PROPOSED DESIGN FOR A PROGRAM OF TOXICOLOGICAL RESEARCH FOR THE ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

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ABSTRACT

A proposed design, and supporting information, for an integrated program of toxicological research for the Alberta Oil Sands Environmental Research Program is presented.

The first major section of the report (Section 2) contains background information pertinent to the development of a research design. The nature and magnitude of present and proposed oil sands development wastes within the AOSERP study area are reviewed, as are the results of studies on air quality, water quality, and toxicology. The general toxicology of inorganic trace elements, sulphur and sulphur compounds, photochemical air pollutants, and organic compounds to mammals, vegetation, and aquatic organisms is reviewed by means of literature searches. A 'Toxicological Index' is proposed to outline the toxicological significance of specific inorganic elements to mammals and aquatic organisms. The index provides a list of elements judged to be of environmental concern. Gaps in information pertinent to the design of a toxicological research program are identified and discussed.

The proposed toxicological program research design is outlined in Section 3. The proposed design is based on the integration of baseline data, inventories of wastes, identification of biological target systems, assessment of toxicity (including preliminary evaluation, biomonitoring, and toxicity testing), and generation of information for management purposes. Requirements for research within the proposed design in each AOSERP Research System are identified and specific projects are recommended. The priority of the projects is indicated.

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1. INTRODUCTION

1.1 OBJECTIVE

The primary objective of this project was to design an integrated program of toxicological research appropriate to the objectives of the Alberta Oil Sands Environmental Research Program (AOSERP), taking into consideration the needs of government and the oil sands industry, and the nature and probable magnitude of the oil sands development. The location of the AOSERP study area is given in Figure 1. For the purposes of this project, toxicology is defined as the study of the ability of a substance or group of substances to cause death, measurable damage, altered behaviour, or observable changes in the normal life cycle of an organism or its constituent cells. The definition includes 'environmental' toxicology since organisms do not exist as isolated individuals but rather function as integrated components of larger biological systems e.g. populations, communities, ecosystems.

1.2 APPROACH

As suggested in the Terms of Reference of the contract for the project (see Appendix 5.1), the report contains two major sections:

1. Section 2; a review and evaluation of existing information pertaining to oil sand development and toxicology in the AOSERP study area; and
2. Section 3; a program design, i.e., the proposed toxicology program research design and recommendations for an implementation of the proposed research design.

The background information in Section 2 comprises:

1. A review and evaluation of oil sands wastes in the AOSERP study area;
2. A review and evaluation of previous and ongoing AOSERP studies on wastewater, receiving water quality and air quality in the AOSERP study area;
3. A review and evaluation of previous and ongoing toxicological studies dealing with the AOSERP study area;
4. A description of the current physical and chemical characteristics of oil sands development wastes in the AOSERP study area and an assessment of the toxicological significance of the wastes to the biota in the study area; and

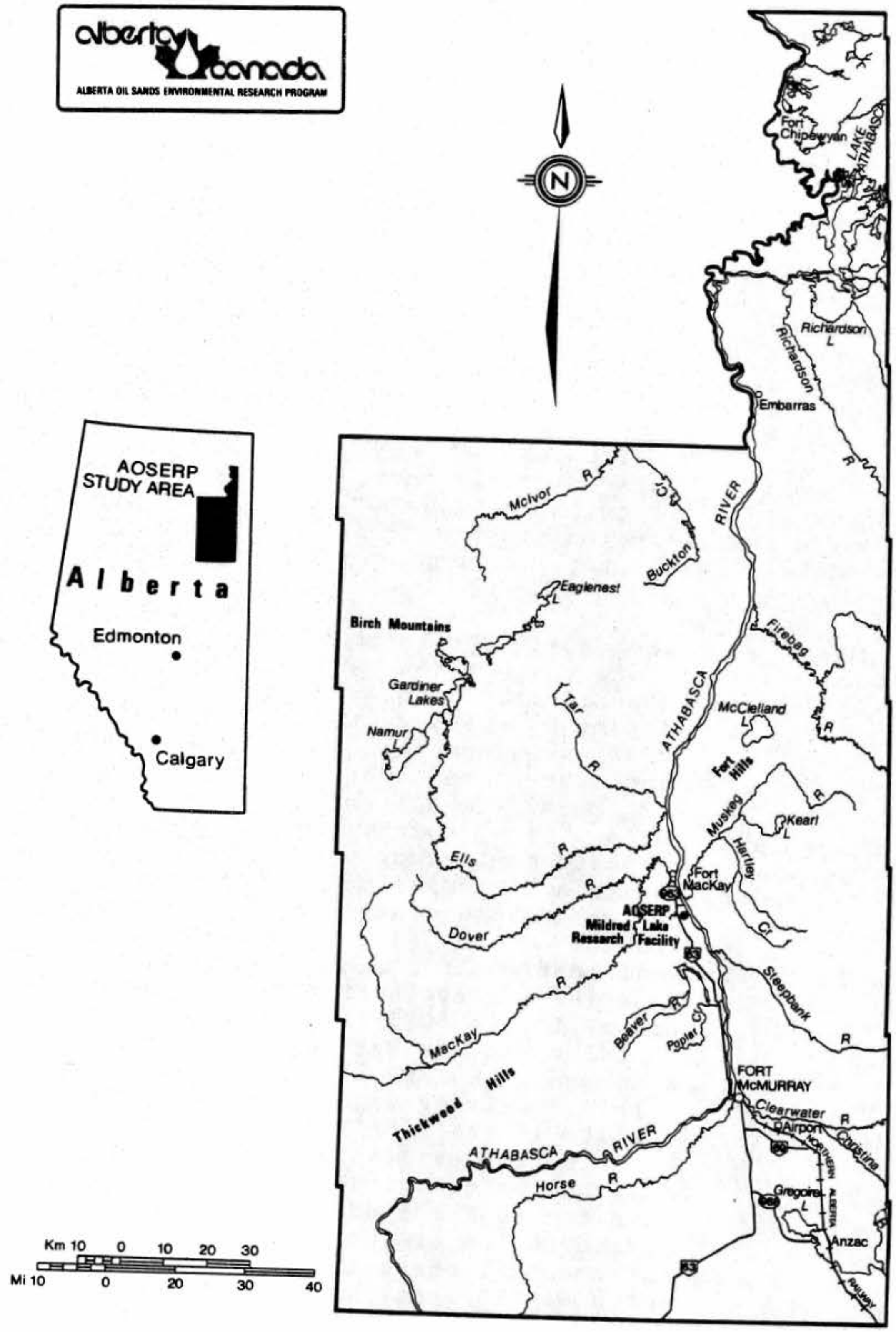

Figure 1. Location of the Alberta Oil Sands Environmental Research Program study area.

5. A determination of the needs of a program of toxicological research through personal contacts with users.

Only studies completed, initiated, or ongoing prior to the 1978/79 fiscal year have been reviewed.

Input from a variety of disciplines including chemistry, physics, engineering, biology, and related areas is required to understand the actions, effects, and relationships between contaminants and the environment. Therefore, a toxicological research program requires a collaborative, multidisciplinary approach.

The proposed toxicology research design is based on extensive collaboration between the Air, Water, Land, and Human Systems of AOSERP during implementation and execution. Since the effects of the emissions and effluents resulting from oil sands development may not conform to the structure and specific jurisdiction of the AOSERP Research Systems (Land, Water, Air, and Human), a holistic approach to toxicological studies in the Athabasca Oil Sands area is essential. AOSERP should have an important role in the planning, integration, and coordination of all toxicological related activities undertaken within and relevant to the AOSERP study area. This would ensure that present and future toxicological concerns in the study area are suitably investigated. This responsibility is recognized in the AOSERP Policy and Direction Statement (AOSERP 1977a).

1.3 ASSUMPTIONS

Certain assumptions were made to carry out this project. These were as follows:

1. That currently available technology will form the basis for the design of oil sands plants for the next three years and hence, that the Great Canadian Oil Sands (GCOS) and Syncrude Canada Ltd. (Syncrude) plants can be used as models for the design of new plants, occurring during this time period;
2. That all plants, presently in operation and proposed, will meet existing provincial standards, or the standards set out in existing licenses, with regard to the quality of emissions and effluents;
3. That there will be no significant development of in situ production schemes beyond the pilot plant stage within the next 5 years; and

4. That a decision has been made to accept local environmental damage provided it is contained within the leased areas and that provision is made for reclamation and restoration of the damaged areas.

1.4 GLOSSARY

A glossary of biological and toxicological terms employed in this report is included in Appendix 5.2.

2. NATURE, MAGNITUDE, AND TOXICOLOGY OF THE WASTES ARISING FROM PRESENT AND POTENTIAL OIL SANDS DEVELOPMENTS

2.1 INTRODUCTION

The waste products arising during oil sands development can be classified under three headings:

1. Wastes remaining within the plant and lease area;
2. Emissions; and
3. Effluents.

Attention is focused on emissions and effluents since they leave the lease areas and enter the general AOSERP study area. The composition and loadings of the known emissions and effluents are outlined and, where possible, comparisons are made with background levels found in the environment into which the various discharges occur. These comparisons are limited since a paucity of data exists on effluents, emissions, and background levels.

The potential toxicity of emissions and effluents is deduced from data in the literature and from a knowledge of the composition of wastes. Gaps in toxicological knowledge pertinent to the AOSERP study area are identified.

2.1.1 Development of Oil Sands Plants

Oil sands processing operations are of two general types: 1) surface or strip mining; and 2) in situ operations. Surface mining may involve either a conventional extraction and upgrading technique, i.e., the Clark hot water process, or an alternative technique(s). To date, all proposals before the Alberta Government for the commercial production of synthetic crude oil in the AOSERP study area have described extraction methods utilizing the Clark hot water process.

GCOS began production in 1967. In 1974, major construction commenced on the Syncrude site and production began in 1978. The Alberta Energy Resources Conservation Board (ERCB) has approved the design specifications of an additional three plants: Shell Canada Ltd. and Shell Explorer Ltd.; Petrofina Canada Ltd., Pacific Petroleums Ltd., and Hudson's Bay Oil and Gas Company Ltd.; and Home Oil Company Ltd. and Alminex Ltd. The most significant difference between GCOS and other plants is the committment by the proponents of the latter plants that wastewaters from their bitumen extraction and upgrading facilities will not be discharged to surrounding watercourses.

During the last three years, in situ pilot schemes using various processes have been announced and at least three are operational in the Athabasca Oil Sands (Texaco, Alberta Oil Sands Technology and Research Authority (AOSTRA)/Amoco, and AOSTRA/Numac). The environmental effects of in situ extraction are not well known. They are discussed briefly in Section 2.3.3.

2.2 COMPOSITION OF BITUMEN

Most recoverable reserves of synthetic crude oil and bitumen are located within the AOSERP study area (Energy Resources Conservation Board 1974). The Athabasca Oil Sands have been extensively described (Carrigy 1963a, 1973a, 1973b, 1973c; Hamilton and Mellon 1973). 'Raw' oil sand contains, on the average, 83% sand, 13% bitumen, and 4% water; by weight bitumen content may vary from 0 to 18% (Kirk-Othmer 1969). The 'sand' portion consists predominantly of quartz (84%) with minor amounts of other materials including potash, feldspar, chert, garnet, staurolite, kyanite, tourmaline, and zircon (Mellon 1956; Carrigy 1959, 1962, 1963b; Fahrig 1961; Hamilton and Mellon 1973). The recovered 'oil' portion, consists of the thick, tarry, viscous material known as bitumen.

Although little data are available on the specific chemical composition of bitumen, it is believed to be relatively constant throughout the Athabasca deposit (Strausz 1977). A summary of available analyses for elements in bitumen recovered after hot water extraction is given in Table 1. From these data it is possible to estimate the amount of each element entering a plant the size of Syncrude. These estimates are summarized in Table 2.

It is noteworthy that the concentrations of some potentially toxic elements such as lead, cadmium, and beryllium have not been determined.

2.3 COMPOSITION OF WASTES

If it is assumed that current technology will form the basis for the design of oil sands plants for the next three years, the GCOS and Syncrude plants can be used as a basis of discussion for this time period.

Table 1. Typical analysis of recovered bitumen.

Element	Analysis	Units
Carbon	0.819 - 0.836[a]	g/g
Hydrogen	95 - 106[a]	mg/g
Sulphur	38 - 54[a]	mg/g
Oxygen	2 - 29[a]	mg/g
Nitrogen	3 - 6[a]	mg/g
Ash	6.5[b]	mg/g
Vanadium	210 - 290[a]	μg/g
Sodium	21;40[c]	μg/g
Iron	75[a]	μg/g
Iron	142;254[c]	μg/g
Nickel	80 - 100[a]	μg/g
Chlorine	7.96[c]	μg/g
Copper	2 - 5[a]	μg/g
Manganese	3853[c]	ng/g
Cobalt	1349;1998[c]	ng/g
Chromium	1014;1682[c]	ng/g
Rubidium	377;720[c]	ng/g
Selenium	286;517[c]	ng/g
Arsenic	321;400[c]	ng/g
Gallium	267;315[c]	ng/g
Scandium	191;199[c]	ng/g
Bromine	104;155[c]	ng/g
Mercury	82[c]	ng/g
Cesium	25.9;68.5[c]	ng/g
Antimony	27.7;30.6[c]	ng/g
Europium	9.0;30.6[c]	ng/g
Gold	1.3[c]	ng/g

[a]Source: Putagunta et al. (1977).
[b]Source: Wise (1974).
[c]Source: Hitchon et al. (unpublished analyses of two samples, Alberta Research Council No. CS693.).

Table 2. Estimated quantities of trace elements entering an oil sands plant[a] (based on data given in Table 1).

Constituent	Assumed Content in Bitumen µg/g	Daily Feed Rate in kg/day
Vanadium	250	6600
Iron	150	3900
Nickel	90	2400
Sodium[b]	30	800
Chlorine[b]	7.9	210
Copper[b]	4	110
Manganese[b]	3.8	100
Cobalt	1.7	45
Chromium	1.4	37
Rhubidium[b]	0.5	13
Selenium[b]	0.4	11
Arsenic[b]	0.35	9
Gallium[b]	0.3	8
Scandium[b]	0.2	5
Bromine[b]	0.15	4
Mercury[b]	0.08	2
Cesium[b]	0.04	1
Antimony[b]	0.03	0.8
Europium[b]	0.015	0.4
Gold[b]	0.001	0.03

[a]Assumptions: Production = 125 000 barrels per day. 75% recovery, therefore bitumen feed = 166 700 barrels per day. 1 barrel of bitumen (API Gravity = 10) is 350 lbs. (158.75 kg). Bitumen feed rate = 26 500 000 kg/day.

[b]Based on only one or two analyses of bitumen.

2.3.1 Known Wastewaters

Wastewaters from oil sands mining and processing originate from three main sources:

1. Wastewaters produced during the preparation of the area to be mined and during mining operations, including waters from:
   - 1a) Overburden drainage,
   - 1b) Mine depressurization, and
   - 1c) Accumulation of run-off and seepage during mining operations;
2. Industrial wastewater streams produced during the extraction and upgrading of bitumen including:
   - 2a) Tailings stream from the extraction process,
   - 2b) Upgrading process wastewater,
   - 2c) Run-off from coke and sulphur processing stockpiles, and
   - 2d) Seepage from tailings ponds; and
3. 'Domestic' wastewater (sewage).

Although several effluent streams of GCOS and Syncrude have been examined and their acute toxicity to aquatic organisms determined, no comprehensive inventory and characterization of oil sands development wastewaters and effluents have been published.

In terms of quantity, the major wastewater streams from the plant and the mine are:

1. Extraction tailings streams;
2. Upgrading process wastes; and
3. Groundwater from mine depressurization.

Under present policies, extraction tailings streams are not and will not be discharged as effluents, however, there could be seepage of tailings constituents beneath retaining dikes. Upgrading process wastes are discharged by GCOS but will not be released by other plants. Mine depressurization water, if it is produced, will constitute an effluent.

