ALBERTA OIL SANDS
ENVIRONMENTAL
RESEARCH PROGRAM

Ecological Bench-marking and Biomonitoring for Detection of Airborne Pollutant Effects on Vegetation and Soils

Project LS 3.4

December 1980

Alberta
ENVIRONMENT

15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta, Canada
T5K 2J6

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

RESEARCH REPORTS

These research reports describe the results of investigations funded under the Alberta Oil Sands Environmental Research Program. This program was designed to direct and co-ordinate research projects concerned with the environmental effects of development of the Athabasca Oil Sands in Alberta.

A list of research reports published to date is included at the end of this report.

Enquiries pertaining to the reports in the series should be directed to:

Research Management Division
15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta
T5K 2J6
(403) 427-3943

Ecological Bench-Marking and Biomonitoring for Detection of Airborne Pollutant Effects on Vegetation and Soils

Project LS 3.4

AOSERP Report 111

This report may be cited as:

Addison, P.A. 1980. Ecological bench-marking and biomonitoring for detection of airborne pollutant effects on vegetation and soils. Prep. for the Alberta Oil Sands Environmental Research Program by Northern Forest Research Centre, Canadian Forestry Service. AOSERP Report 111. 48 pp.

The Hon. J.W. (Jack) Cookson
Minister of the Environment
222 Legislative Building
Edmonton, Alberta

Sir:

Enclosed is the report "Ecological Bench-Marking and Biomonitoring for Detection of Airborne Pollutant Effects on Vegetation and Soils.

This report was prepared for the Alberta Oil Sands Environmental Research Program, through its Land System, under the Canada-Alberta Agreement of February 1975 (amended September 1977).

Respectfully,

W. Solodzuk, P.Eng.
Chairman, Steering Committee, AOSERP
Deputy Minister, Alberta Environment

ECOLOGICAL BENCH-MARKING AND BIOMONITORING FOR DETECTION OF AIRBORNE POLLUTANT EFFECTS ON VEGETATION AND SOILS

DESCRIPTIVE SUMMARY

Long term exposure to low concentrations of pollutants may result in changes in composition of plant communities and soils leading to forest decline. Early detection of pollutants in such a decline is important for maintaining environmental quality and providing a basis for review of emissions standards and controls. Biomonitoring is a technique whereby biological samples are used both as indicators of pollution impingement and as a measure of pollution impact.

This study was undertaken to: (1) evaluate the effects of air-borne pollutants on structure and composition of native vegetational communities; (2) relate these changes in community structure to the differential physiological responses of the species; and (3) document the baseline levels of potentially hazardous air pollutants in the AOSERP study area.

Several biomonitoring techniques were tested throughout the 5 year study period of this project. The biomonitoring plots established in 1976 and 1977 did not reveal any measurable changes in the vascular plant community of the lower stratum, the cryptogamic plant community of black spruce branches, or in the chemical composition of both soils and plants.

This report has been reviewed and accepted by the Alberta Oil Sands Environmental Research Program.

W.R. McDonald

W.R. MacDonald
Director

ECOLOGICAL BENCH-MARKING AND BIOMONITORING FOR DETECTION OF AIRBORNE POLLUTANT EFFECTS ON VEGETATION AND SOILS

by

P.A. ADDISON

Northern Forest Research Centre

Canadian Forestry Service

for

ALBERTA OIL SANDS

ENVIRONMENTAL RESEARCH PROGRAM

Project LS 3.4

December 1980

TABLE OF CONTENTS

TABLE OF CONTENTS (CONCLUDED)

LIST OF TABLES

LIST OF TABLES (CONCLUDED)

LIST OF FIGURES

ABSTRACT

Biomonitoring plots established in 1976 and 1977 were revisited in 1979 and quantified with respect to their vascular plant community of the lower stratum, lichen community of black spruce branches, and both soil and plant element contents. There was no measurable change in any of the above factors.

Several biomonitoring techniques were tested throughout the 5 year study period of this project. Although there was little measurable effect of air pollution in the area as a whole, certain techniques showed promise for long-term biomonitoring for pollution effects.

In general, there was only very limited evidence of biological responses to increased pollutant content in spite of significantly higher pollutant levels in tissues close to existing industrial developments.

ACKNOWLEDGEMENTS

The research Project LS 3.4 was funded by the Alberta Oil Sands Environmental Research Program, a joint Alberta-Canada research program, established to fund, direct, and co-ordinate research into the effects of oil sands development on the renewable resources of the Athabasca Oil Sands. Field and laboratory assistance provided by J. I. Ridgway, R. A. Blundon, S. Abbas, F. Radford, and M. Grandmaison is gratefully acknowledged.

1. INTRODUCTION

Biomonitoring is a technique whereby biological samples are used both as indicators of air pollution impingement and as a measure of air pollution impact. Obviously, the state of health of any organism is the best measure of air pollution impact on that organism. In addition, biomonitoring may relate to specific processes or formations in the ecosystem. In the same manner as with the organism, the process or whole plant community response is the most effective way to assess pollutant impact to those ecosystem components.

Several plant groups, particularly mosses and lichens, have been shown to be very efficient in taking up and storing airborne pollutants (Addison and Puckett in press). If the vegetation of an area can provide a reliable and consistent measure of both the impingement and impact of a specific pollutant, the expense of establishing and maintaining high technology monitoring instrumentation can be eliminated in certain cases.

In the Athabasca Oil Sands area, there appears to be little obvious air pollution injury to the forest ecosystem as a result of Suncor operations (Addison and Baker 1979a). In spite of this, the potential for forest injury in northeastern Alberta is particularly great in view of the current and proposed expansion of oil sands extraction and processing by Syncrude Canada, Alsands, and several other oil companies and consortia (Chaapel 1974). In response to this concern, a set of biomonitoring sites was established in 1976 and 1977 in order to determine a current condition of forest vegetation in the oil sands area (Addison and Baker 1979a; Addison 1980).

The aims of this study in 1979 were to:

1. Re-examine the biomonitoring sites in an attempt to assess air pollution impact over the past 3 to 4 years; and
2. Assess the effectiveness of several techniques to detect air pollution injury to forest components.

2. STUDY AREA

Jack pine stands at 13 locations were chosen for permanent plots (Figure 1, Table 1). Each stand was dominated by *Pinus banksiana* Lamb. and had an understory of *Cladina* lichens where possible. In all cases, the most open stand was selected to ensure the maximum exposure of all components at each location. These locations were selected in 1976 based upon winter pollutant deposition patterns, topography, and distance from both current and proposed pollutant sources in the area (Addison 1980). In addition, several sites where certain biomonitoring techniques were being tested (Figure 2; Addison and Baker 1979b) were maintained in 1979.

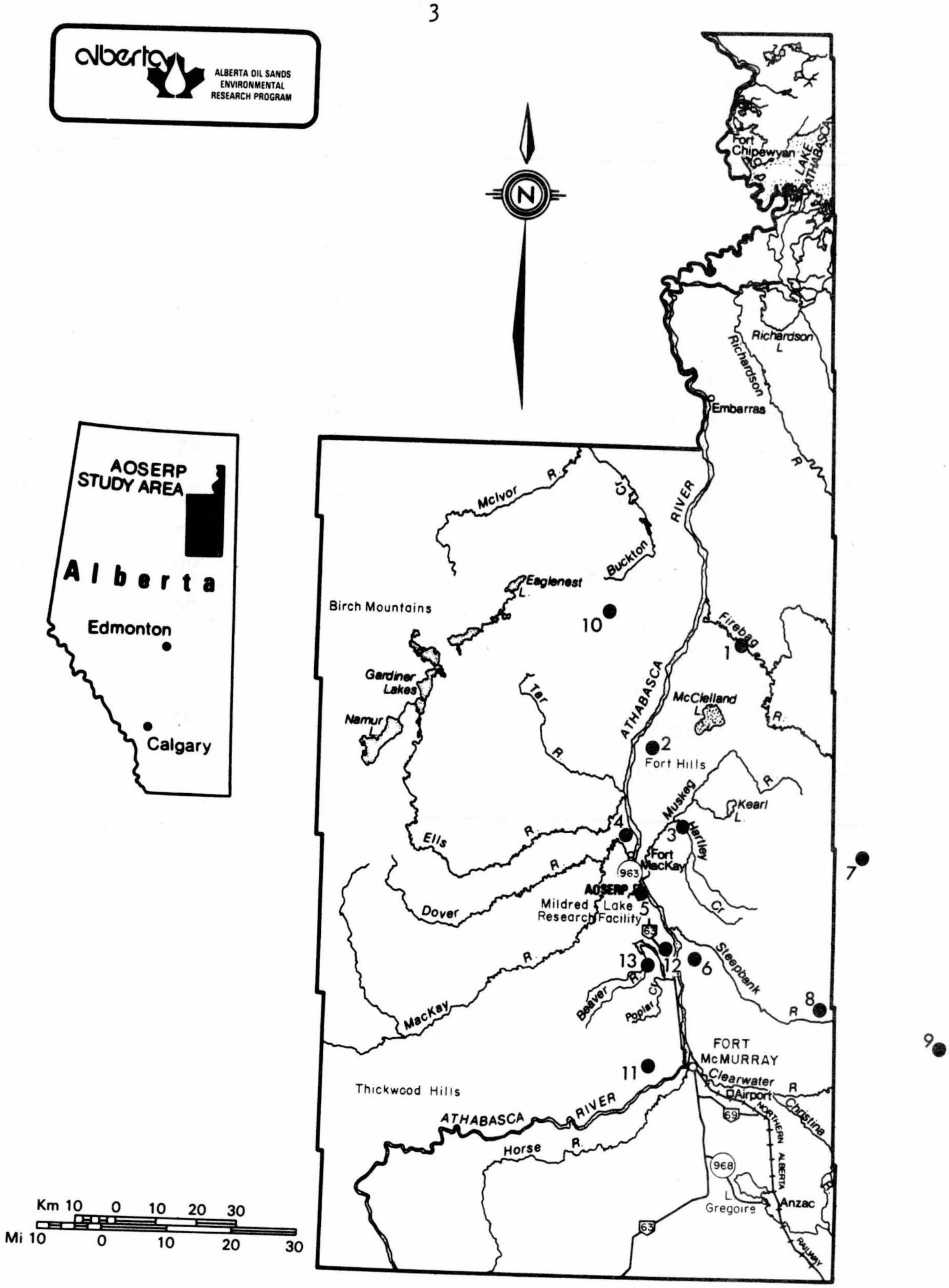

Figure 1. Location of permanent biomonitoring plots in the Athabasca Oil Sands area. For site names, see Table 1.

