaf of the external metal particulate without affecting the internal composition of some other element.

The internal zinc has been acquired by natural processes; absorption by the root and translocation to the shoot system. The external metal has been deposited onto the leaf surface and may not have a significant effect on the function of the leaf. It will however be freely available to herbivores, which eat the foliage and to microbial populations in the soil which breakdown organic materials.

**Jack Pine Foliage vs. Soil Zinc**

A distinct linear relationship (figure 8) exists between jack pine foliar zinc levels and the levels of zinc in the LFH material. This relationship does not indicate that all of the zinc found in the leaf material has been translocated from the soil via the roots but rather, that both have been achieved through aerial deposition of metal particulate.

**PHYSICAL TRAPS - MOSS BAGS**

Soil and foliar analysis provides information concerning deposition over time. In the case of soils deposition of particulates could be occurring over several decades. For foliar materials deposition usually takes place over one field season or perhaps more when considering conifers. Using the proper methods it is possible to determine relative rates of deposition and areas of impingement by the use of physical traps. A sampling network of physical traps (moss rings or bags) was established in Flin Flon in 1978 and has been described in the methods section. Some of the results of this endeavor are shown in figure 9 (for June-July, 1978).
Figure 8. The relationship between the zinc levels found in soil LFH samples and those found in the foliage of jack pine.
Figure 9a. Zinc content of physical traps exposed for June-July, 1978.

Figure 9b. Copper content of physical traps exposed for June-July, 1978.
The results shown in this figure indicate that a log/log relationship exists between copper and zinc levels found in moss bags and distance from the smelter. The results indicate that the vast majority of metal fallout occurs within 10 km of the smelter but that a measurable deposition of copper/zinc occurs up to 30 km from the source. Levels of metals in the moss bag are highly correlated with those in the soil and indicate that the deposition patterns which contributed to the metals in the soil material are still in effect. The results of a correlation analysis shown in table 27 indicate the strong relationship which exists between metals which are being emitted. It also shows the correlations between the levels of pollutants in the soil LFH layer and the levels found in the moss bags for the June-July period in 1978. All correlations were highly significant.

Table 27. Correlation coefficients for total soil LFH levels of metals and metals in moss bags for the months of June-July, 1978

<table>
<thead>
<tr>
<th></th>
<th>Cu Moss</th>
<th>Pb Moss</th>
<th>Cu Soil</th>
<th>Zn Soil</th>
<th>Pb Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn Moss</td>
<td>0.9539</td>
<td>0.9165</td>
<td>0.8896</td>
<td>0.8878</td>
<td>0.6924</td>
</tr>
<tr>
<td>Cu Moss</td>
<td>0.9595</td>
<td>0.9289</td>
<td>0.9177</td>
<td>0.7663</td>
<td></td>
</tr>
<tr>
<td>Pb Moss</td>
<td>0.8554</td>
<td>0.8272</td>
<td>0.7229</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu Soil</td>
<td>0.9452</td>
<td>0.8439</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn Soil</td>
<td></td>
<td>0.6754</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All correlations are significant (p<0.001)

SNOW SAMPLING SURVEYS

Air pollutant particulates are known to accumulate in the winter snow pack and the chemical analysis of snow is a useful tool in determining the identity, quantity and distribution of pollutants near sources of air pollution. A snow survey of each sample plot in the Flin Flon network was conducted in early March 1979 and January 1980. Results to date include sulphate and heavy metal analysis of the 1979 samples and pH values from the 1980 survey as presented in the following sections. Detailed sampling procedures are found in section A3.3.4.

Results of 1979 Snow Survey

Chemical analysis results of 1979 samples for sulphates, zinc, nickel, lead, copper, iron, arsenic and cadmium are summarized in table 28 and graphically presented in figure 10, 11, 12 and 13.
<table>
<thead>
<tr>
<th>Number from stack</th>
<th>Distance</th>
<th>Place</th>
<th>Pb</th>
<th>Cu</th>
<th>Fe</th>
<th>As</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
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</tr>
<tr>
<td>4</td>
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<td></td>
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<td>3</td>
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<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The results of sulphate and zinc analysis are illustrated in figure 10. The highest sulphate values were found to be 10 mg/l at plot 5 located 5.8 km south of the stack. The second highest values were found at plots 1 and 2 in the southeastern transect at 6.2 mg/l. Snow samples from all other plots including the control were at the detection limit of the instruments (table 28).
Figure 12: Levels of Arsenic and Cadmium found in snow, Flin Flon, 1979.

Figure 13: Levels of Copper and Iron found in snow, Flin Flon, 1979.
The results of analysis for zinc were considerably higher. Samples from plot 2 were found to contain the most zinc (43.0 mg/l). Results of zinc analysis from plots both indicated a distinct gradient of decreasing zinc levels with increasing distance from the smelter.

Levels of nickel and lead found in 1979 snow samples are shown in figure 11. In general, nickel values were not found to be above background and did not fall in any particular pattern with regard to the smelter.