It is probable that there will be differences in the composition of wastewater streams among the various oil sands plants. Each plant is expected to have its own upgrading process wastewater characteristics since upgrading technology will vary from plant to plant. In addition to technological differences, industrial wastewaters may also vary with the composition of the raw oil sands and the extracted bitumen. Mine depressurization effluents are also expected to differ in quality since generally saline groundwater in the area of oil sands development contains a wide range of inorganic chemicals within a relatively small geographic area (see Section 2.3.1.2). Extraction tailings are expected to be relatively similar in composition in the GCOS, Syncrude, and the third oil sands plant since all three will utilize the same extraction process (Clark hot water).

2.3.1.1 Wastewaters from the GCOS plant. These have been studied by Hrudey (1975) and by GCOS personnel (letter dated 7 December 1977 from W. Cary, Environmental Conservation Department, GCOS, Fort McMurray, Alberta). The data are summarized under the categories listed previously:

1. Wastewaters, produced during the preparation of the area to be mined and during mining operations including waters from:
   - 1a) Overburden drainage. Drainage of the muskeg produces a wastewater laden with humic acid. The wastewater streams are impounded and later discharged into the Athabasca River through a system of ditches; the quality and quantity of the water is not monitored.
   - 1b) Mine depressurization. This is not produced on the GCOS lease.
   - 1c) Accumulation of run-off and seepage during mining operations. This wastewater is pumped into ditches, the sediment and grease trapped in catch basins, and the water discharged into the Athabasca River. The quantity and quality of this water is not monitored.
2. Industrial wastewater streams produced during the extraction and upgrading of bitumen including:
   - 2a) Tailings streams from the extraction process. These streams are discharged in a slurry form and stored in an 800 ha pond retained by 60 m dikes. The sand and clay which settle out are stored in the pond, or if necessary, in mined out areas. Approximately 80% of the water may be recycled to the extraction plant since the upper layer of the water in the tailings pond is low in mineral fines. The

remaining water, oil, sand, and clay form a thick oily sludge. The GCOS permit to operate requires the company to collect representative grab samples from the pond semi-annually. The parameters monitored are the same as those described for upgrading process wastewater (see 2b below). This data is filed with the Pollution Control Division of Alberta Environment. At present, tailing streams are not discharged into natural water courses.

2b) Upgrading process wastewater. This water is utilized primarily for cooling purposes. However, some water is used for cutting deposited coke out of the delayed coking units. The wastewater is an effluent discharged into the Athabasca River. It amounts to approximately 30×10^6 L/d, equivalent to approximately 10×10^7 L/year. This wastewater is monitored daily, weekly, and monthly for specified parameters set out in the GCOS permit and the data is filed with the Pollution Control Division of Alberta Environment. The following parameters are examined: (Alberta Environment 1973):

i) Daily (24 h composite sample): pH, total suspended solids, phenolics, threshold odor number, ammonia nitrogen, chemical oxygen demand, and oil and grease;
ii) Weekly: total sulphide, biochemical oxygen demand, and total organic carbon; and
iii) Monthly: total heavy metals including arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, tin, and zinc.

Periodic sampling and testing of this water is also conducted by the Water Quality Control Branch of Alberta Environment (conversation of 1 November 1977 with B. Lake, Pollution Control Division, Alberta Environment, Edmonton, Alberta).

2c) Run-off from the coke and sulphur stockpiles. Stockpiled coke is stored adjacent to an upgrading wastewater holding pond. There is no information on the disposition of wastewater from this source. Wastewater (run-off) from the sulphur stockpile is added to 2b) above. It amounts to approximately 60,000 L/d, equivalent to 20^6 L/year. Its composition is not monitored other than indirectly through 2b) above.

2d) Seepage from tailings ponds. The dike of the tailings pond produces drainage waters which are collected and returned to the tailings pond (letter dated 7 December 1977 from W. Cary, Environmental Conservation Department, GCOS, Fort McMurray, Alberta). Seepage through the bottom of the tailings pond is not monitored. It is assumed to be 'sealed' *(Ibid.)*.

3. 'Domestic' wastewater (sewage). Sanitary sewage from the plant site is discharged into one of three lagoons where it is retained for a minimum of about eight months. Sewage is discharged into the Athabasca River from the holding lagoons during the summer under the control of Alberta Environment. The volume of effluent is measured and a representative 'grab' sample analyzed according to the terms of the permit issued to GCOS by Alberta Environment (Alberta Environment 1973). Phenolics, total residue, suspended solids, oil and grease, chemical oxygen demand, ammonia nitrogen, total phosphates, threshold odor number, total sulphides, and pH were measured. The information is filed with the Pollution Control Division of Alberta Environment.

2.3.1.2 Wastewaters from the Syncrude plant. Information was supplied by J. Retallack (letters dated 2 and 8 December 1977 from J. Retallack, Environmental Affairs, Syncrude Canada Ltd., Edmonton, Alberta). The data are summarized under the categories listed in 2.3.1.1 as follows.

1. Wastewaters produced during the preparation of the area to be mined and during mining operations including waters from:
   1a) Overburden drainage. There is no detailed information on the quantity and composition of this effluent. A portion of it ends up in the mine depressurization water holding area.
   1b) Mine depressurization water. The purpose of a depressurization scheme is to improve the safety of the mine high wall by decreasing fluid pressures in the basal aquifer sands below the oil sand (Nichols 1975). Considerable variability exists in the chemical composition of this fluid on the Syncrude lease (see Table 3). During 1977, approximately 633×10^6 L of depressurization water were discharged to the Beaver Creek Reservoir.

      The present operating permit requires Syncrude to monitor the mine depressurization effluent. The discharge of saline water must be carried out so that the eventual chloride concentration in Poplar Creek (at a site near the Poplar Creek Bridge on Highway 63) does not exceed 400 mg/L above ambient levels. The volume of mine depressurization water discharged to the Beaver Creek Reservoir is monitored daily. The water is also to be analyzed for contaminants according to the following schedule:
      i) daily (representative grabs): chloride ion, pH, total suspended solids, chemical oxygen demand, and phenolics; and
      ii) weekly (24 h composite sample): anion concentration (chloride, sulphate, fluoride, carbonate, and bicarbonate), oil

Table 3. Analyses of water on Syncrude Canada Ltd. Lease # 17. Data was provided by Syncrude Canada Ltd. Values are reported as mg/L unless otherwise specified.

Constituent	Wells 2600S and 4800E[a]		Other wells in area	
	mean	range	mean	range
Total Dissolved Solids (approx.)	12 262	10 504-13 537	10 864[c]	1 146-36 613
Chloride	4 488	3 890- 4 807	4 560[b]	19-19 854
Sodium	4 242	3 885- 4 500	3 517[b]	564-10 698
Bicarbonates	3 188	2 626- 3 523	2 017[b]	532- 3 431
Carbonates	166	0- 446	494[b]	0- 1 230
Magnesium	51.3	35- 59	69.6[b]	3- 411
Sulphate	30.0	19- 49	66.5[b]	0- 377
Calcium	48.5	14- 96	56.0[b]	3- 316
Potassium	38.5	31- 48	33.0[b]	4- 112
Silica	ND[d]	ND	22.4[b]	18- 27
Iron	0.93	0.75- 1.10	11.40[c]	<0.01- 128.0
Boron	4.30	3.50- 5.30	5.80[c]	2.00- 8.00
Aluminum	<1.00		1.60[c]	<0.01- 5.20
Manganese	<0.01	<0.01- 0.01	0.90[c]	<0.01- 6.63
Zinc	0.02	<0.01- 0.02	0.65[c]	<0.01- 7.51
Phosphate	ND	ND	0.3[b]	0.17- 0.41
Nitrate	ND	ND	0.3[b]	0.20- 0.75
Barium	0.10	<0.10- 0.20	<1.00[c]	
Titanium	<1.00		<1.00[c]	
Vanadium	<1.00		<1.00[c]	
Cadmium	<0.01	<0.01- 0.01	ND	ND
Lead	<0.10	<0.01- 0.26	0.05[c]	<0.01- 0.22
Nickel	<0.02		<0.02[c]	
Arsenic	<0.01		<0.01[c]	
Chromium	<0.01		<0.01[c]	
Cobalt	<0.03		<0.01[c]	
Copper	<0.01	<0.01- 0.01	<0.01[c]	
Mercury (ppb)	1.10	0.20- 2.20	<0.20[c]	

[a]Sample size = 4
[b]Sample size = 72
[c]Sample size = 28
[d]Symbol ND = No Data

and grease, pH, total suspended solids, total dissolved solids, chemical oxygen demand, and phenolics.

Once every two months mine depressurization water discharged to the Beaver Creek Reservoir is tested for toxicity (static LC50 - fish). Also, the concentration of metals including vanadium, iron, copper, nickel, arsenic, titanium, zirconium, potassium, sodium, mercury, lead, zinc, and silver is determined (based on one 24 h composite sample). The information collected under the permit is filed with the Pollution Control Division of Alberta Environment.

The distribution of mine depressurization water in the Beaver Creek Diversion System is presently monitored by Syncrude although this is not required by permit. The monitoring program consists of seven "master" stations and 20 "slave" stations. The "master" stations are sampled at 1 m depth intervals for chloride, bicarbonate, sulphate, sodium, calcium, magnesium, potassium, temperature, dissolved oxygen, and conductivity. This sampling program provides more than 40 samples per monthly sample run. The "slave" stations, also measured at 1 m depth intervals, provide information on temperature, dissolved oxygen, and conductivity.

1c) Accumulation of run-off and seepage during mining operations. Surface run-off and seepage from the mine drains into a sump and is eventually pumped into an effluent pond. Surface water within the initial mining area drains into conveyor ditches. This water, in conjunction with overburden drainage water and depressurization water, is pumped into the Beaver Creek Reservoir. Surface water from outside the initial mining area drains into the east and west surface interceptor ditches. These drain respectively into the effluent pond and the recycle pond.

2. Industrial wastewater streams produced during the extraction and upgrading of bitumen. At present there is no information available on extraction tailings streams, upgrading process water, runoff from coke, and sulphur stockpiles, or seepage from tailings ponds. Syncrude will monitor the seepage from tailings ponds, if it occurs it will be pumped back to the tailings pond.

2.3.1.3 <u>Wastewaters from a third oil sands plant</u>. It is anticipated that the next oil sands plant will meet the requirements of Alberta Environment.

Assuming conventional technologies, the major anticipated wastewaters from the third plant are extraction tailings streams, upgrading process wastes, and mine depressurization waters. Like Syncrude, current proposals for a third oil sands plant indicate that there will be no discharges of wastewaters from the bitumen extraction and upgrading operations to nearby watercourses.

2.3.1.4 <u>Summary and loadings of major effluents</u>. The GCOS upgrading process water is the only GCOS effluent for which information on composition has been published. The quality of this effluent is usually within Alberta Environment standards. There has been no analysis of overburden drainage or mine runoff. Analyses of the mid-summer discharges of domestic wastes are filed with the Pollution Control Division of Alberta Environment. These analyses were unavailable for this report. There is no attempt to monitor seepage through the bottom of the GCOS tailings pond since it is assumed the pond is sealed.

Syncrude, and plants subsequent to Syncrude, are committed to no discharge of wastewaters arising from their extraction and upgrading facilities. The only effluent that Syncrude is discharging is mine depressurization water. This effluent is discharged into Beaver Creek Reservoir in the Beaver Creek Diversion System. The water in the diversion system eventually reaches the Athabasca River via Poplar Creek.

The published analyses and calculated annual loadings of selected parameters in the GCOS upgrading process water and Syncrude mine depressurization water are presented in Table 4. Data for the Athabasca River are also included as background information. It should be emphasized that, except for the Syncrude mine depressurization water, the number of samples analyzed is low. The parameters selected were those that were ranked by the Toxicological Index described in Section 2.5.2. The high Toxicological Index implies a high potential for harm or concern.

On the Syncrude lease, the quantity and inorganic composition of groundwater may vary extensively from well to well within a small geographic area (Table 3). Additional information on the composition and quantity of groundwater likely to be removed as mine depressurization water on other leases exists in unpublished government and industry files.

2.3.2 Known Emissions

2.3.2.1 Emissions from GCOS and Syncrude. A report to AOSERP (Shelfentook 1978) provides the most extensive assessment to date of emissions from these two plants. Table 5 and Table 6, developed from information presented by Shelfentook, provide annual emission estimates for GCOS and Syncrude, respectively. The 1976 and projected 1985 emissions from the two plants are also provided.

In the extracted bitumen, metals tend to concentrate in the heavy or bottom distillate fractions, such as coke, during the upgrading process. Therefore, it is anticipated that fly ash emitted from the GCOS steam/power plant (which burns coke generated from the upgrading process) will contain metals. Table 7 gives results of GCOS fly ash analysis. As with the analyses of bitumen, it is considered that the data shown in Table 7 are incomplete for the assessment of potentially toxic components such as heavy metals. Analytical results given in this table may not represent Syncrude particulate emissions because different primary conversion processes are used (delayed coker at GCOS versus fluid coker at Syncrude) and Syncrude has a different steam/power plant configuration. Particulate emissions from the GCOS plant are primarily caused by combustion of coke in the steam/power plant.

Table 4. Water quality of the Athabasca River, GCOS upgrading effluent (process waste effluent), and Syncrude mine depressurization water for elements rated by a Toxicological Index. An example of the format used in the table is as follows:

0.005^A	A = mean concentration in mg/L except where otherwise indicated
$0.002\text{-}0.007^B$	B = concentration range in mg/L except where otherwise indicated
1.3×10^{5C}	C = mean annual loading in kg/yr[a]

Mean annual loadings were not calculated when mean concentrations were below detection limit.

	Athabasca River 0.5 km upstream of Fort McMurray[b]	Athabasca River intake water at GCOS[c]	Athabasca River water in the vicinity of lease # 17[d]	GCOS upgrading effluent[e]	GCOS upgrading effluent[f]	Syncrude mine depressurization water[g]	Syncrude mine depressurization water[h]
HIGH TOXICOLOGICAL INDEX (13-16)							
Mercury	0.0067 µg/l[i] <0.0001-0.0044 µg/l		<0.002 µg/l		0.0010 µg/l <0.0005-0.0027 µg/l 1.3×10^{-2}	<0.0002* µg/l <0.0002-0.0022 µg/l	0.0034 µg/l <0.0001-0.07 µg/l 2×10^{-3}
Cadmium	0.002 <0.001-0.019 4.4×10^4	0.001 0.001-0.001 2.2×10^4	<0.01	0.001 0.001-0.001 1.5×10	0.002 <0.001-0.005 2.5×10	<0.05* <0.01-0.32	0.013 <0.001-0.053 10
Chromium	0.004 <0.002-0.018 8.7×10^4		<0.01		0.011 <0.001-0.028 1.4×10^2	<0.01*	0.008 <0.002-0.036 6
Arsenic	0.0065 <0.0025-0.02 1.4×10^5		<0.01		0.356 0.140-0.570 4.6×10^3	<0.01	0.004 <0.0002-0.02 3
Copper	0.019 0.002-0.059 4.1×10^5	0.004 0.002-0.006 8.8×10^6	<0.01	0.004 0.003-0.005 5.0×10	0.045 <0.001-0.315 6.0×10^2	<0.01*	0.015 <0.001-0.032 10
Zinc	0.053 0.014-0.069 1.2×10^6	0.001 <0.001-0.001 2.2×10^4	0.03 <0.01-0.06 6.5×10^5	0.003 0.001-0.005 4.0×10	0.02 0.008-0.03 2.5×10^2	0.65* <0.01-7.5 5.0×10^2	0.024 <0.001-0.2 2.0×10
Cobalt	0.005 <0.002-0.043 1.1×10^5	<0.002	<0.01	0.002 <0.002-0.003 2.5×10	0.008 <0.001-0.017 10^2	<0.01*	0.05 <0.002-0.165 4.0×10
MODERATE TOXICOLOGICAL INDEX (8-12)							
Beryllium		<0.005		<0.005			
Aluminum	2.1 0.43-10.6 4.6×10^7		<1			1.6* <0.01-5.2 1.2×10^3	0.16 <0.005-2.3 1.2×10^2
Selenium	0.0012 <0.0005-0.0018 2.6×10^4						0.0014 <0.0005-0.003 1
Iron	7.3 0.9-63.0 1.6×10^8	0.48 0.40-0.55 1.0×10^7	0.65 0.43-0.91 1.4×10^7	0.46 0.44-0.50 6.0×10^3	0.6 <0.1-2.5 7.8×10^3	11.4 <0.01-128 8.7×10^3	1.51 <0.04-7.45 1.1×10^3
Silver	<0.005						0.011 <0.005-0.03 10
Lead	0.006 <0.002-0.026 1.3×10^5	<0.004		<0.004	0.011 <0.001-0.045 1.4×10^2	0.05 <0.01-0.22 4.0×10	0.028 <0.002-0.142 2.0×10
Nickel	0.014 <0.002-0.08 3.1×10^5	0.003 <0.002-0.004 6.5×10^4	<0.02	0.119 0.019-0.41 1.5×10^3	0.030 0.006-0.037 4.0×10^2	<0.02*	0.059 <0.002-0.32 4.0×10
Titanium			<1			<1*	
Manganese	0.24 0.06-1.7 5.2×10^6	0.030 0.027-0.033 6.5×10^5	<0.01	0.045 0.031-0.056 6.0×10^2	0.093 0.014-0.421 1.2×10^3	0.90 0.01-6.63 7.0×10^2	0.194[j] 0.65-1.2
Barium			<1			<1	

continued . . .