Table 1. Legal description of jack pine biomonitoring sites in the Athabasca Oil Sands area.

Site Number	Site Name	LSD	Sec	Twp	Range
1	Firebag River	14	02	100	8
2	Bitumount Tower	15	27	96	10
3	Hartley Creek	13	09	95	9
4	Fort MacKay	12	36	94	11
5	Mildred Lake Camp	1	19	93	10
6	Fina Airstrip	15	20	92	9
7	Muskeg Mountain	4	15	94	6
8	North Steepbank River	8	32	90	7
9	Gordon Lake	10	11	88	4
10	Birch Mountain	10-11	24	100	12
11	Thickwood Hills	4	34	89	11
12	Gradient Site A	7	14	92	10
13	Gradient Site D	11	2	92	10

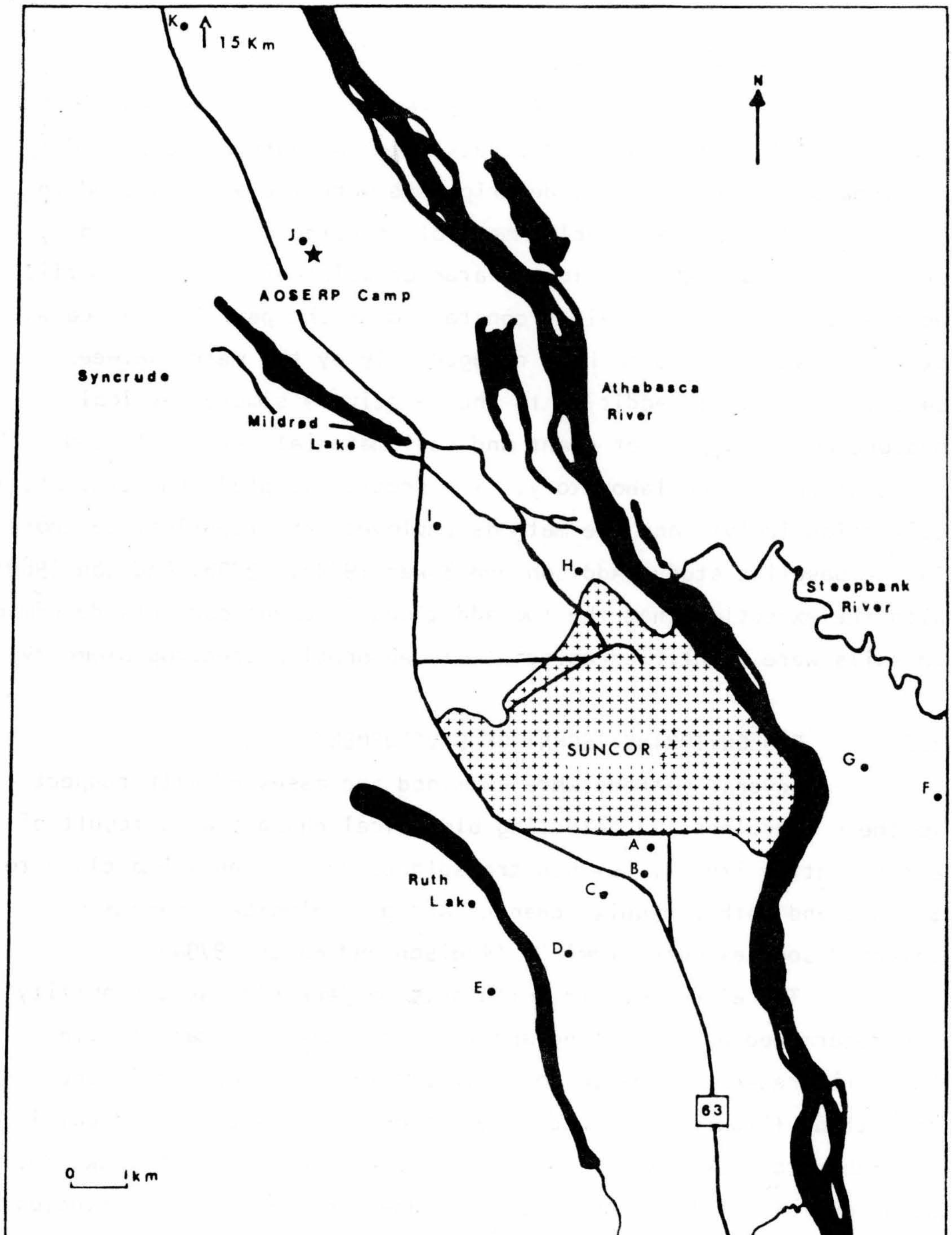

Figure 2. Location of gradient sites and other specific sites used to test biomonitoring techniques.

3. MATERIALS AND METHODS

3.1 SITE RE-EXAMINATION

All sites examined in 1979 were quantified as described previously (Addison 1980). Quadrats used for both vascular and cryptogamic plant community descriptions were the same as used in 1976 and 1977 for the establishment of baseline conditions. Both stand density and the physical characteristics of the soil profile were assumed to have remained constant over the past 3 to 4 years. Stand age was assumed to have changed only by the years between sampling times. In addition to the relatively simple physical measurements, samples of plant and soil material were collected and analyzed in the laboratory. The species sampled, the time of collection (July), and the methods employed were identical to those in the baseline study (Addison and Baker 1979a, 1979b; Addison 1980), with the exception that the two additional element contents determined in soils were quantified using atomic absorption spectrophotometry.

3.2 BIOMONITORING TECHNIQUE DEVELOPMENT

Several methods were examined and assessed with respect to their usefulness in detecting biological changes as a result of air pollution impact. Lichen transplants were established close to Suncor, and both community changes and physiological changes of selected species were examined (Addison and Baker 1979a).

The effect of air pollutants on jack pine seed viability was determined by collecting and testing seeds from mature (i.e., 35 year) trees at sites (A to E) of varying distances from Suncor operations (Figure 2). Seed germination tests were carried out in the laboratory by placing three to five replicates of 50 jack pine seeds on moist filter paper at 20°C (day) and 16°C (night) fluctuating temperatures in the light. Germination was recorded after 3 wk.

Radial increment growth of jack pine was determined at five sites (A, G, H, J, and K, Figure 2) by taking two cores from the south and west sides of from five to 10 trees at each site. The increment for each of the previous 20 years was measured with an Addo-X Tree Ring Measuring Instrument, and the data from the two cores were averaged. Age (at 30 cm above ground) of the trees sampled was also determined since only cores that went through the centre were retained.

At a site close to the pollution source (Site A) and at one about 10 km distant (Mildred Camp), five branches from the top one-third of each of five trees were collected. The length (distance between bud scale scars in millimetres) and the number of needles were determined for each of five age classes on each branch. Tree ages at both sites were from 35 to 40 years. The content of Al, Fe, and S was also determined for each sample of needles by techniques described by Addison (1980).

The biological measurements that were selected to demonstrate plant response to air pollutants characteristic of oil sands operations were compared with physical measurements of pollutant deposition as either a gas (Huey Sulphation Plates) or in total (precipitation and fallout collectors). Methods followed Addison and Baker (1979b) with the exception that the collectors did not utilize a resin column and liquid samples were concentrated through evaporation in the laboratory. The solutions were analyzed using methods described for soil extracts by Addison and Baker (1979b).

4. RESULTS AND DISCUSSION

4.1 SITE RE-EXAMINATION

4.1.1 Vascular Plant Community Description

As stated previously (Addison 1980), no distinct pattern in the 1976 stand description was evident that could be related to the distance of sites from oil sands operations. Figure 2 shows the 1979 pattern of sites superimposed on the 1976 synthesis. The four groups of sites that were related to stand density and site moisture status in 1976 (Addison 1980) were even more clearly defined in the 1979 results. In examining how similar 1979 observations were in comparison to 1976 ones, no relationship with distance or direction could be detected (Table 2). Five sites were less than 85% similar in 1979 compared with 1976, but none of these sites was within the zone of maximum impingement (Addison and Puckett 1980). In addition, the sites with the least change could not be related to distance or direction from the source. It is possible that some of the changes in cover and frequency of plant species at these sites were a result of error in placement of quadrats from one sampling time to another. Individual quadrats were mapped but not permanently marked; hence, errors in re-positioning may have been responsible for some of the changes seen in Figure 2.

In general, the examination of jack pine stands over time (1976 to 1979) provided no evidence of vegetation decline. There was, therefore, no measureable effect of the Suncor operations on the jack pine plant community in the Athabasca Oil Sands area.