Lead levels shown in figure 11 are quite different from those of nickel. In this case, plot 5 samples contained excessively higher levels (0.42 mg/l) than all other sample plots. A distinct gradient of decreasing levels exists in both the southern (plots 5, 6-7) and the southeastern transects (plots 1, 2, 3, 4) as indicated in figure 11. Background levels at plot 8 were found to be 0.012 mg/l and were identical to those at plot 7.

In figure 12, analysis results for copper and iron display clear patterns of decreased deposition with increased distance from the smelter in both the southeastern and southern transects. Results of iron analysis again show that the highest accumulation occurs at plot 5 (1.19 mg/l) while the furthest plot in the southern transect, plot 7, is considerably lower at 0.17. In the southeastern transect, levels decrease with increasing distance from the smelter.

Arsenic and cadmium values are graphically presented in figure 13 and once again, greatest accumulation of these elements is found in samples from plot 5 (table 28). Arsenic values ranged from 0.068 mg/l to less than 0.001 at plot 8. Once again, a relationship between decreasing accumulation and increasing distance from the smelter is clearly illustrated in figure 13 for plots in both the southeastern and southern transects. Results for cadmium concentration were found to be 0.02 mg/l at plots 5 and at 0.005 or less for all other sample plots. No patterns of deposition with distance are noted from figure 13.

Summary of 1979 Snow Survey

Results of chemical analysis for sulphate concentration in the 1979 snow samples did not reveal any clear deposition patterns with regard to distance from the smelter in either the southern
or southeastern transects.

Particulate deposition of cadmium and nickel did not illustrate any distance relationship between element concentration and distance from the smelter.

A distinct gradient of decreasing particulate deposition with increasing distance from the smelter was noted in analysis of zinc, lead, copper, iron, arsenic and cadmium. Levels of zinc accumulation were highest at plot 2, 43.0 mg/l, and ranged down to background levels of 0.28 mg/l. The highest accumulation of lead, copper, iron, arsenic and cadmium was found to be in snow samples from plot 5 located 5.8 km south of the smelter.

Results of 1980 Snow Survey

Generally speaking the results of the 1980 snow survey are similar to those found for the 1979 survey. Distinct gradients are found for sulphate and zinc (figure 15), lead (figure 14), copper and iron (figure 16) and arsenic (figure 17) in relation to distance from the source. Nickel and cadmium do not show any gradient.

pH values are given in table 29, there is no distinct relationship between distance and the acidity of snow samples. All samples are slightly acidic but there is no indication of a severe acid problem. This is true of the 1979 results also. (table 28).

Summary of 1980 Snow Survey

A gradient of arsenic, copper, iron, lead, sulphate and zinc was found in the snow samples from the Flin Flon area. These results confirm the results of analytical work conducted in other parts of the study.
<table>
<thead>
<tr>
<th>Number</th>
<th>Distance from stack (cm)</th>
<th>pH</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>Fe</th>
<th>Zn</th>
<th>Cu</th>
<th>Pb</th>
<th>As</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.67</td>
<td>15.0</td>
<td>0.005</td>
<td>0.19</td>
<td>1.78</td>
<td>0.078 &gt; 0.005</td>
<td>0.01</td>
<td>0.005</td>
<td>0.013 &gt; 0.005</td>
<td>0.01</td>
<td>0.02 &gt; 0.005</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
<td>5.0</td>
<td>3.4</td>
<td>0.425</td>
<td>0.94</td>
<td>0.067 &gt; 0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.002</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>5.84</td>
<td>5.0</td>
<td>10.6</td>
<td>0.005</td>
<td>0.010</td>
<td>0.26 &gt; 0.005</td>
<td>0.075</td>
<td>1.4</td>
<td>1.0</td>
<td>0.026</td>
<td>0.005</td>
</tr>
<tr>
<td>4</td>
<td>38.1</td>
<td>5.0</td>
<td>15.0</td>
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<td>0.005</td>
<td>0.015</td>
<td>0.47</td>
<td>0.023</td>
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<td>0.005</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>6.0</td>
<td>0.01</td>
<td>0.005</td>
<td>0.015</td>
<td>0.005</td>
<td>0.122</td>
<td>0.94</td>
<td>0.005</td>
<td>0.002</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>6</td>
<td>10.2</td>
<td>5.0</td>
<td>1.26 &gt; 0.005</td>
<td>0.005</td>
<td>0.075</td>
<td>1.62</td>
<td>1.0</td>
<td>0.005</td>
<td>0.035</td>
<td>0.005</td>
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<td>0.005</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>5.0</td>
<td>0.95</td>
<td>0.005</td>
<td>0.005</td>
<td>0.015</td>
<td>0.025</td>
<td>0.47</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>8</td>
<td>68.2</td>
<td>5.0</td>
<td>0.13 &gt; 0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Table 79: Chemical analysis of soil from the study places, Pinj II plan 1980.
Figure 14. Levels of nickel and lead found in snow, 1980.

Figure 15. Levels of sulphate and zinc found in snow, 1980.
Figure 16. Levels of arsenic and cadmium in the snow, 1980.