Table 4. Continued.

	Athabasca River 0.5 km upstream of Fort McMurray[b]	Athabasca River intake water at GCOS[c]	Athabasca River water in the vicinity of lease # 17[d]	GCOS upgrading effluent[e]	GCOS upgrading effluent[f]	Syncrude mine depressurization water[g]	Syncrude mine depressurization water[h]
LOW TOXICOLOGICAL INDEX (3-7)							
Calcium	31.4 17.5-40.0 6.8×10^8		35.3 33-44 7.7×10^8		42 23-61 5.5×10^5	56 3-316 4.3×10^4	71 <1-318 5.4×10^4
Potassium	0.9 0.4-1.5 2.0×10^7		1.1 0.6-2.0 2.4×10^7		3.5 2.0-5.4 4.6×10^4	33 4-112 2.5×10^4	45 19-65 3.4×10^4
Magnesium	6.6 4.5-10.0 1.4×10^8		9.3 6.0-14 2.0×10^8		9.5 4-14 1.2×10^5	69.6 3.411 5.3×10^4	134 47-253 10^5
Sodium	9.3 5.9-36.0 2.0×10^8		10.5 8-16 2.3×10^8		108 66-244 1.4×10^6	3517 564-10,698 2.7×10^6	5623 2150-7900 4.3×10^6
Fluorine (as fluoride)	0.09 0.06-0.17						
Vanadium	0.0004 0.001-0.04 8.7×10^4	<0.001	<1	0.40 0.25-0.60 5.2×10^3		<1*	0.004 0.001-0.05 3.0×10
Silicon (as silica)							4.4 2.0-18 3.3×10^3
Chlorine (as chloride)	6.1 1.0-51.0 1.3×10^8		66 28.99 1.4×10^9		76 25-131 9.9×10^5	4560 19-19,854 3.5×10^6	7615 2250-10,500 5.8×10^6
Boron	0.2 0.01-1.51 4.4×10^6		<1			5.8 2.0-8.0 4.4×10^3	2.60 0.48-7.08 2.0×10^3

[a]Assumed discharges for calculation of loadings were as follows:

Athabasca River at Fort McMurray: 2.2×10^{13} l/yr.

Source: Conversation of 17 August 1978 with I. Barnaby, Flow Forecasting Branch, Alberta Environment, Edmonton, Alberta.

GCOS upgrading effluent: 1.3×10^{10} l/yr.

Source: Letter of 7 December 1977 from W. Cary, Environmental Conversation Department, GCOS, Fort McMurray, Alberta.

Syncrude mine depressurization water: 7.6×10^8 l/yr.

Source: Letter of 2 December 1977 from J. Retallack, Environmental Affairs, Syncrude Canada Ltd., Edmonton, Alberta.

[b]Source: Lake and Rogers (in prep.); sample size = 8.

[c]Source: Strosher and Peake (1976); sample size = 2.

[d]Source: Letter of 2 December 1977 from J. Retallack, Environmental Affairs, Syncrude Canada Ltd., Edmonton, Alberta; sample size = 4.

[e]Source: Strosher and Peake (1976); sample size = 4.

[f]Source: Alberta Environment, unpublished water quality data (1967-1975); sample size = 5-15.

[g]Source: Letter of 2 December 1977 from J. Retallack, Environmental Affairs, Syncrude Canada Ltd., Edmonton, Alberta; sample size = 72 (* = 28).

[h]Source: Lake and Rogers (in prep.); sample size = 5.

[i]The data supplied by Lake and Rogers (in prep.) report a mean mercury concentration (0.0067 ppb) that is greater than the maximum concentration (0.0044 ppb); an annual loading (kg/yr) was not calculated.

[j]The data supplied by Lake and Rogers (in prep.) report a mean manganese concentration (0.194) that is less than the reported minimum concentration (0.65); an annual loading (kg/yr) was not calculated.

Table 5. Existing (1976) and projected (1985) emission estimates (g/yr) for GCOS[a].

Component	1976	1985
SO_2	$93\ 000 \times 10^6$	$93\ 000 \times 10^6$
H_2S	13×10^6	ND[c]
CO	$1\ 053 \times 10^6$	$1\ 200 \times 10^6$
Light HC (as CH_4)	326×10^6	
RCHO[b] (as HCHO)	22×10^6	
Heavy Organics	$4\ 533 \times 10^6$	$5\ 000 \times 10^6$
Organic Acids	0.12×10^6	
NH_3	203×10^6	ND
NO_x (as NO_2)	$7\ 368 \times 10^6$	$7\ 500 \times 10^6$
Particulates	$15\ 492 \times 10^6$	$5\ 800 \times 10^6$
H_2O	$13\ 253 \times 10^9$	$13\ 250 \times 10^9$

[a]Source: Shelfentook (1978).
[b]aldehydes
[c]Symbol ND = No Data

Table 6. Existing (1976) and projected (1985) emission estimates (g/yr) for Syncrude[a].

Component	1976	1985
SO_2	45.5×10^6	$103\ 000 \times 10^6$
H_2S	84.2×10^6[b]	ND[d]
CO	33×10^6	$5\ 700 \times 10^6$
Light HC (as CH_4)	13×10^6[b]	
RCHO[c] (as HCHO)	11.2×10^6	
Heavy Organics	$1\ 309 \times 10^6$[b]	$5\ 300 \times 10^6$
Organic Acids	0.18×10^6	
NH_3	$1\ 309 \times 10^6$[b]	ND
NO_x (as NO_2)	$1\ 632 \times 10^6$	$40\ 000 \times 10^6$
Particulates	34.2×10^6	$3\ 200 \times 10^6$
H_2O	$60\ 790 \times 10^9$[b]	$79\ 000 \times 10^9$

[a]Source: Shelfentook (1978).

[b]The majority of emissions on the Syncrude Lease were from natural sources

[c]aldehydes

[d]Symbol ND = No Data

Table 7. GCOS fly ash analysis (weight %)[a].

Compound	Dry Fly Ash June 1976	Carbon Free Fly Ash June 1976	Dry Fly Ash December 1977
Silicon as SiO_2	34.30	42.90	33.10
Aluminum as Al_2O_3	22.40	27.90	15.63
Iron as Fe_2O_3	6.27	7.86	6.66
Vanadium as V_2O_5	4.70	5.87	3.58
Titanium as TiO_2	3.33	4.18	2.98
Calcium as CaO	2.12	2.70	4.09
Sulphur as SO_3	2.09	-	2.48
Potassium as K_2O	1.69	2.13	1.40
Nickel as NiO	1.36	1.69	1.74
Magnesium as MgO	1.23	1.55	1.10
Sodium as Na_2O	0.50	0.63	0.83
Molybdenum as MoO_3	0.18	0.23	-
Manganese as MnO	0.16	0.21	0.18
Phosphorus as P_2O_5	0.14	0.17	0.17
Lithium as Li_2O	-	-	0.03
Ignition loss before analysis	-	20.41	25.96
No. of samples	17	17	8

[a]Source: Conversation of 7 December 1977 with M. Strosher, Pollution Control Division, Alberta Environment, Edmonton, Alberta.

2.3.2.2 <u>Emissions from a third oil sands plant</u>. It is assumed that the next oil sands plant will meet Alberta Environment's emissions control requirements. The Standards and Approvals Division has recently revised their emission objectives for the next oil sands plant. These revised objectives require a considerable reduction in sulphur dioxide emissions compared to the limits which were in effect in 1976 and which were applied to Syncrude. The revised emission objectives for sulphur dioxide, nitrogen oxides and particulate emissions are shown in Table 8.

To stay within the permissible sulphur dioxide requirements, Syncrude is stockpiling high sulphur coke in favour of burning "clean" natural gas. Future plants will probably not be allowed to follow this practice and will likely burn high sulphur coke, thus significantly increasing the quantity of sulphur which must be controlled.

2.3.2.3 <u>Summary of major emissions</u>. Previous tables and discussions have described the emissions from GCOS, Syncrude, and a third oil sands plant. It must be emphasized that the majority of emission quantities given in the previous tables are only estimates.

Sulphur dioxide emissions for 1976 from GCOS averaged 93×10^9 g/yr (255 long tons per day (LTD)). The main sources are the steam/power plant, sulphur recovery plant, and from flaring. Syncrude, when operating at full production, will emit approximately 103×10^9 g/yr (282 LTD). A third plant similar in size to Syncrude and designed to meet Alberta Environment's 1977 objectives would emit approximately 25×10^9 g/yr (70 LTD). Total sulphur dioxide emissions from the three plants would be approximately 220×10^9 g/yr (605 LTD).

Particulate emissions from GCOS are currently exceeding the Clean Air Act Regulations. However, the company is on a compliance schedule which will have emissions reduced to approximately 5×10^9 g/yr (13.6 LTD). Syncrude particulate emissions will gradually increase from the time of start-up until 1980 when emissions should stabilize at approximately 3.8×10^9 g/yr (10.9 LTD). A third plant would emit particulates at a rate similar to Syncrude. Total particulate emissions from three plants would thus be approximately 12.6×10^9 g/yr (35.4 LTD).

Table 8. Current objectives for sulphur dioxide, nitrogen oxides, and particulate emissions[a].

	1977
Total SO_2 emissions must be less than:	0.5 long tons SO_2 per 1 000 barrels of bitumen feedstock to the upgrading process
Sulphur recovery plant efficiency	98–98.5%
Flaring of sour water stripping gas	Not allowed
Standby sulphur recovery Train of at least 50% capacity maintained in a hot condition	Required
NO_2 emissions	Not to exceed 400 ppm at 50% excess air and dry conditions
Particulate emissions	Not to exceed 0.2 lbs per 1000 lbs of flue gas

[a]Source: Conversation of 9 February 1978 with S.L. Dobko, Standards and Approvals Division, Alberta Environment, Edmonton, Alberta.

2.3.3 Potential Wastes

If future Athabasca oil sands plants use surface mining and the hot water extraction process, it is reasonable to assume that wastes produced by them will be basically similar to those of the first three plants. It can be expected that some variations in the composition of emissions and effluents will occur (see Sections 2.3.1 and 2.3.2).

Future plants may employ in situ mining techniques (reviewed by Nicholls and Luhning 1977), but such techniques are still in the pilot plant stage and operating plants will not use them before the mid-1980's. If plants use the basic hot water extraction method for the surface portion of refining, effluents and emissions from the actual plants themselves may not be peculiar to the in situ method (Carrigy and McLaws 1973). The in situ mines, however, may generate wastes that are different from those produced by surface oil sand mines, since in the in situ method a portion of the bitumen extraction process is performed underground instead of at the plant. A general review of all impacts likely to be associated with in situ technology was conducted by Carrigy and McLaws (1973).

In situ mining methods can be grouped into those using some form of steam or hot water injection (wet thermal) and those employing underground combustion. Other methods, such as solvent extraction (Redford 1976), have been suggested, but these methods are not well developed and no information exists concerning the wastes they may produce. Steam or hot water injection methods (wet thermal) result in water returning with bitumen in the recovery wells. This water may be saturated in clay minerals and may contain toxic elements (Boon 1977). Cotsworth and Redford (1974) observed that water produced from a pilot plant adjacent to the Steepbank River contained much silt and bitumen. Carrigy and McLaws (1973) noted that the steam injection method may occasionally cause the release of hydrogen sulphide. Other than these preliminary indications, no other information exists concerning emissions or effluents likely to be produced by wet thermal in situ mining methods.

In situ mining using underground combustion methods (e.g., the COFCAW process-combination of forward combustion and water flooding) may produce more complex and toxic wastes than wet thermal methods because of materials injected to promote combustion and the products of that combustion. Very little analytical information exists concerning those wastes. Barbour et al. (1977) made a preliminary laboratory examination of wastewaters produced during an experimental in situ retorting of oil sands in Utah and found that more water than oil may be obtained from the recovery wells. The water recovered with the oil contained low to moderate concentrations of inorganic ions, very high organic compound concentrations (due primarily to low molecular weight carboxylic acids), and had a low pH. Waters left in the formation were higher in inorganic, but lower in organic compounds than produced waters, and were near neutrality. Carrigy and McLaws (1973) point out that in situ mining with underground combustion may result in groundwater contamination because of the geologically shallow nature of the deposits and the use of chemicals for promoting combustion, emulsifying oil, etc. They name several chemicals which may be injected and may remain in the formation and enter groundwater. In addition they present a preliminary analysis of saline formation water produced along with bitumen by the Muskeg Oil COFCAW process. In an environmental study prepared for Amoco Canada Petroleums Ltd. (Lombard North Group 1974), it is stated that mine wastewaters will contain about 10 000 ppm total dissolved solids, and about 3350 ppm dissolved chloride. The report also states that there will be no surface effluents from the plant and that wastewaters will be disposed in underground reservoirs. However, the report concedes that under full production conditions, and especially if other plants are operating in the area, this could result in regional effects on groundwater and consequently on river valley springs.

Concerning air emissions from underground combustion in situ mines, the Amoco report simply states that air emissions will be within government standards. Redford (1976) notes that sulphur dioxide, hydrogen sulphide, and carbon monoxide will be produced underground by the combustion method. Carrigy and McLaws (1973) state that these combustion gases (termed field gases if vented at the wells) will contain water, carbon monoxide, sulphur dioxide and nitrogen oxides if flared. They present data on the probable amounts of field gases which will be produced.

2.4 CURRENT KNOWLEDGE OF THE TOXICOLOGY OF WASTES

2.4.1 Water System

Aquatic toxicological research was first proposed by the former Aquatic Fauna Technical Research Committee (AFTRC) of AOSERP and developed almost simultaneously along three experimental lines.

1. Whole effluent toxicity (Lake and Rogers in prep.);
2. Component toxicity (Sprague et al. 1978; Anderson in progress; Giles et al. in prep); and
3. Habitat manipulation (Schindler et al. in prep.; Barton and Wallace 1979)

In addition to baseline biological studies, a synoptic survey of baseline levels of selected contaminants in water, sediments, fish, and invertebrates was conducted (Lutz and Hendzel 1977) as was a literature review on the effects of saline water on aquatic biota (Machniak 1977). Studies relevant to toxicology were also carried out under the auspices of the former Hydrology Technical Research Committee (HYTRC), including research on the organic constituents of synthetic oil production effluents (Strosher and Peake 1976; Strosher and Peake 1978), the acidification potential of lakes in the Athabasca Oil Sands area (Hesslein in prep), and heavy metal interactions with sediment (Allan and Jackson 1978) and humic substances (Korchinski in prep). A study was also initiated on the biochemical ecology of the Athabasca River in relation to industrial use (Costerton and Geesey in prep.) This project was expanded to include studies on changes in the assimilative capacity of the Athabasca River due to microbial degradation of organic compounds (Nix et al. in prep.). The projects conducted in the Water system in 1977-78 are listed in Table 9.