4.1.2 Lichen Community Description

All 11 sites where lichen communities were quantified in 1976 were re-examined in 1979 with respect to the cover of the four species groups (Table 3) described by Addison (1980). No significant differences in cover between 1976 and 1979 were found for any species group at any site, with two exceptions (Table 4). Evernia showed a

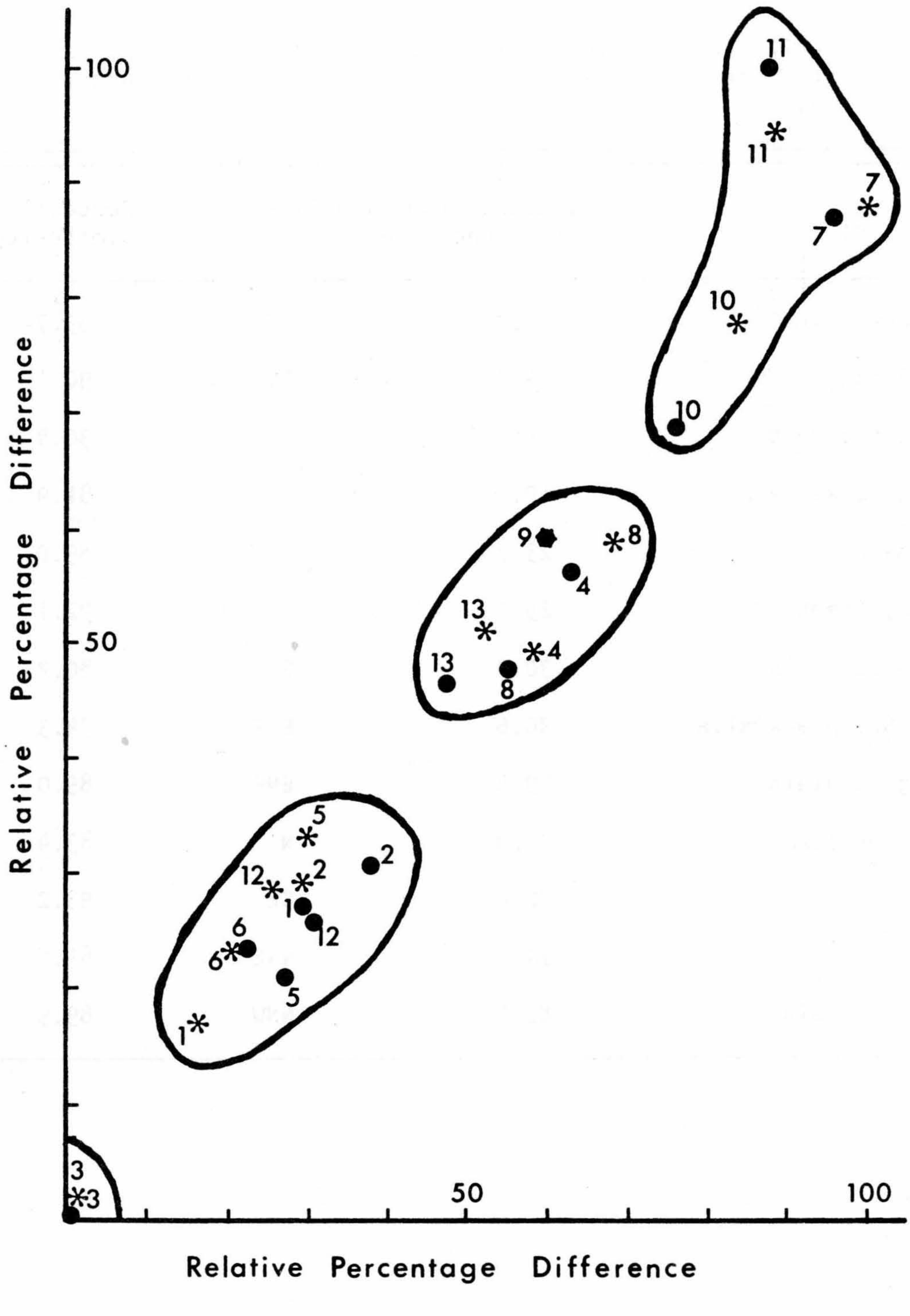

Figure 3. Bray-Curtis ordination of jack pine biomonitoring plots based on frequency-cover indices of lower stratum vascular plants 1976 (•) and 1979 (*).

Table 2. Similarity of sites in 1976 versus 1979 from a Bray-Curtis ordination of lower stratum vascular species frequency-cover indices.

Site	Distance (km) and Direction from Suncor Inc.		Percent Similarity
Gradient Site A	2.8	SSW	89.7
Fina Airstrip	4.0	ESE	90.1
Gradient Site D	5.3	SSW	90.4
Mildred Lake Camp	10.5	NW	81.9
Fort MacKay	23.7	NNW	89.0
Hartley Creek	25.0	N	92.1
Thickwood Hills	30.0	SW	80.2
North Steepbank River	30.6	ESE	74.3
Muskeg Mountain	39.4	ENE	85.0
Bitumount Tower	39.8	N	83.4
Gordon Lake	72.8	SE	93.2
Firebag River	74.0	NNE	81.5
Birch Mountain	80.0	NNW	89.9

Table 3. Predominant macrolichens occurring on black spruce branches in the Athabasca Oil Sands area of Alberta. Group name indicates grouping used in transplant studies.

Species	Group
Evernia mesomorpha Nyl.	Evernia
Usnea spp. (tufted)	Evernia
Usnea spp. (pendulate)	Evernia
Ramalina spp.	Evernia
Hypogymnia physodes (L.) W. Wats.	Hypogymnia
Parmelia sulcata Tayl.	Hypogymnia
Cetraria halei W. Culb & C. Culb	Cetraria
C. pinastri (Scop.) S. Gray	Cetraria
Bryoria glabra (Mot.) Brodo & D. Hawksws	Bryoria

Table 4. Changes in cover of dominant lichen species groups at biomonitoring sites in the Athabasca Oil Sands area.

Site	Year	Evernia	Bryoria	Hypogymnia	Cetraria
1. Firebag	1976	29.37 ± 3.50	0.35 ± 0.24	4.57 ± 0.93	2.05 ± 0.93
River	1979	31.77 ± 3.93	0.40 ± 0.30	5.30 ± 0.72	2.44 ± 0.90
	Difference	2.4	0.05	0.73	0.39
3. Hartley	1976	10.35 ± 4.16	0	7.01 ± 1.20	0.36 ± 0.25
Creek	1979	2.72 ± 2.42	0	8.04 ± 3.02	0.48 ± 0.40
	Difference	-7.63 [a]	0	1.03	0.12
4. Fort MacKay	1976	36.53 ± 5.99	0.37 ± 0.24	5.68 ± 0.72	0.51 ± 0.26
	1979	34.45 ± 5.02	0.08 ± 0.07	6.44 ± 0.92	1.09 ± 0.58
	Difference	-2.08	-0.29 [b]	0.76	0.58
5. Mildred	1976	44.15 ± 3.68	0.98 ± 0.35	9.09 ± 3.11	0.65 ± 0.32
Camp	1979	47.25 ± 3.12	0.60 ± 0.43	10.75 ± 1.97	0.87 ± 0.39
	Difference	3.10	-0.38	1.66	0.22
6. Fina	1976	10.03 ± 6.14	0.12 ± 0.15	7.22 ± 2.96	1.28 ± 1.13
Airstrip	1979	7.61 ± 6.54	0.04 ± 0.09	5.89 ± 2.72	1.51 ± 1.15
	Difference	-2.42	-0.08	-1.33	0.23
8. North	1976	25.42 ± 5.22	0.28 ± 0.20	2.77 ± 0.67	2.28 ± 0.47
Steepbank	1979	22.19 ± 7.16	0.31 ± 0.22	3.35 ± 0.97	1.73 ± 0.40
River	Difference	-3.23	0.03	0.58	-0.55
9. Gordon	1976	26.33 ± 4.60	0.33 ± 0.18	5.26 ± 0.72	1.38 ± 0.57
Lake	1979	23.73 ± 5.84	0.12 ± 0.19	4.87 ± 1.42	1.07 ± 0.53
	Difference	-2.60	-0.21	-0.39	-0.31
10. Birch	1976	24.42 ± 5.49	0.34 ± 0.36	3.55 ± 0.67	0.60 ± 0.32
Mountain	1979	22.87 ± 5.09	0.06 ± 0.10	3.47 ± 0.76	0.39 ± 0.35
	Difference	-1.55	-0.28	-0.08	-0.21
11. Thickwood	1976	10.57 ± 2.45	0.07 ± 0.07	3.97 ± 0.56	2.90 ± 0.72
Hills	1979	11.21 ± 4.78	0.12 ± 0.11	4.07 ± 0.70	2.63 ± 0.58
	Difference	0.64	0.05	0.10	-0.27
Syncrude	1976	41.52 ± 4.93	0.30 ± 0.24	8.71 ± 1.53	1.44 ± 0.45
Turnoff	1979	38.46 ± 5.85	0.29 ± 0.25	7.84 ± 1.94	1.65 ± 0.87
	Difference	3.06	-0.01	0.87	0.21
Mildred	1976	3.93 ± 2.33	0.09 ± 0.09	7.05 ± 0.91	0.23 ± 0.18
Airstrip	1979	2.24 ± 2.27	0.09 ± 0.20	5.83 ± 1.42	0.28 ± 0.27
	Difference	-1.69	0	-1.22	0.05

significant ($p < 0.01$) reduction in cover at Hartley Creek, and Bryoria showed a significant ($p < 0.05$) reduction at Fort MacKay. Whether these changes were a result of sampling or analytical errors or whether these changes represent the natural variation that can be expected with this technique is not known. Since both of these sites were well removed from the pollution source and since all but one species group at each site showed no significant change from 1976 to 1979, it is extremely unlikely that atmospheric pollutants had any role in causing these changes.

One difficulty with this technique is the natural attrition of the permanent sampling quadrats. In the first 4 years of study, eight quadrats or 7.5% of the total were lost for a variety of reasons. This indicated that, unless damaged or lost quadrats were replaced on a regular basis, the maximum period of time over which this type of study could be conducted is about 20 years. It is estimated that by that time, sufficient loss of lichen quadrats may occur so that effective analysis and interpretation of the results may not be possible.