Figure 17. Levels of copper and iron in the snow, 1980.
SUMMARY AND CONCLUSIONS

Smelting activities in the Flin Flon area have lead to a general decline in the forest community in the immediate vicinity of the smelter. A similar decline has been observed in other regions of North America and is generally attributed to the combined effects of sulphur dioxide and heavy metal particulates.

Severe degradation is obvious in relic jack pine and spruce stands located a few kilometers to the south of the smelter complex. These sites are depleted of species which are sensitive to atmospheric pollutants. A complete absence of lichens and other bryophytes was observed at these sites indicative of the intensity of the fumigations which have occurred in the past. Severe erosion has taken place at these sites and the thin mantle of soil which was present on out crops has been lost. A few pollution tolerant species exist in localized pockets of soil which remain at these sites. In these soil areas symptoms associated with sulphur dioxide and metal particulate injuries are evident.

These areas are found within a few kilometers of the smelter stack. Generally speaking the damage is less obvious at sites which are further removed from the smelter. At these sites the immediate damage is less apparent as it may not be immediately obvious to the untrained observer.

This study has been aimed at investigating areas which are beyond the immediate localized impact zone. The closest study site is 5 km from the stack and was selected on the basis of relatively complete vegetative cover. This means that the major trees species were present and there were no apparent S0₂ or metal injury symptoms on the vegetation. The results given in the study are not maximum or highest values, from areas immediately adjacent to the smelter but values from the actual study sites.

The nature to the pollutant complex in the Flin Flon area is well defined; S0₂, arsenic, cadmium, copper, iron, lead and zinc are the major emitted elements. These results confirm those found in earlier studies. These elements are found in increased levels in almost all materials which are analyzed. What emerges is a general picture of deposition of metal particulates on most surfaces, vegetated or otherwise, around the stack. The rate and extent of pollutant loading is more difficult to determine. The maximum readily detectable extent of metal particulate
deposition in the south and southeast section is 30 km. This has been demonstrated by soil, plant, snow pack and physical trap analysis. Assuming an even distribution of wind frequency and speed around the smelter stack this would mean that a zone 30 km in diameter is currently under the influence of metal deposition from the Flin Flon smelter. This would mean that 280,600 hectares or 698,300 acres are currently accumulating metal particulates. Obviously the forest closer to the stack will be accumulating at a higher rate than the regions on the farthest edge of the 30 km radius. The relationship between metal level and distance from the stack has been clearly demonstrated for a number of the metals.

The rate of accumulation of metal particulates is, of course, a function of particle size, distance from the source, wind speed, surface roughness and a number of other characteristics. Any rate of accumulation must be calculated from each plot from existing reliable data. The most reliable estimates would come from soils data which have been corrected for background levels of metals. As an example, if we assume that plot 1 has accumulated zinc in the LFH layer at a constant rate over 50 years (an unlikely assumption) the metal would have been accumulated at the rate of 147 mgZn/Kg soil/Yr. to reach the present day level of 7400 mg/Kg. This level is more than seventy times the background concentration of zinc. The annual deposition rate would decrease, however, as one moved away from the stack.

The effect of pollutant loading on the forest system itself is much more difficult to determine. Our investigations to date have examined community structure, reproduction processes, nutrient composition of the major species involved in each community. The preliminary conclusions based on these investigations are that:

1. there has been no significant effect on the presence or absence of higher plant (trees, shrubs) at distances greater than 5 km from the source.

2. there is a definite absence of lichens, mosses and other lower plants from the sites which are closest to the smelter stack. This would appear to be a direct effect of S02 fumigation and metal deposition. Further work is required to identify a more definite causal relationship

3. there has been no significant effect of pollutant emission on the ability of conifers to set seed. There is also no effect on the ability of that seed to germinate in vitro. There may be an effect on seed weight but this does not appear to effect
4. there has been a significant effect on the foliar level of metals (internal and external) but this has not had an effect on the nutrient composition of the foliage of the dominant species.

5. there has been a significant accumulation of metals in the soil LFH material. This is of concern from the standpoint of soil microbial activity and stand regeneration.

The latter effect is one of great concern and attempts are being made at present to investigate the effects of metals in soils on the rooting capacity of seedlings. At sites close to the source it is doubtful whether seedlings could germinate and grow in the native soils. Investigations in other areas, and in the present study have shown this to be a problem in metal contaminated areas. Seedlings cannot survive on the site then it is obvious that the regeneration potential is extremely limited.

These same soils also pose a problem from the standpoint of microbial decomposition of organic materials. The presence of high levels of metals will inhibit the action of the soil microflora and fauna in breaking down the forest litter. An accumulation of organic materials would be expected to result in a reduction in the rate of nutrient release and ultimately the productivity of the site. Both, microbial activity and regeneration potential of each site are being examined in detail as part of the continuing forest study.

The present study has made a significant inroad into understanding the magnitude of the effect of smelter effluents in the Flin Flon area. A great deal of background information on baseline conditions with respect to species presence, composition, nutrient status, pollutant deposition and rate of accumulation has been obtained. However, more information is required before it will be possible to determine the ultimate long term fate of the forest system which surrounds the smelter complex.
LITERATURE CITED