Within its study area, AOSERP has established a network of hydrometric, suspended sediment and water quality monitoring stations (HYTRC projects HY 1.1, 1.3, 2.5, 2.8.1; see Table 9). A federal agency, Water Survey of Canada, installed and maintains the hydrometric and suspended sediment sampling stations (under contractual agreement with AOSERP), while the water quality stations are maintained by the Pollution Control Division of Alberta Environment (also under contractual agreement with AOSERP). Data collected routinely at water quality stations are given in Table 10. To date, no summary reports have been produced;

Table 9. AOSERP Research Projects, Water System, 1977-78.

Project No.	Project Title
AF 2.0.1	Invertebrate Resource Studies of the AOSERP Study Area
AF 2.0.2	Primary and Secondary Production of Muskeg Drainage in the AOSERP Study Area
AF 2.3.1	Studies of Lake Acidification and Cycling of Heavy Metals in Aquatic Ecosystems
AF 2.5.1	Ecology and Life Cycles of Aquatic Invertebrates in Hartley Creek
AF 2.6.1	Assimilative Capacity of the Athabasca River due to Microbial Degradation of Organic Components
AF 3.5.1	Acute and Chronic Toxicity of Vanadium to Fish
AF 3.6.1	Multiple Toxicity of Nickel, Vanadium and Phenol to Fish
AF 4.3.2	Biological Sampling and Tagging of the Major Fish Species of the Athabasca River
AF 4.4.1	A Preliminary Study of Aquatic Habitat Mapping
AF 4.5.1	Intensive Study of the Fish Fauna of the Muskeg River Watershed
AF 4.5.2	Intensive Study of the Fish Fauna and Aquatic Habitat of the Steepbank River Watershed
AF 4.8.1	Fisheries Investigation of the Athabasca and Clearwater Rivers Upstream from Fort McMurray (2 Vols.)
AF 4.9.1	The Effects of Sedimentation on the Aquatic Biota
AF 4.9.2	Review of Stream Diversions and Stream Restoration Techniques and Associated Effects on Aquatic Biota
HG 1.0	Regional Hydrogeology of the Athabasca Oil Sands

continued . . .

Table 9. Concluded.

Project No.	Project Title
HG 1.1	Hydrogeological Investigations of the Muskeg River Basin
HY 1.1	Alberta Oil Sands Region Stream Gauging Data
HY 1.3	Suspended Sediment Data Collection of some Hydrometric Stations
HY 2.5	Intensive Water Quality Study of the Muskeg River Basin
HY 2.8.1	Regional Water Quality of the AOSERP Study Area
HY 3.1.2	Water Quality Investigation into the Form of Organic Compounds in the AOSERP Study Area.

Table 10. Parameters for regional and delta water quality study.

PARAMETER[a]	NAQUADAT CODE[b]
Sediment Digestion	
Calcium	20103 L
Magnesium	12102 L
Sodium	11102 L
Potassium	19102 L
Chloride	17203 L
Sulphate	16306 L
Total Alkalinity	10101 L
pH	10301 L
Carbonate	06301 L
Bicarbonate	06201 L
Total Hardness	10603 L
Silica	14101 L
Conductance	02041 L
Color (Filtered sample)	02021 L (or 02022 L)
Tannin & Lignin	06551 L
Total Filt. Residue	10451 L
Total Filt. Residue Fixed	10551 L
Total Non-Filt. Residue	10401 L
Total Non-Filt. Residue Fixed	10501 L
Humic Acids	
Total Organic Carbon	06001 L
Total Inorganic Carbon	06051 L
Total Diss. Organic Carbon	06101 L - substitute a glass filter
Nitrate & Nitrite Nitrogen	07110 L
Turbidity **	02073 L
Total Kjeldahl Nitrogen	07013 L
Total Phosphorous	15406 L
Ortho-Phosphorous	15256 L
Phenol	06532 L
Oil and Grease **	06521 L
Sulphide **	16101 L
Cyanide **	06603 L
Chlorophyll A **	06711 L
Chemical Oxygen Demand **	08301 L
Hexavalent Chromium *	24101 L
Copper *	29305 L
Iron *	26304 L
Lead *	82302 L
Manganese *	25304 L

continued . . .

Table 10. Concluded.

PARAMETER[a]	NAQUADAT CODE[b]
Titanium *	
Zinc *	30305 L
Vanadium *	23022 L
Selenium *	34102 L
Mercury	80011 L
Arsenic *	33104 L
Nickel *	28302 L
Aluminum	13302 L
Cobalt *	27302 L
Boron	05105 L
Silver * (detection limit less than 1 ppb)	

[a]Symbols: * = unfiltered samples analyzed monthly
= field filtered samples analyzed quarterly
** = Run occasionally when specified

[b]Specifying method and detection limit

however, a summary of water quality data is presently in preparation (Seidner in prep.).

There are several other sources of information in addition to AOSERP research. Syncrude funds baseline aquatic studies and conducts a water quality sampling program in the immediate area of its lease. In particular, the toxicity of saline groundwater (from the lease) to fish and benthic macroinvertebrates has been investigated (McMahon et al. 1977). Studies instigated by the Environmental Protection Service of Fisheries and Environment Canada to characterize effluents from the GCOS plant (Hrudey 1975) and examine their toxicity (Hrudey 1975; Hrudey et al. 1976) have been completed. Also, to meet their permit obligations, GCOS is required to carry out routine water quality monitoring on various wastewater streams and monthly bioassays on the upgrading process effluent.

Reviews and evaluations of available reports on the toxicity of liquid wastes are presented in Appendix 5.3.1.

Toxicological and related research as it pertains to the oil sands area can be summarized as follows:

1. Inorganic water quality monitoring data (collected over approximately 1 year) on natural water sources in the AOSERP area is available (Seidner in prep.).
2. Inorganic characterization of Syncrude mine depressurization water (McMahon et al. 1977; Lake and Rogers in prep.; Giles et al. in prep.) and GCOS upgrading effluent (Hrudey et al. 1976) has been undertaken. Information is available on GCOS dike drainage (Hrudey 1975; Lake and Rogers in prep.). Syncrude has unpublished data on mine depressurization water. GCOS has unpublished data on its upgrading effluent.
3. Preliminary organic characterization of various effluents has been undertaken:
    - 3a) GCOS upgrading plant effluent (Strosher and Peake 1976, 1978).
    - 3b) GCOS dike drainage (Strosher and Peake 1976, 1978).
    - 3c) Athabasca River water near GCOS (Strosher and Peake 1976, 1978).

3d) Syncrude mine depressurization water (Strosher and Peake 1978).

4. Several features of mine depressurization water have been investigated. Lake and Rogers (in prep.) and Giles et al. (in prep.) have examined the effect of storage on the toxicity of whole mine depressurization effluent. Syncrude is conducting a study on the fate of mine depressurization water discharged to Beaver Creek Reservoir.
5. Short term bioassay data (96 hour acute lethality) are available for the following effluent streams:
   - 5a) Syncrude saline mine depressurization water (McMahon et al. 1977; Lake and Rogers in prep; Giles et al. in prep.).
   - 5b) GCOS process upgrading effluent (Hrudey 1975). GCOS and Alberta Environment Pollution Control Division have unpublished data on this effluent.
   - 5c) GCOS dike filter drainage (Lake and Rogers in prep.; Hrudey 1975).
6. Relatively complete short term toxicity experiments (utilizing both fish and invertebrates) on saline mine depressurization water have been completed (McMahon et al. 1977; Giles et al. in prep). Preliminary long term experiments on the toxicity of saline mine depressurization water on invertebrates have been conducted (Giles et al. in prep.).
7. Toxicological information is available on:
   - 7a) The effects of tailings sludge on benthic invertebrates (Barton and Wallace 1979).
   - 7b) The toxicity of single components
     - Copper (Giles et al. in prep. ; Anderson in prep.)
     - Vanadium (Giles et al. in review; Sprague et al. 1978.)
     - Nickel (Anderson in prep.)
     - Organics (BHT, butylated hydroxytolune; DBP, di-n-butyl phthalate; BEHA, bis(2-ethylhexyl)adipate;

BEHP, bis(2-ethylhexyl) phthalate (Hrudey et al. 1976).

7c) The toxicity of mixtures--nickel, vanadium, phenol (Anderson in prep.

8. Preliminary studies have been conducted on the dynamics of inorganic and organic compounds:
   8a) Organics in effluents, receiving waters and sediment (Strosher and Peake 1976, 1978).
   8b) The interactions of metals and sediment (Allan and Jackson 1978).
   8c) Interactions of metals and humic substances (Korchinski in prep.).
   8d) Assimilation of organics by microbes (Costerton and Geesey in prep.: Nix et al. in prep.).

2.4.2 <u>Air System</u>

To date, projects in the Air System have concentrated on:

1. Collection of meteorological and climatological data
2. Collection of air quality data and estimation of emissions
3. Studies of plume dispersion and dispersion modelling, and
4. Studies of pollutant transformation and interactions with snow, rain, and fog.

Thus, the approach to air system research has been oriented towards the collection of baseline data and the development of predictive modelling capabilities. Information generated by these studies is available to investigators in other environmental systems.

Studies which have been completed or projects which are ongoing are shown in Table 11 and the major areas associated with the studies indicated. Some of these projects include material from other major areas, but for the purposes of this study, only the most important area has been indicated. The projects carried out during 1977-78 are given in Table 12.

Although models for predicting air quality will ultimately be very useful, they are not yet operational. The work to date which is considered to have greatest toxicological significance is ambient

Table 11. Ongoing or completed studies in the Air System.

Study	Major Area
Meteorological and Climatological Data Acquisition	
- Meteorological Tower (ME 1.1)	Meteorological
- Climatological Network (ME 1.2)	Climatological
- Mobile Minisonde (ME 1.3)	Meteorological
- Precipitation Chemistry Network (ME 1.4)	Climatological
- Intensive Field Studies (ME 1.5)	Meteorological
- Feasibility of Weather Radar (ME 1.6)	Climatological
- Feasibility of Satellite Remote Sensing (ME 1.7)	Climatological
Air Quality Data Acquisition	
- Air Monitoring Network (ME 2.1)	Air quality
- Sources and Emissions Inventory (ME 2.2)	Emissions
- Plume Dispersion Surveys (ME 2.3)	Dispersion
Background Air Chemistry (ME 3.2)	Air quality
Pollutant Transformation Processes (ME 3.5)	Transformation
Fog Occurrence and Problems (ME 3.3)	Interaction
Low Level Air Trajectories (ME 3.4)	Dispersion
Plume Rise and Diffusion (ME 3.8.1)	Dispersion
Turbulence Measurements (ME 3.8.2)	Dispersion
Climatological Dispersion Model (ME 4.1)	Dispersion
Dispersion and Transport Model (ME 4.2.1)	Dispersion

Table 12. AOSERP research projects, Air System, 1977-78.

Project No.	Project Title
ME 1.1	Meteorological Tower
ME 1.2	Meteorological Network
ME 1.3	Mobile Minisonde
ME 1.4	Precipitation Chemistry 1. Climatology of the AOSERP Study Area
ME1.5.3	Meteorological and Air Quality Summer Field Study, June 1977.
ME 2.1	1. Ambient Air Quality in the AOSERP Study Area, 1977
ME 2.2	An Inventory System for Atmospheric Emissions in the AOSERP Study Area
ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plant
ME 3.2	Background Air Quality in the AOSERP Study Area
ME 3.5.2	SO_2 Oxidation in the Plumes from the GCOS Extraction Plant under Summer Conditions
ME 3.5.4	Plume Chemical Reaction - Modelling and Verification
ME 3.6	Literature Review on Pollution Deposition Processes
ME 3.8.3	Calculate Sigma Data for the AOSERP Study Area
ME 4.2.2	Air Quality Simulation Modelling

air quality monitoring. Therefore, this aspect is discussed in detail.

2.4.2.1 Ambient air quality.

1. Existing monitoring programs. AOSERP air quality monitoring is designed to supplement the monitoring carried out by GCOS and Syncrude near their plants. With the exception of the station at Fort McMurray, data presently collected by the AOSERP network represents regional, background, or baseline conditions.

   The air quality monitoring program of GCOS has been in existence for a number of years. Syncrude has recently established their own air monitoring network. Monitoring stations operated by the two plants are usually in the areas most likely to be affected by their emissions.

   The air monitoring networks in the AOSERP study area are described in more detail by Strosher (1978).

2. Sulphur dioxide. Alberta ambient air quality standards are designed to protect the environment (Alberta Department of Health 1970). Since their objectives are to "protect the health and welfare of all citizens ..." and "... prevent insofar as possible deleterious effects to animals, plants and property" (Ibid), then violations can be considered potentially deleterious. The number of violations of sulphur dioxide standards recorded by GCOS has been summarized by Strosher (1978) and are shown in Table 13. The GCOS monitoring locations where 0.5 hour violations have occurred have been determined by Stanley Associates Engineering Ltd. (letter of 9 December 1977 from B. Croft, Stanley Associates Engineering Ltd., Edmonton, Alberta) from violation data supplied by Alberta Environment. This data is presented in Table 14. Data collected from the AOSERP continuous monitoring stations, located further from emission sources, indicate sulphur dioxide concentrations well below the 0.5 hour regulation level.

Table 13. Summary of sulphur dioxide violations of Alberta Ambient Air Quality Standards recorded by GCOS[a].

Time Period[b]	Standard[c]	Number of Readings Violating Standards 1974 2 stations	1975 3 stations	1976 5 stations
0.5 hour	0.20 ppm	85	154	64
1 hour	0.17 ppm	57	90	46
24 hour	0.06	4	8	6

[a]Source: Strosher (1978)

[b]Assumes monitoring equipment operational 100% of time.

[c]Alberta Ambient Air Quality Standards

Table 14. GCOS monitoring locations where 0.5 hour sulphur dioxide violations occurred[a].

Location	Number of Readings Violating 0.5 hour Regulations 1974	1975	1976
Supertest	43	12	8
Mildred Lake	42	14	32
Petrofina Airstrip	ND[b]	128	16
Mannix	ND	ND	6
Ruth Lake	ND	ND	2

[a]Source: Letter of 9 December 1977 from B. Croft, Stanley Associates Engineering Ltd., Edmonton, Alberta.

[b]Symbol ND = No Data, station not operational.

3. Particulates. Particulates have not been monitored to the same extent as sulphur dioxide. Total suspended particulates are being monitored at the AOSERP stations and by GCOS at the Mannix location. Results of a limited amount of sampling at these stations have been summarized by Strosher (1978).

   Particulate matter on some May 1977 filters have been analyzed for sulphates, nitrates, two carcinogens (benzo(a)pyrene and benzo(k)fluranthene), and heavy metals. The results are shown in Tables 15 and 16. Strosher warns that the results in Table 16 could have been influenced by helicopter and local diesel generator exhausts.
4. Other pollutants. The AOSERP stations also monitor air quality other than sulphur dioxide and particulates. Results have been summarized by Strosher (1978) and compared to the Alberta Ambient Air Quality Standards, where these exist, for the following:
   a) total oxides of nitrogen (nitrogen oxides = nitric oxide + nitrogen dioxide);
   b) nitrogen dioxide;
   c) ozone;
   d) reactive hydrocarbon (reactive hydrocarbon = total hydrocarbon - methane);
   e) total hydrocarbon; and
   f) carbon monoxide.

   These data indicate that the ozone concentrations at Birch Mountain regularly exceed Alberta Ambient Air Quality Standards. This may be of significance in photochemical reactions between oxides of nitrogen and reactive hydrocarbons.