4.1.3 Element Content

4.1.3.1 Soils. No distinctive pattern could be detected in the S, Al, or Fe content of soils from the biomonitoring plots either individually (Appendix 8, Tables 16, 17, 18) or when combined into groups of varying distances from the Suncor operation (Table 5). Although the magnitude of the means of the total S, Ni, and V contents of the LFH horizon seem to show a pattern of decreasing levels with distance from Suncor (Table 5), the variability was very great. In spite of the great variability, these increases of S, Ni, and V in the LFH close to Suncor may be of significance since levels of these elements in the C horizon (parent material) were actually lower close to the pollutant source. The raised levels therefore appear to be related to pollutant deposition rather than site specific characteristics. Substantially more sampling is necessary, however, before a definite conclusion can be reached. Sulphur levels in the LFH appear to be higher than those

Table 5. Element content (ppm) of soils from the biomonitoring sites in the Athabasca Oil Sands area 1979.

Distance From	Ammonium Acetate Extract (1N @ pH 4.8)					Total Digest (HNO + HF)				
Suncor (km)	LFH	Ahe	Ae	Bm	C	LFH	Ahe	Ae	Bm	C
SULPHUR										
<10	7	1	1	3	1	629	71	39	42	34
	±14					±434	±29		±51	±70
10-25	7	3	-	2	2	585	34	-	35	40
	±14	±6		±5	±5	±310	±1		±56	±20
>25	8	<1	<1	1	1	542	106	57	81	94
	±4	±1	±1	±1	±2	±200	±88	±47	±60	±72
ALUMINIUM										
<10	41	32	35	101	37	7 270	6 579	8 194	12 261	8 536
	±93	±27		±22	±75	±2 792	±6 316		±6 316	±5 052
10-25	7	34	-	55	27	4 726	9 431	-	15 010	13 351
	±16	±27		±86	±60	±9 608	±9 527		±14 713	±14 144
>25	28	67	72	130	68	7 660	11 799	14 475	21 207	18 389
	±15	±56	±68	±105	±71	±3 467	±11 062	±10 316	±10 434	±10 756
IRON										
<10	20	11	16	32	8	3 512	2 537	3 354	6 815	5 461
	±51	±19		±54	±16	±2 709	±2 618		±6 504	±5 382
10-25	6	29	-	16	6	2 408	2 832	-	6 503	7 173
	±5	±58		±18	±3	±1 889	±2 091		±5 899	±4 092
>25	10	23	30	28	11	3 208	3 262	4 372	10 091	8 278
	±4	±16	±24	±17	±8	±1 217	±1 232	±3 072	±5 064	±3 811
VANADIUM										
<10						217	25	-	26	18
						±356	±26		±14	±39
10-25		NOT				70	13	-	25	23
	DETECTABLE					±62	±34		±60	±49
>25						35	22	25	30	28
						±10	±16	±8	±12	±16
NICKEL										
<10	7	1	N/D[a]	N/D	N/D	105	7	5	4	5
	±12	±1				±185	±5		±2	±2
10-25	2	N/D	-	N/D	N/D	34	2	-	7	6
	±1					±16	±1		±8	±9
>25	1	1	<1	N/D	N/D	24	6	7	14	11
	±1	±1				±6	±8	±6	±11	±10

[a] N/D = Not Detectable

measured in 1976-77 (Addison 1980) whereas, in the Ah and Ahe horizons, S levels were lower in 1979. The rest of the profile appears unchanged over the 3 year period. In 1979, Ni and V were added to the elements of interest (Appendix 8, Tables 19, 20) since they are present in the industrial emissions and may be phytotoxic (Malhotra and Khan 1979; LeSueur and Puckett 1980). In addition, an ammonium acetate extract at pH 4.8 (close to the soil pH) was analyzed and will permit comparison in future years. The most apparent limitation of this approach to pollutant deposition is the amount of sampling that is required for an accurate estimate of the element content of soils. It is necessary to sample the soil in a very detailed manner since this will be the only way that an accurate estimate of the soil chemical regime can be obtained. This should be done in the very near future.

4.1.3.2 Selected plant species. Unlike the soils, most of the plant species sampled demonstrated decreasing levels of S, Al, and Fe with increasing distance from Suncor (Table 6). The pattern was very similar to that measured in 1976-77 (Addison 1980). It appears that for all plant species, except *Ledum groenlandicum*, leaf S content (Appendix 8, Table 21) reflects the air quantity (Table 15). Lichens and mosses seem to present a more distinct pattern of S, Al, and Fe content than did vascular plants when compared with distance from Suncor (Table 6). Vascular plants have been shown to exclude pollutants through stomatal control (Farrar et al. 1977; Caput et al. 1978) and, in fact, plant populations resistant to SO_2 injury have been shown to have higher stomatal resistance (Braun 1977). Feathermoss appeared to be the best pollutant deposition indicator. Dry lichens are virtually inert to pollutants (Marsh 1975) and, since boreal forest ground lichens are dry for much of the year (Rouse and Kershaw 1971), it was not surprising that lichens did not show as distinct a pollutant deposition pattern as feathermoss.

Using feathermoss as a bioindicator, the gradients in pollutant content seen in 1976-77 (Addison 1980) appear to be still present. In addition, a much more distinct maximum impingement zone

Table 6. Element content (ppm) of plant material from biomonitoring plots in the Athabasca Oil Sands area, 1979 (mean ± 95% confidence limits).

	Distance from Suncor (km)[a]	*Pinus banksiana*	*Picea glauca*	*Arctostaphylos uva-ursi*	*Ledum groenlandicum*	Ground Lichens	Feathermoss
	<10	870 ± 120	566 ± 78	564 ± 44	1060 ± 137	327 ± 43	1209 ± 146
SULPHUR	10-25	705 ± 83[b]	604 ± 65	482 ± 63	1297 ± 143	255 ± 28	853 ± 96
	>25	653 ± 42	412 ± 52	439 ± 48	985 ± 58	154 ± 17	682 ± 50
	<10	702 ± 86	166 ± 30	308 ± 68	334 ± 52	484 ± 117	2021 ± 358
ALUMINIUM	10-25	624 ± 76	205 ± 99	237 ± 45	203 ± 37	341 ± 55	1096 ± 121
	>25	470 ± 33	48 ± 20	106 ± 24	107 ± 16	203 ± 23	730 ± 48
	<10	184 ± 36	99 ± 12	153 ± 21	203 ± 17	143 ± 26	1098 ± 201
IRON	10-25	108 ± 30	108 ± 28	164 ± 38	152 ± 27	224 ± 58	798 ± 159
	>25	60 ± 5	44 ± 5	68 ± 8	77 ± 5	107 ± 6	348 ± 22

[a] Three sites occurred 10 km from Suncor, three sites from 10 to 25 km, and seven sites 25 km.

[b] Vertical lines indicate means not significantly different ($p < 0.05$) in a Student-Newman-Keuls test.

extending to about 10.5 km is evident (Appendix 8, Tables 21, 22, and 23). The levels of S, Fe, and Al in tissue do not appear to be related to the soil concentrations which supports the hypothesis that the source of these elements was the atmosphere.

4.2 BIOMONITORING TECHNIQUE DEVELOPMENT

4.2.1 Lichen Transplants

4.2.1.1 Community analysis. The dominant lichen species occurring on black spruce branches in the Athabasca Oil Sands area (Table 3) form a plant community that was similar to that on scots pine (*Pinus silvestris* L.) in Norway (Horntvedt 1975), on black spruce in Northern Ontario (Yarranton 1972), and on lodgepole pine (*Pinus contorta* Loudon var. *latifolia* Engelm.) on the eastern slopes of the Rocky Mountains (Skorepa and Vitt 1976). Douglas and Skorepa (1976) identified several other lichen species on black spruce branches in the Athabasca Oil Sands area that were not found during this study. Even though each species (Table 3) could be recognized, the species were placed into four groups readily recognizable by a nonlichenologist.

In a relatively nonpolluted area (Fort MacKay), the lichen plots that were transplanted under conifers appeared to change in a manner similar to naturally occurring ones (Table 7). The amount of change in both the transplants (two replicates) and the natural plots (mean of 12 values) over a 3 year period was similar to that in the transplants at Site E (10 replicates) in 2 years (Table 8). The cover of all species groups in lichen transplants under aspen, on the other hand, was reduced substantially. Apparently the reduction resulted from physical damage of the quadrats by aspen branches during high wind incidents. The open microsite did not appear to be affected physically but, unlike all transplants under conifers, showed a reduction in Hypogymnia, which appears to be an effect of exposure. Although the cover of both Evernia and Bryoria groups increased more than at all other locations, no explanation for this is proposed.

Table 7. Change in cover of naturally occuring and transplanted lichen stands at Fort MacKay from 1976 to 1979. A negative sign indicates a reduction.

Habitat	Evernia	Bryoria	Hypogymnia	Cetraria
Naturally Occurring				
Black Spruce	-2.1	-0.3	+0.8	+0.6
Transplants				
Black Spruce	-0.5	-0.1	+1.2	-0.8
White Spruce	-1.4	-0.2	+1.8	+0.7
Jack Pine	+1.3	-0.5	+0.7	+0.2
Trembling Aspen	-25.1	-0.3	-4.3	-0.7
Open	+9.1	+0.7	-1.2	-0.4

Table 8. Change in cover of lichen transplants in the vicinity of Suncor in the Athabasca Oil Sands area from 1977 to 1979. A negative sign indicates a reduction.

Site	Distance from Suncor (km)	Evernia	Bryoria	Hypogymnia	Cetraria
A	2.8	-14.00	-1.05	-1.02	-2.55
C	4.2	-26.08	-0.66	+0.26	-1.53
D	5.3	- 9.33	-0.56	+0.18	-0.10
E	8.3	- 3.74	-0.20	+0.96	+0.13

In general, based upon the response of lichen transplants over a 3 year period, the environments under aspen and in the open were substantially different from those under conifers. Most micro-environments within the canopy of conifer species, however, elicited similar lichen responses with respect to survival and growth. It appears, therefore, that the concern that small changes in micro-environment may dramatically affect lichen community composition and cover on a short-term basis is unfounded. The assumption can be made that, over a 3 year period, lichen transplants positioned within the conifer canopy responded in a manner similar to those occurring naturally if not exposed to air pollutants.

The response of lichen transplants placed under black spruce close to Suncor (Table 8) was dramatically different from that at Fort MacKay (Table 7). Although the changes at Site E (8.3 km) were similar to those at Fort MacKay, all other sites had either a much greater reduction or a much smaller increase in cover by each lichen group during a 2 year period. The change in cover was significantly ($p < 0.01$) correlated with distance from Suncor, but in spite of this it was not possible to demonstrate a regression coefficient that was significantly different from zero. The inability to characterize the response pattern appears to stem from the high level of variability at all sites and the unexpected magnitude of the response at Site C. Addison and Puckett (1980) indicated that Site C had the highest V concentrations in lichen tissue in the area and, in laboratory studies, V has been shown to affect lichens detrimentally at levels found in the field (LeSueur and Puckett 1980). It is proposed, therefore, that the lichen response seen in the vicinity of Suncor is the result of a complex of factors that includes several pollutants as well as natural environmental stresses.

4.2.1.2 <u>Chemical analysis</u>. The results of measurements of the available to total ratios of potassium and magnesium in transplanted *Evernia mesomorpha* material (Table 9) demonstrated no pattern that could be related to either the presence of air pollutants in the area

Table 9. Sulphur content (ppm) and available to total ratios for potassium and magnesium in *Evernia mesomorpha* material transplanted under jack pine canopies in May 1977 at the gradient sites in the Athabasca Oil Sands area.

Element	Site	Time of Sampling			
		May 1977	Sept. 1977	July 1978	July 1979
Potassium	A	0.29	0.24	0.35	0.38
	B	0.28	0.18	0.19	0.37
	C	0.44	0.23	0.27	0.38
	D	0.36	0.20	0.24	0.25
	E	0.31	0.18	0.15	0.17
Magnesium	A	0.22	0.28	0.43	0.46
	B	0.24	0.19	0.34	0.62
	C	0.16	0.22	0.33	0.49
	D	0.17	0.23	0.49	0.16
	E	0.18	0.14	0.28	0.12
Sulphur	A	891	1889	3064	1249
	B	624	1202	2020	1257
	C	915	1324	1700	1434
	D	931	1700	1615	1561
	E	1107	1664	1159	1238

(Addison and Puckett 1980) or to the distance from Suncor operations. During the first year, sulphur content increased in a dramatic and expected manner, but the exceptional losses in S in the second year suggest that the fluxes of S may be very great and, hence, that a measure of S content may not be a particularly good method by which to examine deposition. Variability of all measurements was great, and it is clear that in its present form the introduction of lichen material for detailed examination of S uptake or changes in lichen condition is inadequate as a biomonitoring tool. The technique, however, many be effective if more meaningful biological measurements are made and greater replication is ensured.

4.2.2 Seed Germination

The jack pine seed germination rate appeared to be reduced close to the Suncor operations (Table 10). Site A had a significantly ($p < 0.05$) lower germination rate than Site E, whereas the other sites were intermediate and were not significantly different from either A or E. There was also a significant ($p < 0.05$) correlation of seed germination rate with distance from the source. An arcsine transformation was used on percentage germination to obtain homogeneous variances before a statistical treatment. Seed germination rate did not appear to be related to tree age (Table 10).

4.2.3 Tree Growth

4.2.3.1 Basal area. There did not appear to be a relationship between the cross-sectional area increment and distance from the pollutant source (Table 11). There was actually greater growth in the last 10 years relative to the previous 10 years close to Suncor than at 10 km from the source. Even though this form of self-standardization (comparing each tree's increment with itself before industrialization) can eliminate much of the site-induced variability, it appears that growth changes still need to be very large before detection is possible.

Table 10. Jack pine seed viability of trees in the vicinity of Suncor in the Athabasca Oil Sands area.

Site	Distance from Suncor (km)	Tree Age (years)	Seed Germination (%)
A	2.8	54.6	81.5 [a]
B	3.5	33.6	89.4
C	4.1	29.1	90.9
D	5.3	40.0	94.2
E	8.3	42.0	95.8

[a] Lines join means that are not significantly different ($p < 0.05$) in a Student-Newman-Keuls test.

Table 11. Ratio of wood cross-sectional area growth before versus after start-up of oil extraction process in the Athabasca Oil Sands area in 1966.

Site	Distance (km) and Direction from Suncor		Ratio of wood area 1968-77 ÷ 1957-67 (mean ± 95% confidence limits)
A	2.8	SSW	2.16 ± 1.26
Suncor	3.0	N	1.15 ± 0.16
Steepbank	3.5	ESE	1.02 ± 0.50
Fina	4.0	ESE	1.62 ± 0.29
Mildred Camp	10.5	NW	1.48 ± 0.29

4.2.3.2 Shoot length. Over the past 5 years, the jack pine at Site A produced significantly ($p < 0.01$) longer leaders of the lateral branches than did jack pine at Mildred Camp (Table 12). This observation concurs with the basal area growth measurements that showed over twice the radial growth at Site A (435 $mm^2 \cdot a^{-1}$) than at Mildred Camp (215 $mm^2 \cdot a^{-1}$). The differences seen in Table 12 are presumably a result of substantially better growing conditions at Site A, and air pollution effects have not been great enough to be measurable.

4.2.3.3 Leaf number. The needle number of the most recent three age classes indicated that jack pine sampled at Site A produced more needles than did those at Mildred Camp (Table 13). This is consistent with both the leader length and the basal area increment measurements, which also demonstrated greater growth at Site A than at Mildred Camp. In years 3 and 4, however, there were fewer needles per internode at Site A than at Mildred Camp (Table 13), although the differences were not significant. It is felt that the dramatic reduction in needle number in years 3 and 4 may be a result of premature aging and abscission of leaves caused by air pollutants. Because so many natural factors can influence needle retention, no definite conclusion can be reached. It should be noted that, even if premature needle drop does occur in the vicinity of Suncor, there is no evidence that it has detrimentally affected plant growth.

4.2.4 Physical Pollutant Traps

4.2.4.1 Precipitation collectors. No pattern of pollutant deposition could be detected using samples of precipitation collected at the top of the forest canopy throughout the snow-free period (Table 14). Several sites, however, had exceptionally high levels of certain elements such as copper and sodium relative to the rest of the sites. No explanation for the elevated levels is presented other than that there was a high potential for sample contamination with the methods used. Further work is required on this technique before reliable results can be assured.

Table 12. Leader lengths of lateral branches of jack pine at Site A and at Mildred Camp in the Athabasca Oil Sands area (mean ± 95% confidence limits).

Age Class	Internode Length (cm)	
	Site A	Mildred Camp
Current	21.2 ± 2.2	15.8 ± 1.4[a]
1 year	24.0 ± 2.5	19.3 ± 2.2
2 year	23.4 ± 2.2	17.5 ± 1.9
3 year	27.6 ± 2.5	17.9 ± 1.6
4 year	25.4 ± 2.9	21.2 ± 1.9

[a] There are significant ($p < 0.05$) differences between sites for all age classes.

Table 13. Number of needles per internode of the lateral branches of jack pine at Site A and at Mildred Camp in the Athabasca Oil Sands area (mean ± 95% confidence limits).

Age Class	Number of Needles per Internode		
	Site A	Mildred Camp	Significance
Current	115 ± 10	104 ± 8	NS
1 year	119 ± 11	100 ± 9	$p < 0.05$
2 year	132 ± 13	93 ± 8	$p < 0.001$
3 year	58 ± 22	63 ± 13	NS
4 year	14 ± 10	22 ± 10	NS

Table 14. Precipitation analysis of biomonitoring plots in the Athabasca Oil Sands area in 1979. Values are averages of two to three replicates.

	Sites	Distance (km) and Direction from Suncor		Element Concentration ($\mu g\ L^{-1}$)										
				S	Al	Fe	V	Ni	Ca	Mg	K	Na	Mn	Cu
12	Gradient Site A	2.8	SSW	4	25	27	ND[a]	2	198	22	13	9	2	ND
6	Fina Airstrip	4.0	ESE	4	10	7	ND	1	53	2	39	15	ND	ND
13	Gradient Site D	5.3	SSW	5	17	24	ND	1	108	9	21	2	1	ND
5	Mildred Lake Camp	10.5	NW	9	101	46	ND	3	321	29	21	30	4	8
4	Fort MacKay	23.7	NNW	6	8	12	ND	2	81	15	15	13	1	3
3	Hartley Creek	25.0	N	3	ND	25	ND	3	63	ND	22	18	1	4
11	Thickwood Hills	30.0	SW	3	9	20	ND	1	62	8	80	50	1	1
8	North Steepbank River	30.6	ESE	5	ND	8	ND	ND	27	7	ND	11	1	ND
7	Muskeg Mountain	39.4	ENE	1	30	8	ND	1	29	ND	19	8	2	ND
2	Bitumount Tower	39.8	N	3	9	37	ND	10	352	39	676	54	6	26
9	Gordon Lake	72.8	SE	7	26	21	ND	7	233	23	55	34	2	5
1	Firebag River	74.0	NNE	1	ND	107	ND	4	36	ND	63	32	1	ND
10	Birch Mountain	80.0	NNW	1	7	23	ND	1	65	3	20	17	1	3

[a] ND = Not Detectable

[b] High levels of elements not expected to be present in the environment indicate a high likelihood of sample contamination.

4.2.4.2 Sulphation plates. There were substantial differences in the S deposition to sulphation plates between sites close to Suncor and those some distance away (Table 15). Sulphur deposition was negatively but significantly ($p < 0.05$) correlated with distance from the source. It appears that the SO_2 concentration in the air may be the major factor controlling plant S content, since S deposition to sulphation plates was significantly correlated with jack pine, white spruce, and feathermoss tissue concentrations (Appendix 8, Table 21). It was not possible, however, to correlate S content in the LFH horizon of the soil (Appendix 8, Table 16) with gaseous S deposition (Table 15). Apparently there was little directionality to the S deposition pattern, probably because of the long averaging times of this method (5 mo). This technique appears to provide a reasonable measure of gaseous pollutant deposition and appears useful in providing a reference with which to compare biological measures of S distribution.