2.4.3 Land System

2.4.3.1 Vegetation and soils. AOSERP studies carried out to date on vegetation and soils (including microflora) have been oriented primarily toward the collection of baseline information, basic applied research in the area of reclamation, and studies of the effects of sulphur dioxide on vegetation. These

Table 15. High volume sampler results, Fort McMurray area, 1977[a].

Station	Sample Date	Parameter					
		Benzo(a)pyrene		Benzo(k)fluranthene		Sulphate (SO_4)	Nitrate (NO_3)
		μg/1000 m^3 air	μg/gm particulate	μg/10^3 m^3 air	μg/gm particulate	μg/m^3 air	μg/m^3 air
Birch Mountain	19-5-77	0.008	0.440	0.000	0.000	2.1	0.00
	25-5-77	0.002	0.069	0.002	0.069	3.0	0.02
	31-5-77	0.002	0.175	0.002	0.175	2.8	0.02
Bitumount	13-5-77	0.001	0.018	0.002	0.036	2.3	0.02
	19-5-77	0.001	0.073	0.001	0.073	9.2	0.05
	31-5-77	0.007	0.850	0.000	0.000	3.1	0.02
Mannix	25-5-77	0.007	0.058	0.007	0.058	11.1	0.17
Town (Fort McMurray)	13-5-77	0.001	0.008	0.003	0.023	6.0	0.06
	19-5-77	0.008	0.066	0.015	0.123	3.0	0.03
	25-5-77	0.008	0.031	0.010	0.040	8.1	0.17
	31-5-77	0.006	0.049	0.017	0.140	5.0	0.14

[a]Source: Strosher (1978).

Table 16. Metals in high volume samples, Fort McMurray area, 1977[a].

Station	Sample Date	Parameter (ug/m^3 air)[b]													
		Cu	Pb	Zn	Ni	Co	Cd	Be	Mo	Mn	Cr	Hg	Fe	Al	V
Birch Mountain	19-5-77	0.0179	0.018	0.034	0.005	0.003	0.002	*	*	0.017	*	0.0002	0.266	*	*
	25-5-77	0.198	0.016	0.030	0.007	0.002	0.001	*	*	0.011	*	0.0003	0.152	*	*
	31-5-77	0.168	0.009	0.042	0.003	*	*	*	*	0.011	*	0.0002	0.145	*	*
Bitumount	13-5-77	0.194	0.045	0.039	0.003	0.003	*	*	*	0.031	*	*	0.428	*	*
	19-5-77	0.132	0.037	0.012	0.002	0.004	*	*	*	0.004	*	0.0005	0.113	*	*
	31-5-77	0.210	0.018	0.004	0.002	0.002	*	*	*	0.004	*	0.0001	0.162	*	*
Mannix	25-5-77	0.220	0.042	0.021	0.068	0.006	0.003	*	0.010	0.037	0.014	0.0002	1.893	*	0.011
Town (Fort McMurray)	13-5-77	0.188	0.014	0.048	0.008	0.001	0.001	*	*	0.071	*	0.0002	1.401	*	*
	19-5-77	0.230	0.090	0.024	0.005	0.003	0.002	*	*	0.040	*	*	1.920	*	*
	25-5-77	0.172	0.053	0.046	0.016	0.007	0.003	*	*	0.117	0.021	*	5.863	*	0.002
	31-5-77	0.107	0.039	0.052	0.023	0.005	0.001	*	0.003	0.090	*	0.0003	4.215	*	0.005
Detection Limit		0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.008	0.010	0.0001	0.005	0.020	0.002

[a]Source: Strosher 1978.

[b]Symbol * = Below detection limit

latter studies have been the focus of the land-based toxicological program since 1975. Studies which have been carried out or projects which are ongoing are listed in Table 17. The major area of each study is indicated. Reviews and evaluations of these reports are placed in Appendix 5.3.2. The research projects for 1977-78 are given in Table 18.

2.4.3.2 Wildlife. AOSERP wildlife studies to date have focused exclusively on baseline data collection. It is not within the scope of this project to review and evaluate these studies. The studies funded by AOSERP during the 1977-78 fiscal year are listed below (see Table 18 for an explanation of project numbers):

1. Moose, caribou, and wolf ecology (TF 1.1) Bear ecology - management strategies (TF 1.4)
2. Avifauna baseline studies (TF 2.1)
3. Rare and sensitive species: white pelican (TF 2.2)
4. Baseline states of rare sensitive avian species (TF 2.3)
5. Semi-aquatic mammals (TF 3.1)
6. Small mammals control (VE 7.1.1)
7. Reptiles and amphibians (TF 5.1
8. Resource utilization (TF 6.2, 6.3)

2.4.4 Human Systems

To date, there have been no AOSERP toxicological studies of the effects of oil sands development on humans. Research on the effects of airborne pollutants on humans in an oil sands environment was considered during 1976 (letter of 4 November 1976 from E.E. Cudby, Environmental Control, Chevron Standard Ltd., Calgary, Alberta) but the project was never initiated.

Table 17. Ongoing or completed studies in the Land System.

Study	Major Area
Soils Inventory of Oil Sands Area (VE 2.1)	Baseline
Preliminary Vegetation Survey (VE 2.2)	Baseline
Vegetation Inventory (VE 2.3)	Baseline
Visual symptomology of sulphur dioxide to vegetation (VE 3.1)	Toxicology
Pre-visual injury of sulphur dioxide to vegetation (VE 3.3)	Toxicology
Ecological bench marking and biomonitoring (VE 3.4)	Toxicology
Physical properties of soils and mined materials in relation to reclamation (VE 4.1)	Baseline/Reclamation
Chemical properties of soils and methods of improving mined materials for plant growth (VE 4.1)	Baseline/Reclamation
Sulphur deposition and acidification of soils (VE 4.2)	Baseline/Toxicology
Characterization and utilization of peat (VE 5.2)	Baseline/Reclamation
Long term prediction of vegetation performance for dike management (VE 6.1)	Prediction
Reclamation for afforestation by suitable tree and shrub species (VE 7.1)	Reclamation
Controlled environmental tests for suitable revegetation species (VE 7.2)	Reclamation
Field trials for seed production and handling (VE 7.3)	Reclamation

Table 18. AOSERP Research Projects, Land System, 1977-78.

Project No.	Project Title
TF 1.1	Moose, Caribou, Wolf Ecology
TF 1.1.1	Analysis of the 1978 Moose Census Data and Associated Visibility Bias
TF 1.4	Black Bear Ecology
TF 2.1	Avifauna Baseline States
TF 2.2	Rare and Sensitive Avian Species White Pelicans
TF 2.3	Baseline States of Rare and Sensitive Avian Species
TF 3.1	Semi-Aquatic Mammals
TF 5.1	Reptiles and Amphibians
TF 6.2	Impact of Tar Sands Development on the Fur Industry
TF 6.3	Integration of Remote Sensed and Field Acquired Information
TF 8.1	Baseline States - Insect Fauna
VE 2.1	Soils Inventory of the Oil Sands Area
VE 2.3.1	Phase I Habitat Mapping of the AOSERP Study Area
VE 3.1, 3.3, 3.4	Effects of SO_2 on Vegetation
VE 4.1	Soils Research Related to Revegetation of the Oil Sands Area
VE 4.2	Rates and Extent of Soil Changes Induced by Sulphur in the Oil Sands Area
VE 5.2	Characterization and Utilization of Peat in the Oil Sands Area

continued . . .

Table 18. Concluded.

Project No.	Project Title
VE 6.1	Long Term Prediction of Vegetation for Dike Management
VE 7.1	Reclamation Afforestation
VE 7.2, 7.3, 7.4	Tests of Native Species for Oil Sands Reclamation
VE 9.1	Reinstatement of Biological Activity in Disturbed Soils and Mine Wastes
VE 7.1.1	Small Mammal Control

2.5 TOXICOLOGY OF WASTES FROM OIL SANDS MINING AND PROCESSING

2.5.1 Interactions of Wastes with Biological Groups

Probable regional and local interactions between various wastes and biological groups in the AOSERP study area are outlined in Table 19. High altitude atmospheric emissions could potentially interact (directly and indirectly) with all ecosystem components. For low altitude emissions, effects on humans are probably most important. However, nearby water bodies and vegetation could also be affected. At present, mine depressurization water interacts with local components of the aquatic biota; however, as other plants come into production, and if more watersheds are involved, progressively larger effects may occur. It is anticipated that other liquid wastes will interact only with local segments of biota. However, if significant levels of bioaccumulating and/or carcinogenic/teratogenic elements and compounds occur in effluents, regional effects could result.

2.5.2 Toxicity of Wastes

Information on the toxicity of wastes to the biological groups specified in the Terms of Reference (Appendix 5.1) was collected by literature searches. Because of the large number of biological groups and individual references to potential waste constituents, searches focused primarily on the gathering of review articles. Searches were restricted to non-radioactive inorganic elements and to organic compounds other than conventional biocides e.g., herbicides, pesticides. Biocides and radioactive substances were not considered since they are not a direct product of the oil sands industry. Publications which reviewed the effects of specific contaminants on certain groups (e.g. bacteria, algae, aquatic invertebrates, fish, and birds) were scarce. It was not feasible to assess the toxicity of single elements in detail since some reviews on single elements contained as many as 4100 references (e.g. Cambell and Mergard 1972). Therefore, in this section only general information is presented and bibliographic sources are referenced.

The chemical constituents of emissions and effluents have yet to be completely characterized. To evaluate the potential toxicological effects of the known and possible waste components, a ranking system, the Toxicological Index, has been devised to

Table 19. Probable interactions of oil sands wastes with biological groups in the AOSERP area. "R" indicates regional effect. "L" indicates local effect. Brackets indicate possible effects which are more difficult to predict.

WASTES	BIOLOGICAL GROUP											
	Bacteria	Algae	Aquatic Invertebrates	Fish	Semi-aquatic Mammals	Terrestrial Mammals	Waterfowl	Other birds	Terrestrial Vegetation	Aquatic Vegetation	Soils	Humans
EMISSIONS												
High Altitude	R	R	R	R	R	R	R	R	R	R	R	R
Low Altitude												L
WASTEWATERS AND EFFLUENTS												
Mine depressurization water	L(R)	L(R)	L(R)	L(R)	L(R)		L(R)			L(R)		
Overburden drainage water	L	L	L	L	L		L					
Extraction tailings							L(R)					
Upgrading wastes (GCOS)	L(R)	L(R)	L(R)	L(R)	L(R)		L(R)					
Tailing Pond Seepage[a]												
Plant Site Runoff[b]	L	L	L	L	L	L	L	L	L	L	L	L

[a]Effects unknown

[b]Includes runoff from coke and sulphur stockpiles

assess the potential for harm of a given component. This system can be applied to both organic and inorganic compounds. The ranking was based on four factors, rated on a scale of 0 or 1 to 4. The sum of the four ratings yielded what is termed a Toxicological Index. The four factors that contribute to the Toxicological Index are inherent toxicity, direct availability, indirect availability, and carcinogenicity/teratogenicity. A high Toxicological Index indicates a potentially significant contaminant, i.e., one with a high potential for harm or concern. A high Toxicological Index implies high or moderate rankings of inherent toxicity, direct and indirect availability, and known carcinogenicity or teratogenicity. However, a moderate (or low) ranking is not the same as moderate (or low) inherent toxicity, since the Index takes into consideration other factors as well. For example, lead has only a slight inherent toxicity ranking to mammals but because it accumulates and is a known carcinogen and teratogen, it places near the top of the moderate category in the Index for mammals.

To the extent possible, the known and potential constituents of oil sand emissions and effluents are ranked. In the ranking of inorganic components, suitable information existed for only two major biological target groups, mammals (including humans) and aquatic organisms. There was insufficient information to evaluate and rank organic compounds and photochemical oxidants. Photochemical oxidants, which are a result of interactions between inorganic and organic components, are briefly discussed in this section, i.e., 2.5.2. A general discussion of the toxicity of organic compounds is given in Section 2.5.3.

The four factors in the Toxicological Index are:

1. Inherent toxicity

   Inherent toxicity is a relative term used to compare the toxicity of one chemical or compound with another. Toxicity is defined as the ability of any chemical or substance to affect adversely the activity of living organisms (Luckey et al. 1975; Luckey and Venugopal 1977). Common criteria for toxicity are early mortality, retarded growth, impaired reproduction, neonatal mortality, neoplasms, and varied disease symptoms (Luckey et al. 1975; Luckey and Venugopal 1977). Adverse effects also include behavioural changes in individual organisms and ecological changes that affect populations. Toxic effects in an organism may occur at tissue, cellular, subcellular, and molecular levels. Toxic effects are dose-dependent. Along this gradient an element may be innocuous, essential as a nutrient, stimulatory, therapeutic, harmful, or lethal. Generally, the response varies with the species of organism, and according to the environment, diet, and condition of the animal as well as the chemical form of the element, dosage, and mode and length of exposure. Inherent toxicity was rated as:

4. high
3. moderate
2. slight
1. practically non-toxic

2. Direct availability

This factor ranks the direct availability of a substance to an organism through food, water, and/or air. Factors such as volatility, solubility, and absorption through organs such as gills, mucous membranes, skin, and the gastrointestinal tract are involved. Direct availability was rated as:

4. high
3. moderate
2. low
1. practically non-available

3. Indirect availability

This factor ranks the indirect availability of a substance to an organism through mechanisms such as the ability to concentrate in an organism or accumulate in the food chain, synergisms with other substances, mobilization processes (e.g. mercury mobilization by bacteria), transformation processes capable of altering existing environments (e.g. acid precipitation), etc.

Indirect availability was rated as:

4. high
3. moderate
2. possible
1. none reported.

The "possible" rating was applied when there was evidence of an effect but it was not direct evidence (e.g. when a metal was known to concentrate in algae in a marine system it was given a "possible" status in a freshwater system).

4. Carcinogenicity/Teratogenicity

Because of the insidious nature of these possible effects it was decided to include this as a ranking criterion. This factor ranks the ability of a substance to cause carcinogenic (malignant tumour producing) or teratogenic (embryological alterations) effects. While most work has been done in mammals, it has become increasingly evident that fish, birds, and invertebrates can be affected by substances having these effects (Harshbarger 1977; Kraybill et al. 1977). There are few specific data available for many of the groups of organisms listed in the Terms of Reference. However, since there is substantial evidence that DNA is the target of chemical carcinogens, it can be assumed that any substance that causes DNA damage in microbial, plant, or animal cells is a potential carcinogen (Hart et al. 1977). Further, in assessing carcinogenicity, there is also general agreement among various biological testing systems, i.e., microbial, plant, animal (Hart et al. 1977). Therefore, it has been assumed that carcinogenic/teratogenic effects can be applied across various phyla. Substances were rated for carcinogenicity and teratogenicity as:

4. proven effects
2. suspected effects
0. no effects reported.

The highest value for carcinogenic or teratogenic effects was taken as the final ranking.

From the proposed ranking system it is clear that a Toxicological Index of '16' involves high inherent toxicity, high direct and indirect availability, and proven carcinogenicity or teratogenicity. For the purpose of this report the indices have been grouped arbitrarily into high (13-16), moderate (8-12), and low (3-7) categories.

One other factor that should be incorporated into the ranking system is 'loading'. However, at the present time this information is incomplete. In the Air System, the published estimates of annual emission loading for GCOS and Syncrude have been previously presented in Tables 5 and 6. From a toxicological point of view, chemical analysis of emissions is far from complete (see Section 2.3.2). In the Water System, reported mean values and ranges for known effluent components have been used to make preliminary estimates of annual loadings. These are compared with background loadings in the receiving water (see Table 24).