Table 15. Deposition of SO_2 to sulphation plates at the biomonitoring sites in the Athabasca Oil Sands area, 1979. Values are averages of four measurements.

	Site	Distance (km) and Direction from Suncor		Sulphur Deposition ($mg \cdot m^{-2} \cdot d^{-1}$)
12	Gradient Site A	2.8	SSW	2.89
6	Fina Airstrip	4.0	ESE	2.54
13	Gradient Site D	5.3	SSW	2.34
5	Mildred Lake Camp	10.5	NW	1.76
4	Fort MacKay	23.7	NNW	0.94
3	Hartley Creek	25.0	N	0.87
11	Thickwood Hills	30.0	SW	0.48
8	North Steepbank River	30.6	ESE	0.23
7	Muskeg Mountain	39.4	ENE	0.70
2	Bitumount Tower	39.8	N	0.46
9	Gordon Lake	72.8	SE	0.19
1	Firebag River	74.0	NNE	0.25
10	Birch Mountain	80.0	NNW	0.26

5. CONCLUSIONS

1. No measureable change in either vascular plant or lichen communities could be detected between 1976 and 1979.
2. No difference was observed in the S, Al, or Fe contents of plant material between measurements taken in 1976 versus these in 1979. In both years, however, higher levels of these elements were found close to Suncor (<10 km) than at same distance away.
3. The LFH horizon of the soil indicated raised levels of S, V, and Ni close to the oil sands operations which were not related to the content of these elements in the mineral soil.
4. Lichen community transplants placed close to Suncor changed substantially from 1976-79 whereas lichens placed into similar microenvironments >25 km from the source did not.
5. Seed germination and leaf number appeared to indicate that jack pine close to a pollutant source were affected whereas both basal area increment and shoot length did not. A more detailed examination of these factors is necessary before their effectiveness as a biomonitoring tool can be assessed.

b. Sulphur deposition to sulphation plates was correlated with distance from the pollutant source as well as with plant sulphur content. This indicates that long-term effects may indeed be highly likely, particularly if one considers metal deposition in addition to sulphur.

6. RECOMMENDATIONS

1. There should be continued involvement by the Province of Alberta in a biomonitoring network in northeastern Alberta to ensure that significant environmental damage does not occur as a result of continued oil sands development. Plant community analysis as well as both soil and plant chemical analyses should be used for long-term studies. These parameters do not fluctuate substantially from year to year and they provide an idea of the response of the entire soil-plant system. Expansion of the biomonitoring system to include other dominant forest and soil types should be attempted.
2. The specific biomonitoring techniques that have been developed in LS 3 should be refined further so that early detection of air pollution injury to forests can become a reality. Several methods show promise and effort should be expended on: (a) biochemical and physiological responses; (b) lichen transplants; and (c) growth measurements. In all cases, greater replication is necessary.
3. Because of the difficulties associated with the explanation of field pollutant responses based on either laboratory responses or tissue concentration of a single element, it is recommended that both laboratory and field studies on the influence of pollutant mixtures be initiated. This is critical if any attempt is to be made to relate plant response to the complex of industrial emissions under field conditions.
4. There is a need for development of a method to quantify both wet and dry pollutant deposition at remote sites.

7. REFERENCES CITED

Addison, P.A. 1980. Baseline condition of jack pine biomonitoring plots in the Athabasca Oil Sands area, 1976-77. Prep. for the Alberta Oil Sands Environmental Research Program by Environment Canada, Canadian Forestry Service. AOSERP Project LS 3.4.2. 38 pp.

Addison, P.A., and J. Baker. 1979a. Interim report on ecological bench-marking and biomonitoring for detection of air-borne pollutant effects on vegetation and soils, 1975 to 1978. Prep. for the Alberta Oil Sands Environmental Research Program by Environment Canada, Canadian Forestry Service. AOSERP Report 46. 41 pp.

Addison, P.A., and J. Baker. 1979b. Interim report on ecological bench-marking and biomonitoring for detection of air-borne pollutant effects on vegetation and soils, 1978-79. Prep. for the Alberta Oil Sands Environmental Research Program by Environment Canada, Canadian Forestry Service. AOSERP O.F. 3. 17 pp.

Addison, P.A., and K.J. Puckett. 1980. Deposition of atmospheric pollutants as measured by lichen element content in the Athabasca Oil Sands area. Can. J. Bot. (in press).

Barrie, L.A. 1979. The concentration and deposition of sulphur compounds and metals around the GCOS oil extraction plant during June 1977. Pages 186-212 in F. Fanaki et al. Air system summer field study in the AOSERP study area. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Atmospheric Environment Service. AOSERP Report 68. 248 pp.

Barrie, L.A., and D.M. Whelpdale. 1978. Background air and precipitation chemistry. Pages 124-159 in F. Fanaki, ed. Meteorology and air quality field study in the AOSERP study area, March 1976. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Atmospheric Environment Service. AOSERP Report 27. 249 pp.

Braun, V.G. 1977. Über die Ursachen and Kriterien der Immissionsresistenz bei Fichte, *Picea abies* (L.) Karst. Eur. J. For. Path. 7:129-152.

Caput, C., Y. Belot, D. Auclair, and N. Decourt. 1978. Absorption of sulphur dioxide by pine needles leading to acute injury. Environ. Pollut. 16:3-15.

Chaapel, D.S. 1974. The oil sands fulfill their promise. Our Sun Magazine, Autumn 1974.

Douglas, G.W., and A.C. Skorepa. 1976. Monitoring air quality with lichen: a feasibility study. Syncrude Canada Ltd. Environmental Research Monograph 1976. 269 pp.

Farrar, J.R., J. Relton, and A.J. Rutter. 1977. Sulphur dioxide and the growth of *Pinus sylvestris*. J. Appl. Ecol. 14:861-875.

Horntvedt, R. 1975. Epiphytic macrolichens on Scots pine related to air pollution from industry in Odda, Western Norway. Meddelelsen fra Norsk. Institute for Skogforskning. 31:584-604.

LeSueur, P., and K.J. Puckett. 1980. Effect of vanadium on the phosphatase activity of lichens. Can. J. Bot. 58:502-504.

Malhotra, S.S., and A.A. Khan. 1979. Interim report of physiology and mechanisms of air-borne pollutant injury to vegetation 1978-79. Prep. for the Alberta Oil Sands Environmental Research Program by Environment Canada, Canadian Forestry Service. AOSERP O.F. 2. 23 pp.

Skorepa, A.C., and D.H. Vitt. 1976. A quantitative study of epiphytic lichen vegetation in relation to SO_2 pollution in Western Alberta. Environment Canada, Canadian Forestry Service, Northern Forest Research Centre. Information Report NOR-X-161 26 pp.

Strosher, M.M. 1978. Ambient air quality in the AOSERP study area, 1977. Prep. for the Alberta Oil Sands Environmental Research Program by Alberta Environment, Pollution Control Division. AOSERP Report 30. 74 pp.

Yarranton, G.A. 1972. Distribution and succession of epiphytic lichens on black spruce near Cochrane, Ontario. Bryologist 75:462-480.

8. APPENDIX

Table 16. Sulphur content (ppm) of soils in the Athabasca oil sands area.

	Sites	Distance (km) and Direction from Suncor		Ammonium Acetate Extract (1N @ pH 4.8)					Total Digest (HNO_3 + HF)				
				LFH	Ah + Ahe	Ae	Bm	C	LFH	Ah + Ahe	Ae	Bm	C
12	Gradient Site A	2.8	SSW	7.7	0	2.7	10.3	0	820.5	71.1	39.3	54.0	65.1
6	Fina Airstrip	4.0	ESE	11.3	2.8	-	0	3.4	588.1	82.2	-	53.7	10.0
13	Gradient Site D	5.3	SSW	0.5	0	-	0	0	478.8	58.9	-	18.4	27.0
5	Mildred Lake Camp	10.5	NW	0.3	1.5	-	0	0	545.6	33.1	-	23.3	35.6
4	Fort MacKay	23.7	NNW	8.6	2.4	-	2.7	4.0	724.8	34.1	-	21.3	49.8
3	Hartley Creek	25.0	N	10.8	5.9	-	3.4	2.7	484.6	34.1	-	61.1	35.5
11	Thickwood Hills	30.0	SW	16.0	0	0	0	0.3	743.6	181.9	135.7	13.6	39.3
8	North Steepbank River	30.6	ESE	5.6	-	0	0	5.7	587.9	-	68.2	160.9	201.5
7	Muskeg Mountain	39.4	ENE	2.8	-	0	0.8	1.9	180.5	-	60.3	156.7	125.1
2	Bitumount Tower	29.8	N	2.8	0	0	0	0	725.5	173.3	52.8	86.5	175.3
9	Gordon Lake	72.8	SE	11.3	1.9	2.1	0	0	467.2	30.6	11.0	23.3	0
1	Firebag River	74.0	NNE	7.7	1.6	-	0	0	731.2	101.6	-	108.1	95.2
10	Birch Mountain	80.0	NNW	6.7	0	0	3.2	0	361.0	41.2	15.6	15.9	19.6

Table 17. Aluminium content (ppm) of soils in the Athabasca oil sands area.

	Sites	Distance (km) and Direction from Suncor		Ammonium Acetate Extract (1N @ pH 4.8)					Total Digest (HNO_3 + HF)				
				LFH	Ah + Ahe	Ae	Bm	C	LFH	Ah + Ahe	Ae	Bm	C
12	Gradient Site A	2.8	SSW	20	26	35	111	28	8 304	7 865	8 194	15 174	10 844
6	Fina Airstrip	4.0	ESE	18	25	-	96	71	7 433	6 695	-	10 485	7 007
13	Gradient Site D	5.3	SSW	84	44	-	96	13	6 074	5 178	-	11 126	7 757
5	Mildred Lake Camp	10.5	NW	11	47	-	73	45	4 788	7 007	-	10 131	7 007
4	Fort MacKay	23.7	NNW	11	28	-	15	0	4 312	13 852	-	21 599	18 016
3	Hartley Creek	25.0	N	0	28	-	77	37	5 078	7 433	-	13 299	15 029
11	Thickwood Hills	30.0	SW	35	128	183	142	86	12 066	25 750	28 658	31 868	35 648
8	North Steepbank River	30.6	ESE	15	-	37	30	0	10 724	-	22 421	32 993	18 473
7	Muskeg Mountain	39.4	ENE	28	-	44	366	224	7 113	-	8 416	28 536	30 503
2	Bitumount Tower	39.8	N	16	40	62	51	30	3 483	6 176	6 902	11 327	7 540
9	Gordon Lake	72.8	SE	16	23	0	94	21	4 725	3 574	3 574	7 974	4 596
1	Firebag River	74.0	NNE	23	44	-	69	25	3 939	8 305	-	8 864	11 085
10	Birch Mountain	80.0	NNW	60	100	107	157	90	11 572	15 189	16 878	26 887	20 899

Table 18. Iron Content (ppm) of soils in the Athabasca oil sands area.

	Sites	Distance (km) and Direction from Suncor		Ammonium Acetate Extract (1N @ pH 4.8)					Total Digest (HNO_3 + HF)				
				LFH	Ah + Ahe	Ae	Bm	C	LFH	Ah + Ahe	Ae	Bm	C
12	Gradient Site A	2.8	SSW	7.6	5.2	16.1	22.1	5.0	4 708	3 742	3 354	9 231	7 275
6	Fina Airstrip	4.0	ESE	8.0	8.8	-	57.0	15.9	2 573	2 082	-	4 033	3 062
13	Gradient Site D	5.3	SSW	43.0	19.8	-	17.0	4.0	3 256	1 787	-	7 180	6 046
5	Mildred Lake Camp	10.5	NW	5.2	23.2	-	15.0	4.6	3 256	3 742	-	5 379	7 087
4	Fort MacKay	23.7	NNW	7.6	55.0	-	9.4	5.2	1 787	2 671	-	9 231	8 861
3	Hartley Creek	25.0	N	3.8	9.7	-	24.1	6.8	2 181	2 082	-	4 900	5 570
11	Thickwood Hills	30.0	SW	9.7	41.0	68.9	53.0	18.9	3 645	3 984	4 612	8 304	11 875
8	North Steepbank River	30.6	ESE	6.2	-	41.0	12.6	25.6	3 548	-	9 231	17 131	11 424
7	Muskeg Mountain	39.4	ENE	12.8	-	15.0	13.1	11.6	2 573	-	1 590	12 324	12 145
2	Bitumount Tower	39.8	N	5.8	23.6	28.0	9.2	3.8	2 082	2 866	3 839	7 650	4 226
9	Gordon Lake	72.8	SE	5.0	5.4	3.2	47.0	6.8	2 475	1 688	1 293	4 515	1 984
1	Firebag River	74.0	NNE	12.6	19.8	-	38.9	4.4	2 279	3 839	-	3 839	6 141
10	Birch Mountain	80.0	NNW	18.2	26.7	20.7	23.7	6.2	5 856	3 936	5 665	16 875	10 150

Table 19. Nickel content (ppm) of soils in the Athabasca oil sands area.

	Sites	Distance (km) and Direction from Suncor		Ammonium Acetate Extract (1N @ pH 4.8)					Total Digest (HNO_3 + HF)				
				LFH	Ah + Ahe	Ae	Bm	C	LFH	Ah + Ahe	Ae	Bm	C
12	Gradient Site A	2.8	SSW	10	0	0	0	0	178	6	5	4	5
6	Fina Airstrip	4.0	ESE	1	1	-	0	0	29	5	-	3	4
13	Gradient Site D	5.3	SSW	9	1	-	0	0	107	9	-	5	6
5	Mildred Lake Camp	10.5	NW	2	0	-	0	0	39	2	-	3	3
4	Fort MacKay	23.7	NNW	2	0	-	0	0	37	2	-	9	10
3	Hartley Creek	25.0	N	1	0	-	0	0	27	3	-	8	5
11	Thickwood Hills	30.0	SW	1	0	1	0	0	33	10	14	13	17
8	North Steepbank River	30.6	ESE	0	-	0	0	0	13	-	9	31	31
7	Muskeg Mountain	39.4	ENE	2	-	0	0	0	28	-	2	21	12
2	Bitumount Tower	39.8	N	-	0	0	0	0	22	3	4	4	4
9	Gordon Lake	72.8	SE	0	0	0	0	0	25	0	0	0	0
1	Firebag River	74.0	NNE	0	1	-	0	0	19	1	-	2	4
10	Birch Mountain	80.0	NNW	0	0	0	0	0	25	16	14	25	10

Table 20. Vanadium content (ppm) of soils in the Athabasca oil sands area.

	Sites	Distance (km) and Direction from Suncor		Ammonium Acetate Extract (1N @ pH 4.8)					Total Digest (HNO + HF)				
				LFH	Ah + Ahe	Ae	Bm	C	LFH	Ah + Ahe	Ae	Bm	C
12	Gradient Site A	2.8	SSW						335	27	0	27	27
6	Fina Airstrip	4.0	ESE						69	13	-	20	0
13	Gradient Site D	5.3	SSW						228	34	-	31	27
5	Mildred Lake Camp	10.5	NW						84	13	-	0	0
4	Fort MacKay	23.7	NNW						84	27	-	48	34
3	Hartley Creek	25.0	N		NOT				41	0	-	27	34
11	Thickwood Hills	30.0	SW			DETECTABLE			41	34	27	34	41
8	North Steepbank River	30.6	ESE						27	-	34	27	27
7	Muskeg Mountain	39.4	ENE						27	-	27	48	55
2	Bitumount Tower	39.8	N						48	27	20	34	27
9	Gordon Lake	72.8	SE						24	20	13	13	0
1	Firebag River	74.0	NNE						27	0	-	13	20
10	Birch Mountain	80.0	NNW						48	27	27	41	27

Table 21. Sulphur content (ppm) of selected plant species in the Athabasca oil sands area.

	Sites	Distance (km) and Direction from Suncor		Tissue Concentration					
				Pinus banksiana	*Picea glauca*	*Arctostaphylos uva-ursi*	*Ledum groenlandium*	Ground Lichens	Feathermoss
12	Gradient Site A	2.8	SSW	1152 ± 127	706 ± 113	660 ± 77	1077 ± 130	412 ± 73	1250 ± 314
6	Fina Airstrip	4.0	ESE	498 ± 147	396 ± 114	494 ± 55	958 ± 84	215 ± 53	1171 ± 375
13	Gradient Site D	5.3	SSW	886 ± 88	598 ± 138	537 ± 72	1146 ± 142	353 ± 41	1204 ± 109
5	Mildred Lake Camp	10.5	NW	912 ± 152	635 ± 92	497 ± 93	1163 ± 100	322 ± 73	1149 ± 238
4	Fort MacKay	23.7	NNW	680 ± 93	492 ± 145	343 ± 116	1032 ± 133	188 ± 37	758 ± 103
3	Hartley Creek	25.0	N	777 ± 107	606 ± 150	387 ± 94	1566 ± 473	210 ± 49	881 ± 211
11	Thickwood Hills	30.0	SW	450 ± 188	683 ± 171	633 ± 165	1482 ± 379	303 ± 20	625 ± 64
8	North Steepbank River	30.6	ESE	586 ± 61	407 ± 90	450 ± 79	1145 ± 115	183 ± 43	781 ± 101
7	Muskeg Mountain	39.4	ENE	641 ± 130	-	-	853 ± 129	175 ± 47	650 ± 111
2	Bitumount Tower	39.8	N	816 ± 86	-	466 ± 124	944 ± 82	130 ± 45	767 ± 124
9	Gordon Lake	72.8	SE	649 ± 105	419 ± 95	516 ± 101	1091 ± 155	119 ± 22	798 ± 78
1	Firebag River	74.0	NNE	605 ± 112	411 ± 121	323 ± 81	831 ± 227	115 ± 46	446 ± 143
10	Birch Mountain	80.0	NNW	605 ± 112	-	-	1046 ± 66	214 ± 41	650 ± 101

Table 22. Aluminium content (ppm) of selected plant species in the Athabasca oil sands area.

	Sites	Distance (km) and Direction from Suncor		Tissue Concentration					
				Pinus banksiana	*Picea glauca*	*Arctostaphylos uva-ursi*	*Ledum groenlandium*	Ground Lichens	Feathermoss
12	Gradient Site A	2.8	SSW	890 ± 111	170 ± 60	471 ± 116	326 ± 137	724 ± 279	2357 ± 805
6	Fina Airstrip	4.0	ESE	693 ± 153	161 ± 51	123 ± 55	311 ± 94	293 ± 73	1083 ± 196
13	Gradient Site D	5.3	SSW	592 ± 87	182 ± 52	330 ± 62	365 ± 51	435 ± 147	2625 ± 248
5	Mildred Lake Camp	10.5	NW	954 ± 157	250 ± 56	290 ± 89	227 ± 103	477 ± 173	1370 ± 338
4	Fort MacKay	23.7	NNW	460 ± 58	157 ± 20	154 ± 60	188 ± 75	297 ± 53	1159 ± 91
3	Hartley Creek	25.0	N	567 ± 70	114 ± 24	122 ± 42	182 ± 47	257 ± 73	773 ± 231
11	Thickwood Hills	30.0	SW	511 ± 47	344 ± 492	335 ± 85	209 ± 85	332 ± 110	1081 ± 187
8	North Steepbank River	30.6	ESE	393 ± 58	83 ± 42	173 ± 55	143 ± 24	192 ± 53	866 ± 89
7	Muskeg Mountain	39.4	ENE	545 ± 54	-	-	147 ± 32	204 ± 87	820 ± 92
2	Bitumount Tower	39.8	N	408 ± 34	-	122 ± 22	135 ± 29	258 ± 55	813 ± 102
9	Gordon Lake	72.8	SE	381 ± 87	90 ± 130	92 ± 33	126 ± 40	183 ± 61	680 ± 90
1	Firebag River	74.0	NNE	578 ± 66	55 ± 27	64 ± 61	62 ± 75	233 ± 41	426 ± 45
10	Birch Mountain	80.0	NNW	516 ± 127	-	-	63 ± 19	132 ± 41	714 ± 174

Table 23. Iron content (ppm) of selected plant species in the Athabasca oil sands area.