2.5.2.1 Land System. The toxicological impact of oil sands extraction on the Land System will arise primarily from the direct and indirect effects of atmospheric emissions. Such emissions can be classified on the basis of physical-chemical composition as inorganic gases, organic gases, inorganic particulates, and organic particulates (Purves 1977). In Tables 5 and 6 in Section 2.3.2, the existing and projected emission estimates for GCOS and Syncrude, respectively, have been listed, while in Table 7 the analyses of GCOS fly ash have been presented. Inorganic gases include sulphur dioxide, hydrogen sulphide, ammonia, nitrogen oxides, and water vapour; while organic gases include carbon monoxide, light hydrocarbons, aldehydes, heavy organics, and organic acids. The organic gases (except carbon monoxide) are low altitude emissions and their effects may be localized. As previously mentioned, information on organics is limited and this group will be discussed in one section (2.5.3) for all AOSERP research systems. Carbon monoxide, although technically an organic compound, is generally discussed with other inorganic gases such as nitrogen oxides, sulphur dioxide, hydrogen sulphide, etc. Particulates (fly ash) from GCOS consist of an inorganic fraction which is composed of the oxides of various elements, and an organic fraction which is probably unburned coke. Most trace elements in emissions are associated with particulates as metal oxides (Purves 1977), but the oxides of a few elements such as mercury, selenium, and arsenic are emitted as gases. The major emission by weight, excluding water vapour, is sulphur dioxide.

1. Mammals (including humans).

1a) Inorganics. The Toxicological Indices of specific elements for mammals (including humans) are presented in Table 20. The individual rankings of the four factors in the index are given in Appendix 5.4.1. This section focuses on non-radioactive elements and their inorganic compounds. Radioactive elements are identified but their toxicology was neither reviewed nor ranked. They are considered to be highly toxic.

Although the data presented in this section is derived from studies on mammals other than humans, it should be noted that there is a basic biochemical, morphological, nutritional, and toxicological unity among all mammalian species (Luckey and Venugopal 1977).

i) Inherent Toxicity. Luckey et al. (1975) listed the factors which influenced the inherent toxicity of heavy metals and their compounds in mammalian systems:

- the electrochemical character and the state of oxidation of the metal;
- the stability, reactivity, and solubility of the metal compounds in body fluids and tissues;
- the influence of tissue pH on the hydrolysis of heavy metal salts and on the solubility, reactivity, and toxicity of the products of hydrolysis;
- the rate of absorption of the heavy metal compounds from the alimentary tract or respiratory system;

Table 20. Toxicological indices of inorganics for mammals (including humans).

Constituent	Ranking
HIGH (Index 13-16)	
Arsenic (As)	14-16
Beryllium (Be)	15
Thallium (Tl)	15
Cadmium (Cd)	13-14
Copper (Cu)	12-14
Mercury (Hg)	13
MODERATE (Index 8-12)	
Iron (Fe)	12
Silver (Ag)	11-12
Lead (Pb)	10-12
Nickel (Ni)	9-12
Lithium (Li)	11
Selenium (Se)	9-11
Cobalt (Co)	9-11
Molybdenum (Mo)	9-10
Tin (Sn)	9-10
Zinc (Zn)	8-10
Tellurium (Te)	7-10
Sulphur (S)	9
Titanium (Ti)	8-9
Chromium (Cr)	7-9
Zirconium (Zr)	7-8
Vanadium (V)	6-8
LOW[b] (Index 3-7)	
Aluminum (Al)	7
Boron (B)	6-7
Yttrium (Y)	5-7[a]
Indium (In)	6[a]
Rhodium (Rh)	5-6
Antimony (Sb)	4-6
Bismuth (Bi)	4-6
Manganese (Mn)	5
Scandium (Sc)	5
Silicon (Si)	5
Lanthanoids (atomic numbers 57-71)	4-5
Rhubidium (Rb)	4-5
Strontium (Sr)	4-5
Barium (Ba)	4-5
Rhenium (Re)	4-5
Gallium (Ga)	4[a]
Palladium (Pd)	4[a]
Calcium (Ca)	4-5
Sodium (Na)	4-5
Magnesium (Mg)	4-5
Potassium (K)	4-5
Iodine (I)	3-5
Hafnium (Hf)	3-5
Gold (Au)	3-4
Niobium (Nb)	3
Cesium (Cs)	3[a]
Tantalum (Ta)	3
Tungsten (W)	3
Germanium (Ge)	2[a]
Osmium (Os)	2[a]
Platinum (Pt)	2[a]
Iridium (Ir)	2[a]
RADIOACTIVE ELEMENTS[c]	
Technetium (Tc)	
Ruthenium (Ru)	
Polonium (Po)	
Astatine (At)	
Radon (Rn)	
Francium (Fr)	
Radium (Ra)	
Actinoids (atomic numbers 89-103)	

[a]Indicates at least one factor in the index is unknown or an estimate.

[b]The lowest index if all factors are known is 3; if one or two factors are unknown it is possible to obtain an index less than 3.

[c]Not ranked but considered to be highly toxic.

- the transport of the metal compounds in the blood, their distribution and retention in various tissues;
- the rate and route of excretion of heavy metal compounds and their susceptibility to metabolism and detoxification;
- the ability of these heavy metals to chelate with the ligands of biological macromolecules and tissue components and the stability of these metal chelates;
- the efficiency of any homeostatic mechanism which controls the absorption, excretion, distribution, and retention of the toxic metal ions or compounds;
- the capacity of other metals or tissue components to enhance or reduce the toxicity of the metal compound in question;
- the tissue concentration level of metal compounds which influences the physical form of the metal present in the tissues -- ionic, colloidal, or radiocolloidal forms and the degree of hydration associated with these physical forms;
- the ability of the metals to react with, compete with, or activate essential metals or metabolites.

The inherent toxicity ratings used in this study are based on the classification system of Bowen (1966). In this system, elements are arbitrarily classified by LD50 values (expressed as mg of element per kg body weight). The classification scheme is presented in Table 21. The assessment of metals was based on a concensus of the reported effects of various chemical forms.

Table 21. Inherent toxicity rankings for mammals (including humans).

Description	LD_{50}	Rank
Highly toxic	1 to 10 mg/kg	4
Moderately toxic	10 to 100 mg/kg	3
Slightly toxic	100 to 1000 mg/kg	2
Practically non-toxic	greater than 1000 mg/kg	1

[a]Source: Bowen 1966.

The rankings in Table 20 and Appendix 5.4.1 are based on oral and inhalational toxicity data. This information was obtained from published reviews (Casarett and Doull 1975; Luckey et al. 1975; Luckey and Venugopal 1977; Christensen 1976).

ii) Direct availability. The direct availability of elements to mammals was evaluated on the basis of availability through food and water (based on oral and gastrointestinal uptake data), and air (based on pulmonary absorption data). The data used was taken from Luckey and Venugopal (1977) and Casarett and Doull (1975). Direct availability was ranked on a scale of 1 to 4 as described in Section 2.5.2 point 2. In general, the more volatile or soluble an element or compounds is, the more it is available. However, these factors were not directly considered in compilation of rankings in this report for mammals (including humans) since actual experimental data was usually available.

iii) Indirect availability. These rankings were based on the ability of an element to concentrate in an organism or food chain. Elements reported to be highly cumulative and for which the detoxification or excretory mechanisms of organisms are poorly developed (Luckey and Venugopal 1977; Luckey et al., 1975; Casarett and Doull 1975) were ranked as high (4). Elements which can be excreted but are known to accumulate were given a moderate rating (3), while elements reported to accumulate under certain specific conditions were given a 'possible' rating (2). Elements which were reported as non-cumulative were given a low rating (1).

iv) Carcinogenicity and teratogenicity. The known carcinogenic and teratogenic effects of each element were reviewed (Luckey and Venugopal 1977) and ranked separately. Known carcinogens or teratogens were allocated a rating on a 0 to 4 scale as described in Section 2.5.2 point 4.

The elements that had a high Toxicological Index, (arbitrarily an index of 13-16) for mammals were arsenic, beryllium, thorium, cadmium, copper, and mercury. Although sulphur had a moderate Toxicological Index it is the largest atmospheric emission (excluding water vapour). There are recent reviews available on the effects of sulphur compounds on human health (Chipman 1977; Massey et al. 1977) and animals (Colucci 1977). The effects of sulphur oxides on domestic animals have also been reviewed (Lillie 1970). The inorganic sulphur compounds posing the greatest problems to health are gaseous sulphur oxides, sulphuric acid (formed in the presence of water vapour), and particulate sulphates (Chipman 1977). Temperature and humidity have been found to be important variables in epidemiological studies of the chronic effects of exposure to sulphur compounds (Chipman 1977). Toxicity data and standards in Canada and the United States have been presented (Chipman 1977; Christensen 1976; Fisheries and Environment Canada 1976). Data on the carcinogenicity of specific sulphur compounds are available (Christensen 1975).

Nitrogen oxides and carbon monoxide are not generally considered major pollutants, but along with water vapour they can enter into photochemical reactions.

1b) Photochemical Air Pollutants. Photochemical air pollution can result from the interaction of certain organic and inorganic compounds, principally hydrocarbons and the oxides of nitrogen, with the ultraviolet component of solar radiation (Dickson and Quickert 1975). Generally, the photochemical pollutants of concern are ozone, nitrogen oxides, peroxyacyl nitrates (PANs) and hydrocarbons (Dickson and Quickert 1975). Water vapour and carbon monoxide also appear to contribute significantly to photochemical reactions (Demerjian et al. 1974). Literature reviews on the formation, transport, and effects of photochemical pollutants have been published in Canada (National Research Council 1975) and the United States (U.S. Dept. Health, Education and Welfare 1970). The reviews contain information on the toxicological effects and mechanisms of action of ozone, other oxidants (including nitrogen oxides), and PANs on humans and other mammals. In addition, areas of future research on photochemical pollutants have been indicated. The effects of carbon monoxide, ozone, and nitrogen dioxide on humans and other mammals in relation to Canadian national air quality objectives have been reviewed (Fisheries and Environment Canada 1976). A review on the effects of nitrogen oxides, ozone, hydrocarbons, and other air pollutants on domestic animals has also been published (Lillie 1970). The reviews previously mentioned include over 500 references pertinent to photochemical air pollution and its effects on humans and other mammals. Additional data on the toxicity and carcinogenicity of specific photochemical pollutants are presented by Christensen (1975; 1976).

2. Vegetation, soils, and soil microflora

2a) Inorganics. Among the inorganic gases in emissions from Athabasca oil sands extraction plants, sulphur dioxide is the most obvious pollutant to vegetation, soils, and soil microflora. By weight it is the largest emission (excluding water) and problems associated with sulphur dioxide are well documented in industrial regions of the world (Overrein 1977). The effects of sulphur on vegetaton and soils in Canada has been recently reviewed (Rennie and Halstead 1977; Halstead and Rennie 1977). In addition, the impact of sulphur on vegetaton and soils has been the subject of workshops and symposia in Alberta (Sandhu and Nyborg 1977) and the United States (U.S. Dept. of Agriculture 1976).

Sulphur is essential for normal plant and animal life and is present in all vital tissues (Rennie and Halstead 1977). The mobility of sulphur in the biosphere is high since the oxides of sulphur are very soluble in water. However, when compared with other major nutrient elements, knowledge of the dynamics of sulphur and its nutritional and physiological roles in agriculture and forest growth is lacking (Rennie and Halstead 1977).

The direct effect on vegetation of high levels of sulphur dioxide is the destruction of foliar tissues, believed to be due to the inhibition of the enzyme ribulose-1,5-diphosphate carboxylase. However, normally metabolizing plants in healthy soils can and do recover from sulphur dioxide fumigations which result in visible symptoms on the foliage (letter dated 17 January 1978 from G. Loman, Loman and Associates, Calgary, Alberta). Indirect effects of sulphur dioxide involve the lowering of pH of rainwater and soil with resulting effects on ecosystem productivity (Overrein 1977; Nyborg and Walker 1977; Lore et al. 1977; Laverty and Carson 1977; Johnsson 1976; Oden 1976; Frink and Voigt 1976; Norton 1976; Hutchinson and Whitby 1976; Nyborg et al. 1976; Baker et al. 1976; Tamm and Cowling 1976; Knabe and Gunther 1976; Denison et al. 1976; Abrahamsen et al. 1976). Lower soil pH can in turn increase the mobility of certain trace metals (Purves 1977). Hutchinson and Whitby (1976) noted in the Sudbury region that low soil pH was associated with high mobility of metals. They observed accumulations of nickel and copper in soil up to 50 km from the emission source, and this accumulation, in combination with acid precipitation, rendered the soil toxic to seedling establishment and survival. They also noted that aluminum, which was not released in emissions, was mobilized in the soil and became toxic to plants (through the lowering of soil pH).

The direct and indirect effects of sulphur dioxide depend upon such factors as species tolerance, and concentration, frequency, and duration of exposure, soil moisture, and humidity (MacDonald and Klemm 1973). Intraspecies differences can also occur in response to many factors (e.g. age, the growing stage is the most sensitive period for plants). Trembling aspen (*Populus tremuloides*) and jack pine (*Pinus banksiana*) are considered to be the forest species most sensitive to sulphur dioxide (MacDonald and Klemm 1973). As a major aerial emission, sulphur dioxide and its derivatives constitute a potential threat to vegetation and soils in the AOSERP study area.

Nitrous oxides and carbon monoxide are not generally considered direct major pollutants, but along with water vapour they can enter into photochemical reactions. The effects of these reactions on vegetation will be considered briefly under photochemical air pollutants.

Potentially harmful effects on vegetation, soil, and soil microflora can be caused by the trace element components, particularly heavy metals, of atmospheric emissions. Most trace elements that occur naturally, or are present as contaminants in the atmosphere, exist as oxides associated with particulates (Purves 1977). There is a lack of comprehensive reviews on the effect of trace elements on natural vegetation since most research has been conducted on domestic crops. Furthermore, this research has been oriented towards effects via soil contamination while effects via direct intake and/or absorption have received less attention. Effects of trace element soil contamination on soil microflora have also been poorly studied.

Several reviews are available on the chemistry of trace elements in soil (Swaine and Mitchell 1960; Mitchell 1964; Lisk 1972). Purves (1977) discusses aspects of trace element contamination of soil and its relation to increased levels in plants (domestic) and to phytotoxic effects. The extent to which a contaminant will be absorbed by roots varies with the element, and plants can regulate the uptake of some trace elements so as to reduce the effects of variation in concentration in soil solutions. Trace element concentrations in plants vary with the available level in the soil, the species of plant (also varietal effects), the part of the plant, and the degree of maturity. The availability of an element depends on numerous soil characteristics such as the physical and chemical state of the element, the concentration of other cations and salts, pH, cation-exchange capacity, drainage, organic matter content, temperature, compaction, and microbial activity (Purves 1977; National Research Council 1973a). Knowledge of the factors affecting availability can be useful in coping with toxicity problems in the field since controlled alteration of soil conditions (e.g. increasing pH by liming, draining the soil) can reduce availability. It should be noted that results from pot experiments in the laboratory are often inapplicable to plants grown under field conditions (Purves 1977). Hence, it is often useful to compare the composition of plants and corresponding soils in contaminated and uncontaminated areas.

Many elements listed in the bitumen analyses (Table 1), and which could potentially be released from GCOS coke derived from bitumen, have not been analyzed for in emissions (e.g. many of the heavy metals which could be toxicologically significant). The trace elements that have been analyzed for in GCOS fly ash (Table 7) are expressed as the most likely oxidized form and the actual form has not in fact been determined. Also, certain volatile metals such as mercury, selenium and arsenic have not been analyzed for in GCOS emissions. As indicated in Section 2.3.2.1, GCOS particulate emissions can not be expected to represent Syncrude particulate emissions.

At the present time it is not possible to assess the toxicological effects of trace elements in emissions on vegetation. There is insufficient information on the composition of emissions, the loadings of the various constituents, the natural background levels in vegetation and soils, the geochemical and biological cycling of trace elements, and the interactions of various trace elements and their toxicity to natural vegetation and soil microflora. Detailed investigations such as those conducted by the National Research Council of Canada (1976) on chromium are required in order to evaluate the toxicological effects of various individual elements.