	Sites	Distance (km) and Direction from Suncor		Tissue Concentration					
				Pinus banksiana	*Picea glauca*	*Arctostaphylos uva-ursi*	*Ledum groenlandium*	Ground Lichens	Feathermoss
12	Gradient Site A	2.8	SSW	295 ± 26	117 ± 25	205 ± 30	242 ± 28	170 ± 45	1542 ± 320
6	Fina Airstrip	4.0	ESE	114 ± 37	82 ± 10	91 ± 10	161 ± 27	104 ± 50	473 ± 138
13	Gradient Site D	5.3	SSW	127 ± 10	97 ± 26	163 ± 20	206 ± 13	145 ± 59	1278 ± 60
5	Mildred Lake Camp	10.5	NW	239 ± 74	248 ± 39	314 ± 66	282 ± 35	466 ± 160	1512 ± 324
4	Fort MacKay	23.7	NNW	83 ± 12	86 ± 14	98 ± 30	113 ± 15	173 ± 31	761 ± 67
3	Hartley Creek	25.0	N	56 ± 8	49 ± 3	49 ± 7	101 ± 12	108 ± 26	382 ± 91
11	Thickwood Hills	30.0	SW	55 ± 7	48 ± 10	149 ± 16	103 ± 11	150 ± 21	538 ± 80
8	North Steepbank River	30.6	ESE	65 ± 9	53 ± 11	97 ± 24	94 ± 17	111 ± 13	436 ± 41
7	Muskeg Mountain	39.4	ENE	97 ± 16	-	-	77 ± 7	102 ± 17	352 ± 41
2	Bitumount Tower	39.8	N	52 ± 5	-	49 ± 7	71 ± 3	111 ± 16	396 ± 58
9	Gordon Lake	72.8	SE	45 ± 6	36 ± 5	57 ± 13	90 ± 7	120 ± 6	332 ± 40
1	Firebag River	74.0	NNE	53 ± 7	44 ± 6	71 ± 9	69 ± 12	111 ± 13	225 ± 19
10	Birch Mountain	80.0	NNW	52 ± 11	-		59 ± 6	81 ± 14	345 ± 32

9. LIST OF AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "A Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.		
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area
21.		AOSERP Second Annual Report, 1976-77
22.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 1.5.2	Air System Winter Field Study in the AOSERP Study Area, February 1977.
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area

26. AF 4.5.1 Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27. ME 1.5.1 Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28. VE 2.1 Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29. ME 2.2 An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30. ME 2.1 Ambient Air Quality in the AOSERP Study Area, 1977
31. VE 2.3 Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32. AOSERP Third Annual Report, 1977-78
33. TF 1.2 Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34. HY 2.4 Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
35. AF 4.9.1 The Effects of Sedimentation on the Aquatic Biota
36. AF 4.8.1 Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37. HE 2.2.2 Community Studies: Fort McMurray, Anzac, Fort MacKay
38. VE 7.1.1 Techniques for the Control of Small Mammals: A Review
39. ME 1.0 The Climatology of the Alberta Oil Sands Environmental Research Program Study Area
40. WS 3.3 Mixing Characteristics of the Athabasca River below Fort McMurray - Winter Conditions
41. AF 3.5.1 Acute and Chronic Toxicity of Vanadium to Fish
42. TF 1.1.4 Analysis of Fur Production Records for Registered Traplines in the AOSERP Study Area, 1970-75
43. TF 6.1 A Socioeconomic Evaluation of the Recreational Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions
44. VE 3.1 Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978
45. VE 3.3 Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978
46. VE 3.4 Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant Effects on Vegetation and Soils, 1975 to 1978.
47. TF 1.1.1 A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area
48. HG 1.1 Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49. WS 1.3.3 The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50. ME 3.6 Literature Review on Pollution Deposition Processes
51. HY 1.3 Interim Compilation of 1976 Suspended Sediment Date in the AOSERP Study Area
52. ME 2.3.2 Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53.	HY 3.1.2	Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54.	WS 2.3	A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta
55.	HY 2.6	Microbial Populations in the Athabasca River
56.	AF 3.2.1	The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates
57.	LS 2.3.1	Ecological Habitat Mapping of the AOSERP Study Area (Supplement): Phase I
58.	AF 2.0.2	Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
59.	TF 3.1	Semi-Aquatic Mammals: Annotated Bibliography
60.	WS 1.1.1	Synthesis of Surface Water Hydrology
61.	AF 4.5.2	An Intensive Study of the Fish Fauna of the Steepbank River Watershed of Northeastern Alberta
62.	TF 5.1	Amphibians and Reptiles in the AOSERP Study Area
63.	ME 3.8.3	Analysis of AOSERP Plume Sigma Data
64.	LS 21.6.1	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65.	LS 21.6.2	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66.	AS 4.3.2	An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
67.	WS 1.3.2	Aquatic Biological Investigations of the Muskeg River Watershed
68.	AS 1.5.3 AS 3.5.2	Air System Summer Field Study in the AOSERP Study Area, June 1977
69.	HS 40.1	Native Employment Patterns in Alberta's Athabasca Oil Sands Region
70.	LS 28.1.2	An Interim Report on the Insectivorous Animals in the AOSERP Study Area
71.	HY 2.2	Lake Acidification Potential in the Alberta Oil Sands Environmental Research Program Study Area
72.	LS 7.1.2	The Ecology of Five Major Species of Small Mammals in the AOSERP Study Area: A Review
73.	LS 23.2	Distribution, Abundance and Habitat Associations of Beavers, Muskrats, Mink and River Otters in the AOSERP Study Area, Northeastern Alberta
74.	AS 4.5	Air Quality Modelling and User Needs
75.	WS 1.3.4	Interim Report on a Comparative Study of Benthic Algal Primary Productivity in the AOSERP Study Area
76.	AF 4.5.1	An Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
77.	HS 20.1	Overview of Local Economic Development in the Athabasca Oil Sands Region Since 1961.
78.	LS 22.1.1	Habitat Relationships and Management of Terrestrial Birds in Northeastern Alberta

79. AF 3.6.1 The Multiple Toxicity of Vanadium, Nickel, and Phenol to Fish.
80. HS 10.2 & HS 10.1 History of the Athabasca Oil Sands Region, 1980 to 1960's. Volumes I and II.
81. LS 22.1.2 Species Distribution and Habitat Relationships of Waterfowl in Northeastern Alberta.
82. LS 22.2 Breeding Distribution and Behaviour of the White Pelican in the Athabasca Oil Sands Area.
83. LS 22.2 The Distribution, Foraging Behaviour, and Allied Activities of the White Pelican in the Athabasca Oil Sands Area.
84. WS 1.6.1 Investigations of the Spring Spawning Fish Populations in the Athabasca and Clearwater Rivers Upstream from Fort McMurray; Volume I.
85. HY 2.5 An intensive Surface Water Quality Study of the Muskeg River Watershed. Volume I: Water Chemistry.
86. AS 3.7 An Observational Study of Fog in the AOSERP Study Area.
87. WS 2.2 Hydrogeological Investigation of Muskeg River Basin, Alberta
88. AF 2.0.1 Ecological Studies of the Aquatic Invertebrates of the Alberta Oil Sands Environmental Research Program Study Area of Northeastern Alberta
89. AF 4.3.2 Fishery Resources of the Athabasca River Downstream of Fort McMurray, Alberta. Volume 1
90. AS 3.2 A Wintertime Investigation of the Deposition of Pollutants around an Isolated Power Plant in Northern Alberta
91. LS 5.2 Characterization of Stored Peat in the Alberta Oil Sands Area
92. WS 1.6.2 Fisheries and Habitat Investigations of Tributary Streams in the Southern Portion of the AOSERP Study Area. Volume I: Summary and Conclusions
93. WS 1.3.1 Fisheries and Aquatic Habitat Investigations in the MacKay River Watershed of Northeastern Alberta
94. WS 1.4.1 A Fisheries and Water Quality Survey of Ten Lakes in the Richardson Tower Area, Northeastern Alberta. Volume I: Methodology, Summary, and Discussion.
95. AS 4.2.6 Evaluation of the Effects of Convection on Plume Behaviour in the AOSERP Study Area
96. HS 20.3 Service Delivery in the Athabasca Oil Sands Region Since 1961
97. LS 3.4.1 Differences in the Composition of Soils Under Open and Canopy Conditions at Two Sites Close-in to the Great Canadian Oil Sands Operation, Fort McMurray, Alberta
98. LS 3.4.2 Baseline Condition of Jack Pine Biomonitoring Plots in the Athabasca Oil Sands Area; 1976 and 1977
99. LS 10.1 Synecology and Autecology of Boreal Forest Vegetation in the AOSERP Study Area
100. LS 10.2 Baseline Inventory of Aquatic Macrophyte Species Distribution in the AOSERP Study Area
101. LS 21.1.3 Woodland Caribou Population Dynamics in Northeastern Alberta
102. LS 21.1.4 Wolf Population Dynamics and Prey Relationships in Northeastern Alberta

These reports are not available on request. For further information about availability and location of depositories, please contact:

Research Management Division
Alberta Environment
15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta
T5K 2J6
(403) 427-3943