Purves (1977) notes that excesses of elements such as copper, manganese, boron, iron, molybdenum, zinc and iodine, which are essential for plant growth are less likely to result in toxic effects than excesses of non-essential elements such as mercury, cobalt, arsenic, antimony, nickel, cadmium, lead, beryllium and thallium. Plants do not rapidly accumulate some elements such as mercury, lead or copper from contaminated soil; other elements including cadmium, zinc, nickel, and boron can be rapidly taken up by plants and are of primary toxicological concern (Purves 1977). Soil contamination by most trace elements appears to be cumulative and largely irreversible and hence a point can be reached when plant growth is seriously restricted (Purves 1977). Some elements such as boron are rapidly leached from the soil, so that availability is quickly reduced.

Wind blown dusts can also result in soil contamination. There is some evidence that during mining bituminous materials drift into areas adjacent to the mining operations. The potential for heavy metals in the bitumen to contaminate soils is not known. Although this will probably remain a very local problem it could produce harmful effects in reclamation areas and in adjacent natural waters.

2b) Photochemical air pollutants. The major phytotoxic constituents of photochemical air pollution are oxidants, primarily ozone, nitrogen oxides and peroxyacyl nitrates (PANs) (Linzon et al. 1975). Reviews have been published on the chemistry of these compounds (Dickson and Quickert 1975; U.S. Dept. Health, Education, and Welfare 1970) and their effects on vegetation (Linzon et al. 1975; U.S. Dept. of Health, Education, and Welfare 1970; Fisheries and Environment Canada 1976). Air quality criteria for each group of compounds have been formulated (U.S. Dept. Health, Education, and Welfare 1970; Fisheries and Environment Canada 1976).

There is considerable interspecies and intraspecies variability in the response of vegetation to photochemical pollutants (Linzon et al. 1975; U.S. Dept. Health, Education, and Welfare 1970). Available information suggests that ozone is the most important phytotoxicant in the photochemical complex (U.S.Dept. Health, Education, and Welfare 1970; Fisheries and Environment Canada 1976). In addition, the suppression of bacteria by ozone is a well known phenomenon (U.S. Dept. Health, Education, and Welfare 1970). Although not as directly toxic as ozone, nitrogen oxides participate in the production of oxidants (e.g. ozone) and other compounds such as peroxyacetyl nitrate (PAN) (U.S. Dept. Health, Education, and Welfare 1970). Preliminary work on the C3 and C4 homologues of PAN, i.e. peroxypropionyl nitrate (PNN) and peroxybutyl nitrate (PBN) has shown that they are several times more toxic than PAN (U.S. Dept. Health, Education, and Welfare 1970). The effects on vegetation of mixtures of photochemical pollutants alone and in combination with other pollutants has been investigated; however, this research is preliminary and the subject is recognized as an important area of future photochemical research (Linzon et al. 1975; U.S. Dept. Health, Education, and Welfare 1970).

2.5.2.2 Water System.

1. Aquatic Organisms (Fish, Invertebrates, and Algae).

The present major effluents from the oil sands industry are GCOS upgrading process effluent and Syncrude mine depressurization water. Syncrude and future oil sands plants are committed to zero discharge of upgrading process waters. Thus, as oil sand development occurs, mine depressurization water should constitute the major effluent. Tailings streams are retained in ponds but seepage could occur through the bottom of the ponds. Emissions could interact indirectly with aquatic systems (e.g. through acid rainfall).

1a) Inorganic Elements. The Toxicological Indices of inorganic elements for aquatic organisms are presented in Table 22. The individual rankings of the four factors comprising the index are given in Appendix 5.4.2. Non-radioactive elements and their compounds are emphasized in this section.

Unlike the situation for mammals, no published studies are available on the effects of all the elements on aquatic organisms. Fish, invertebrates, and algae were grouped together for the computation of the Toxicological

Table 22. Toxicological indices of inorganics for aquatic organisms.

Constituent	Ranking
HIGH (Index 13-16)	
Cadmium (Cd)	15-16
Mercury (Hg)	14-15
Arsenic (As)	13-14
Copper (Cu)	13-14
Chromium (Cr)	12-14
Zinc (Zn)	12-14
Cobalt (Co)	12-13[a]
MODERATE (Index 8-12)	
Thallium (Tl)	11-13[a]
Beryllium (Be)	11-12
Aluminum (Al)	10-12
Selenium (Se)	10-11
Iron (Fe)	9-11
Silver (Ag)	10[a]
Lead (Pb)	9-10[a]
Nickel (Ni)	9-10[a]
Chlorine (Cl, gas)	9
Sulphur (S)	9
Titanium (Ti)	8-9[a]
Lithium (Li)	8-9[a]
Tin (Sn)	8[a]
Manganese (Mn)	8
Barium (Ba)	7-8
Zirconium (Zr)	7-8[a]
LOW[b] (Index 3-7)	
Molybdenum (Mo)	7[a]
Antimony (Sb)	6-7[a]
Calcium (Ca)	5-7
Potassium (K)	5-7
Sodium (Na)	5-7
Fluorine (Fl, gas)	5-7
Cesium (Cs)	5-6
Vanadium (V)	5-6
Silicon (Si)	5-6[a]
Boron (B)	5-6
Gold (Au)	5[a]
Chloride (Cl^-)	5
Magnesium (Mg)	4-6
Rubidium (Rb)	4-5[a]
Bromine (Br, gas)	4-5[a]
Ruthenium (Ru)	4-5[a]
Tungsten (W)	3-4[a]
Platinum (Pt)	3-4[a]
RADIOACTIVE ELEMENTS[b]	
Technetium (Tc)	
Polonium (Po)	
Astatine (At)	
Radon (Rn)	
Francium (Fr)	
Radinium (Ra)	
Actinoids (atomic numbers 89-103)	
UNKNOWN	
Scandium (Sc)	
Gallium (Ga)	
Germanium (Ge)	
Strontium (Sr)	
Yttrium (Y)	
Niobium (Nb)	
Rhodium (Rh)	
Palladium (Pd)	
Indium (In)	
Tellurium (Te)	
Iodine (I)	
Hafnium (Hf)	
Tantalum (Ta)	
Rhenium (Re)	
Osmium (Os)	
Iridium (Ir)	
Bismuth (Bi)	

[a]Indicates at least one factor in the index is unknown or an estimate.
[b]Not ranked but considered to be highly toxic.

Index. The U.S. Department of Health, Education, and Welfare (Christensen 1976), and the Canadian Fisheries and Marine Service (Clarke 1974) have utilized this grouping of aquatic organisms to evaluate toxicity to aquatic systems. In reviews on the effects of effluents on aquatic systems, aquatic organisms have often been treated as a single group (Christensen 1976; Clarke 1974; Smith 1974; Hunka 1974; Thompson 1974; Gregory 1974; Land 1974; McKee and Wolf 1963; National Research Council 1973b).

i) Inherent toxicity. The toxicity of inorganic elements and salts to aquatic organisms covers a broad spectrum of response from short term lethal effects to long term changes in aquatic populations. The classification scheme used to rank the inherent toxicity of individual elements is outlined in Table 23. This ranking is based on 96 hour LC50 values (expressed as milligrams of element per litre of solution). Acute toxicity data are used in the ranking since these data are more complete. It is recognized that chronic or sublethal effects may ultimately be more important ecological considerations (Christensen 1976). Where information was available for more than one of the groups of aquatic organisms, the figure for the most susceptible group was used.

In order to account for the effects of water hardness in these toxicity rankings, toxicity values from hard water were used whenever available, since they would be more applicable to the AOSERP study area. The primary sources of

Table 23. Inherent toxicity rankings for aquatic organisms.

Description	96 hour LC_{50} Concentration (mg/L)	Rank
Highly toxic	less than 1 mg/L	4
Moderately toxic	1-10 mg/L	3
Slightly toxic	10-1000 mg/L	2
Practically non-toxic	greater than 1000 mg/L	1

inherent toxicity information were Christensen (1976); Clarke (1974); McKee and Wolf (1963); and National Research Council (1973b).

ii) Direct availability. The direct availability of inorganic elements and their salts to aquatic organisms was based on their aqueous solubility. Solubility information was obtained from reviews (McKee and Wolf 1963; National Research Council 1973b; Luckey and Venugopal 1977), and ranked as High (4), Moderate (3), Slight (2) and Low (1). It is assumed in the ranking system that the greater the aqueous solubility of a metal salt the greater its availability. There is no data on the salt form of the metals in the various wastewaters, therefore it was assumed that the metals would exist in the forms reported to be most common in natural waters (e.g. as reported in McKee and Wolf 1963).

iii) Indirect availability. As mentioned previously, these rankings were based on the ability of an element to be concentrated in individual organisms or along the food chain, synergisms with other elements, mobilization processes (e.g. methylation of inorganic mercury by bacteria), and transformation processes (e.g. acid precipitation). Information on these factors was gathered from the publications of McKee and Wolf (1963) and the National Research Council (1973b). An element was ranked as: high (4) if it was highly cumulative and/or if any of the other previously mentioned processes had been identified in literature searches; moderate (3) if it was somewhat cumulative; possible (2) if there was indirect or possible evidence of accumulation (e.g. in marine organisms) or any of the above processes; or low (1) if there was no evidence of any of the above processes. Cumulative effects was the factor that was most often discussed in the literature.

iv) Carcinogenicity and Teratogenicity. The ratings for this factor were based on known or suspected carcinogenicity in any organism (terrestrial or aquatic). The rating system and references were the same as those employed for mammals. As previously noted, (see Section 2.5.2 point 4) it can be assumed that any substance that causes DNA damage in microbial, plant or animal cells is a potential carcinogen (Hart et al. 1977). Harshbarger (1977) notes that neoplasms (tumours) have been observed in five classes of cold blooded vertebrates and in two phyla of invertebrates: the molluscs and the arthropods. There is virtually no information on the ecological significance of tumours in aquatic organisms. It is assumed that since neoplasms have been identified in most tissue systems they could have an ecological effect.

The elements that had a high Toxicological Index (arbitrarily an index of 13-16) for aquatic organisms were mercury, cadmium, arsenic, copper, chromium, zinc, and cobalt. Although the Toxicological Index of sulphur (9) was in the moderate range this element is a major potential concern to aquatic systems in the

AOSERP study area because of the large quantities released. Research prior to 1973 on the effects of sulphur and sulphur compounds on water and aquatic life in Canada has been reviewed (Delisle and Schmidt 1977). In general, most naturally occurring sulphur is in the relatively harmless sulphate form (Delisle and Schmidt 1977). However, other sulphur compounds including metal sulphides, sulphurous acid, thiosulphates, thiocyanates, lignosulphonates, mercaptans and sulphonates may be produced by human activities (Delisle and Schmidt 1977). In the AOSERP study area the potential indirect effects of sulphur dioxide on aquatic biota are a major concern. The identity and quantity of other inorganic and organic sulphur compounds is poorly known. The fallout of sulphur oxides (as acid precipitation) has been shown to be responsible for damage to soft water aquatic systems in Canada (Delisle and Schmidt 1977; Beamish 1974, 1976; Beamish and Harvey 1972; Beamish et al. 1975a, 1975b, 1976; Beamish and Van Loon 1977; Van Loon and Beamish 1977) and elsewhere in the world (Overrein 1977; Almer et al. 1974; Hendrey et al. 1976; Lievestad et al. 1976; Schofield 1976). At a recent symposium, fourteen papers were devoted to acid precipitation and aquatic ecosystems (U.S. Department of Agriculture 1976). As well, a workshop on research needs and priorities in the field of acid precipitation has been held (Dochinger and Seliga 1976). An annotated bibliography with over 200 references on acid precipitation and its effects on aquatic ecosystems has also been published (Wright 1976).

2. Estimates of the loadings of wastes and waste constituents.

Loading information is essential for assessing the toxicological impact of a substance on a receiving water. Ideally, loading information would have been included as a factor in the Toxicological Index by comparing background loadings to effluent loading. However, the evaluation of loadings information was hindered by the lack of suitable information on the water quality of major effluents and of receiving waters. Loading calculations should be included as part of future effluent inventory and characterizations.

Information on the composition and annual loadings of the Athabasca River at Fort McMurray, the GCOS upgrading effluent, and Syncrude mine depressurization water were presented previously in Table 4. The concentration and loadings of specific constituents of effluents are compared with those of the Athabasca River in Table 24. In calculating the loading value in Table 24, it was assumed that water quality data collected by Lake and Rogers (in review) just upstream of Fort McMurray is representative of the Athabasca River between Fort McMurray and GCOS. Clearly, it would have been desirable to obtain water quality data just upstream of oil sand extraction activity. It is recognized that the effluent and river data in Table 24, with the exception of data collected by Syncrude on their mine depressurization water (see footnotes to Table 24), are based on very low numbers of samples.

If it is arbitrarily assumed that a high loading exists when 1) the ratio of mean or maximum effluent concentration to mean concentration in the river is greater than 10; and/or 2) the mean or maximum annual loading in the effluent is greater than 1% of the mean annual loading in

Table 24. Comparison of the concentration (by ratio) and loadings (by percentage) of selected constituents of GCOS upgrading process wastewater and Syncrude mine depressurization water with those of the Athabasca River[a]. The constituents selected are those elements of the Toxicological Index for which suitable data were available. An example of format used in the table is as follows:

$1.0^{A}:2.5^{B}$ A = mean concentration in effluent/ mean concentration in Athabasca River

$(0.06^{C};0.14^{D})$ B = maximum concentration in effluent/mean concentration in Athabasca River

C = (mean annual effluent loading/ mean annual loading in Athabasca River) x 100

D = (maximum annual effluent loading/ mean annual loading in Athabasca River) x 100

The "less than" sign i.e., < indicates that comparisons could not be made since reported values in the wastewaters or in the river were below detection limits.

	GCOS upgrading process wastewater[b]	GCOS upgrading process wastewater[c]	Syncrude mine depressurization water[d]	Syncrude mine depressurization water[e]
HIGH TOXICOLOGICAL INDEX (13-16)				
Mercury		NC[f]	NC[f]	NC[f]
Cadmium	0.5; 0.5 (0.03; 0.03)	1.0; 2.5 (0.06; 0.14)	<; 16 (<;0.54)	6.5; 2.6 (0.02; 0.09)
Arsenic		55;88 (3.3; 5.3)	<;< (<;<)	0.6; 3.1 (0.002; 0.010)
Copper	0.2; 0.3 (0.01; 0.02)	2.4; 1.7 (0.15; 1.0)	<;< (<;<)	0.8; 1.7 (0.002; 0.004)
Chromium		2.8; 7 (0.16; 0.41)	<;< (<;<)	2; 9 (0.007; 0.032)
Zinc	<.1; 0.1 (0.003; 0.006)	0.4; 0.6 (0.02; 0.03)	1.2; 140 (0.04; 0.48)	0.4; 3.8 (0.002; 0.013)
Cobalt	0.4; 0.6 (0.02; 0.03)	1.6; 3.4 (0.09; 0.18)	<;< (<;<)	10; 33 (0.04; 0.12)
MODERATE TOXICOLOGICAL INDEX (9-12)				
Beryllium	<;< (<;<)			
Aluminum			0.8; 2.5 (0.003; 0.008)	<.1; 1.1 (0.0003; 0.004)
Selenium				1.2; 3.0 (0.004; 0.010)
Iron	0.1; 0.2 (0.004; 0.004)	0.1; 0.3 (0.005; 0.020)	1.6; 18 (0.005; 0.061)	0.2; 1.0 (0.0007; 0.0033)
Silver				<;< (<;<)
Lead	<;< (<;<)	1.8; 7.5 (0.11; 0.44)	8.3; 37 (0.03; 0.12)	4.7; 24 (0.01; 0.08)
Nickel	8.5; 29 (0.48; 1.7)	2.1; 2.6 (0.13; 0.16)	<;< (<;<)	4.2; 23 (0.01; 0.07)
Titanium			<;< (<;<).	
Manganese	0.2; 0.2 (0.01; 0.01)	0.4; 1.8 (0.02; 0.10)	3.8; 28 (0.01; 0.10)	NC[f]

continued . . .

Table 24. Concluded.

	GCOS upgrading process wastewater[b]	GCOS upgrading process wastewater[c]	Syncrude mine depressurization water[d]	Syncrude mine depressurization water[e]
LOW TOXICOLOTICAL INDEX (3-7)				
Calcium		1.3; 1.9 (0.08; 0.12)	1.8; 10 (0.006; 0.036)	2.3; 10 (0.008; 0.036)
Potassium		3.9; 6.0 (0.23; 0.35)	37; 124 (0.12; 0.42)	50; 72 (0.17; 0.13)
Sodium		12; 26 (0.70; 1.6)	380; 1200 (1.4; 4.1)	600; 850 (2.2; 3.0)
Vanadium	1000; 1500 (6.0; 9.0)		<;< (<;<)	10; 120 (0.03; 0.43)
Chloride		12; 20 (0.76; 1.3)	750; 3300 (2.7; 11.7)	370; 1100 (4.5; 6.2)
Boron			29; 40 (0.10; 0.14)	13; 36 (0.05; 0.12)

[a]The effluent data was only compared to Athabasca River data provided by Lake & Rogers (in review) since their sample size (8) was greater than other published sources.

[b]Source of data used for calculations: Strosher & Peake (1976).

[c]Source of data used for calculations: Alberta Environment, unpublished water quality data 1967-1975.

[d]Source of data used for calculations: letter of December 2 1977 from J. Retallack, Environmental Affairs, Syncrude Canada Ltd., Edmonton, Alberta.

[e]Source of data used for calculations: Lake & Rogers (in review).

[f]NC: not calculated because of apparent errors in the data reported by Lake & Rogers (in review); see Table 4.

the river, then the following constituents in the GCOS upgrading effluent can be identified as having high loadings: Arsenic, Copper (high Toxicological Index); Nickel (moderate Toxicological Index); and Sodium, Chloride ion, and Vanadium (low Toxicological Index).

It is recognized that the Syncrude mine depressurization water does not immediately enter the Athabasca River; thus ratios of concentrations in the depressurization water to concentrations in the river were not used as criteria for high loading. The annual loading in the depressurization water expressed as a percent of the annual loading in the river were assumed to be comparable (albeit a worst possible case) since the Athabasca River is the eventual receiving water. No annual loadings of parameters in the depressurization water were greater than 1% of the annual loading in the river. Local effects within Syncrude's Beaver Creek Diversion System, which is the direct receiving body, would require separate investigation.

2.5.3 Toxicology of Organic Compounds

2.5.3.1 Effluents. A knowledge of the organic compounds present in industrial effluents is necessary if the toxic implications of their presence are to be fully realized and if an effective effluent treatment program is to be introduced. More than 200 organic compounds have been identified in industrial wastewaters (Webb et al. 1973). These waters are usually complex mixtures of compounds, and separation into individual components is a tedious, time-consuming procedure (Alford 1975). Efficient separation is required before identification and quantification, (also time-consuming procedures) are possible. Relatively few complete investigations of petroleum plant effluents have been carried out.

Strosher (Strosher and Hodgson 1975; Strosher and Peake 1976; Strosher and Peake 1978) provides preliminary data on organic constituents of wastewaters from oil sands extraction plants and in waters and sediments from lakes. In two studies (Strosher and Peake 1976; Strosher and Peake 1978), information on the organic content of GCOS upgrading plant effluent water and tailings pond dike filter drainage was compared with the organic content of the Athabasca River intake waters. Quantitative information (in mg/l) was supplied for total content of a) organics, b) alkanes and alkenes, c) aromatic compounds, and d) polar organic compounds. Concentrations for the latter 3 groups were all considerably less than 1 mg/l. Total amounts of sulphur-containing organic compounds in the water samples examined were about 2.5 to 4.0 mg/l, nitrogen-containing compounds were lower, and phosphorus-containing compounds were present in very low quantities. Total amounts of organic acids, phenols, esters, aldehydes, ketones, and quinones, were also determined but the values obtained are of little toxicological consequence until the components are individually identified. It is significant, however, that appreciable quantities of phenols and organic acids are present, especially in the tailing pond dike filter drainage.

Fifteen aromatic hydrocarbons have tentatively been identified in extracts of GCOS upgrading wastewater (Strosher and Peake 1976), but these identifications require confirmation. Nine sulphur-containing organic compounds were also tentatively identified (Strosher and Peake 1976). Again, additional evidence is required to substantiate these tentative identifications and distinguish between the various isomers possible.

Some simple organic acids, lactones and phenols present in wastewaters produced in in situ retorting of a Utah tar sand deposit have been identified (Barbour et al. 1977). None of the identifed compounds are of toxicological significance. Hrudey (1975) identified four compounds which were present in extracts of wastewaters from the GCOS bitumen extraction and upgrading plant. They were butylated hydroxytoluene (BHT), dibutyl phthalate (DBP), bis(2-ethylhexyl) phthalate (BEHP, also named dioctyl phthalate), and bis(2-ethylhexyl) adipate (BEHA). At present, all available evidence suggests that none of these compounds presents a toxicological danger. In addition, there may be a question whether all of the compounds were constituents of the wastewaters. BHT, a ubiquitous preservative, is used to preserve solvent ether, and was found only in the ether extract examined by Hrudey. Phthalates also are ubiquitous; they may be present in many solvents.

In summary, preliminary data has been gathered on the gross organic content (i.e. on a group basis - acids, esters, aldehydes, ketones, etc.) of GCOS upgrading effluent and dike filter drainage and some aromatic hydrocarbons have been tentatively identified. Smith (1974) has reviewed the effect of organic wastes from petro-chemical industry effluents and Verschueren (1977), presented information on over 1000 organic compounds for physical-chemical properties, water pollution factors, and biological effects. However, until more detailed characterization is available the toxicological significance of organics in effluents in the AOSERP study area cannot be evaluated. At present, the identity and quantity of individual organic constituents is unknown.

2.5.3.2 Emissions. Light hydrocarbons, aldehydes, heavy organics, and organic acids have been analyzed in GCOS emissions (Table 5) and Syncrude emissions (Table 6) but it is not possible to evaluate the toxicological significance of these wastes until the components are individually identified. Several reports (Bertsch et al. 1974; Mieure and Dietrich 1973; National Research Council 1972, Alford 1975) are available which identify over 100 volatile organic compounds which are commonly present in urban and industrial air samples. The toxicities of many volatile organic compounds have not been determined. Verschueren (1977) summarize information on over 1000 organic compounds for physical-chemical properties, air pollution factors, and biological effects.

There is no doubt that various polycyclic organic compounds (PCOC's) are carcinogenic and mutagenic, and that lung cancer may result from the inhalation of these compounds (National Research Council 1972). A list has been compiled of the 49 polycyclic aromatic hydrocarbons and polycyclic azaheterocyclic compounds which have been identified in urban atmospheres, generally as suspended particles. Some are 'strong' carcinogens, e.g. 7,12-dimethylbenz-(a)anthracene, dibenz(a,h)anthracene, benzo(c)phenanthrene, benzo(f)fluoranthene, benzo(u)fluoranthene, cholanthrene, 3-methylcholanthrene, benzo(a)pyrene, dibenzo(a,h)pyrene, dibenzo(a,j)pyrene, dibenzo(b,d,e,f)chysene, dibenz(a,j)acridine, dibenz(a,h)acridine and dibenzo(c,g)carbazole.

PCOCs are formed in any process of combustion of organic compounds, especially combustion of fossil fuels. The formation of PCOCs is the result of the production of reactive C-containing free radicals which combine rapidly at high temperatures (500-800^{o}C). PCOCs are not directly toxic. However, they are converted by solar photo-oxidation, and by the action of atmospheric ozone and other oxidants, including nitrogen oxides, to toxic oxygenated products (National Research Council 1972). They are also metabolized in man and animals to oxygenated products which covalently bind to DNA, RNA and protein, thus causing cancer.

Benzo(a)pyrene and benzo(k)fluoranthene, have both been detected in the air of Fort McMurray and surrounding areas (Strosher 1978). Ozone concentrations near Fort McMurray regularly exceed Alberta Ambient Air Quality Standards (Strosher 1978), and this may contribute to the formation of toxic polycyclic organic compounds.

2.6 GAPS IN INFORMATION PERTINENT TO THE PROPOSED TOXICOLOGY PROGRAM RESEARCH DESIGN

As a result of the information presented in preceding sections, a number of data and information gaps relevant to the toxicology program research design have been identified. These are outlined below and are discussed individually.

2.6.1 Analysis of Bitumen and Coke for Trace Elements

The composition of bitumen and coke has a direct influence on the emissions and effluents from an oil sands processing plant. To date, analyses of bitumen and coke have been limited. With the exception of vanadium, iron and nickel, the inorganic composition of bitumen is known from only one or two analyses. In addition, the concentrations of several elements with a high Toxicological Index (cadmium, beryllium, thallium, zinc) have not been determined in bitumen and this is a major information gap. A complete analysis of bitumen would contribute to the assessment of the impact of emissions on the Land and Water Systems by identifying or eliminating potential toxicants. The analysis of bitumen and coke is further recommended as a supplement to stack testing in order to characterize emissions since some trace elements will be emitted as vapours making stack measurements difficult.

It is suggested that the data gap identified in the preceding paragraph be filled by conducting a "mass balance" of toxic elements around each oil sands processing plant. This would allow toxicologists to learn the ultimate disposition of individual elements and estimate potential levels of exposure. Initially, the elements of concern are those with a high Toxicological Index (see Tables 20 and 22). It is recommended that GCOS be the first plant examined since it has been the major influence on the AOSERP study area to date. A decision to screen Syncrude and subsequent plants in a similar fashion should be made on the basis of the results of studies of GCOS. The following process streams should be considered in a mass balance.

1. Input to Plant: bitumen, make-up water, recycled tailings supernatant, and raw chemicals;
2. Output from Plant: synthetic crude oil, coke, fly ash (collected), emissions (main stack), sulphur, tailings, process wastewater, and water treatment sludges.

2.6.2 Air System

2.6.2.1 Emissions of trace elements. Trace elements in emissions could be potentially significant toxicological factors particularly to the Land System and Human System. The Toxicological Indices devised in this study have ranked the relative toxicities of various elements to mammals (including humans). The review of available literature on the effects of trace elements on vegetation and soils, has indicated that certain heavy metals may be toxicologically significant.

None of the elements identified in this report as having high toxicological indices (Tables 20 and 22), have been analyzed for in fly ash. High efficiency electrostatic precipitators will normally collect approximately 99 percent of all particulate emissions; however, in some cases this will not hold true because of the composition or resistivity of various particle sizes. In addition, coal-fired boilers will emit a portion of antimony, fluorine, and thallium and virtually all of the mercury, selenium and arsenic in the vapor state (Cowherd et al. 1975). A similar situation could be expected with coke-fired boilers.

In order to determine the significance of hazardous emissions it is concluded that a complete inorganic chemical analysis should be carried out on both the steam/power plant fuel and particulate matter emitted from the stacks of oil sands plants.

2.6.2.2 Emissions of trace carcinogenic organics. Cowherd et al. (1975) indicated that there is reason to suspect that polycyclic organic material and possibly polychlorinated biphenyls (PCB's) are formed during combustion of fossil fuels and escape to the atmosphere. Benzo(a)pyrene, one of the key carcinogens present in the atmosphere, has been specifically measured in coal-fired power plant emissions (Burton et al. 1972; Smith and Gruber 1966; Cuffe and Gerstle 1967). Other polycyclic organic materials with high carcinogenicity ratings are indicated by the National Research Council (1972) and the National Institute for Occupational Safety and Health (Christensen 1975, 1976).

No data are available on the occurrence of polycyclic organic matter in the GCOS and Syncrude emissions; therefore, a stack testing program should be undertaken to determine if these compounds exist in the stack gases and, if so, at what concentration. This program should also be applied to future oil sands plants.

2.6.2.3 Particulate sampling near oil sands plants. AOSERP operates four particulate sampling stations, two in remote areas, one at Fort McMurray, and another at the Mannix Camp near the Syncrude site. More sampling near plant sites is recommended. Filters collected from these additional sites could be placed in an archives for future analysis once emissions have been characterized more completely.

2.6.2.4 Computerized data storage system. To date the only air related information which has been computerized is the emission inventory. Data being generated by the monitoring networks and the various field projects are not being stored in a computer data base. AOSERP air system information should be computerized so that it is easily and fully available to all users, including toxicologists.

2.6.2.5 Atmospheric emissions from in situ mining operations. To date there have been no projects carried out to identify, in a preliminary manner, the atmospheric emissions from an oil sands in situ production and upgrading operation. This should be carried out since Texaco and Amoco, in a joint project with the Alberta Oil Sands Technology and Research Authority, are investing heavily in in situ pilot plant facilities.

2.6.3 Water System

2.6.3.1 Effluent inventory and characterization. To date, no study has accurately quantified existing effluents, accurately estimated the loadings or distribution of specific components, or summarized unpublished analytical data from the files of industry and government. Before toxicological research can proceed, information on the inorganic and organic constituents of effluents (and, when applicable, emissions) that affect aquatic systems must be gathered (including the source and quantity, and the rate and pattern of discharge). The information should also consider groundwater discharges that could arise from future oil sands operations.

2.6.3.2 Analytical characterization of organics in wastewaters. Basic analytical methodologies for the examination of inorganic compounds have been developed and reported in the literature. However, techniques for the extraction, separation, identification, and quantification of unknown organic compounds in complex mixtures have not been extensively developed. The investigation of wastewater, water, and sediment samples is presently hindered by the lack of efficient, selective, and cost-effective analytical techniques.

The efficiency and selectivity of various extraction procedures must be determined. A suitable separation technique(s) for organic constituents of aqueous samples must be established. The separation scheme(s) should allow for the toxicity testing of separated samples and also the identification and subsequent quantification of compounds in separated fractions. Thus, the separation scheme and tests used to identify sample constituents must be specific for individual chemical groups.

A comprehensive characterization of organic compounds may not be necessary until an organic fraction is indicated as a source of toxicity. A systematic separation of the organic compounds in various samples into major chemical groups (such as acids, phenols, bases and neutrals), followed by gas chromatography (GC) analysis of each group would be valuable from the "monitor-for-change" point of view. New components in each of the major chemical groups would be indicated by comparisons of current GC traces with those recorded under identical conditions on previous occasions. This information could be related to biological effects observed during biomonitoring. In addition to water samples, a similar approach could be performed on samples from soil, sediment, wildlife, vegetation and air.

2.6.3.3 Computerized data storage system. AOSERP Water System information should be computerized in such a way that it is easily and fully available in response to various requests. In this way, data generated by monitoring networks and various field studies would be readily available for the planning, interpretation and evaluation of toxicology projects. Display formats should be developed to meet specific needs.

2.6.3.4. <u>Assessment of toxicity</u>. The lack of a summary of data collected by industry under government regulations and through existing monitoring programs, has made the identification and study of known or potential inorganic contaminants difficult. Efficient, selective, and cost-effective analytical techniques for organic compounds have not been fully applied in the AOSERP study area. These are necessary for the systematic separation, identification, and toxicological evaluation of complex effluents including the interactions between organic and inorganic substances. Specifically, the following data gaps relevant to the assessment of whole effluents and their constituents have been identified.

1. The acute (short term) screening of whole effluents using reference species is almost complete; however, information on the cause(s) of death and/or pathology of various effluents is needed. This information is necessary for proper planning of long term toxicological studies.
2. Further information is required on the long term effects of saline groundwater on aquatic organisms. This would enable whole effluent discharge guidelines, regulations, or standards to be established which would be appropriate to local conditions and biota. The influence of increased osmolarity on indigenous aquatic species has received study but its implications are poorly understood (McMahon et al. 1977).
3. No systematic evaluation of the toxicity of the organic fractions of effluents has been conducted.
4. The influence of organic constituents of effluents and receiving waters on the availability and hence, toxicity of metals has received relatively little investigation. As previously indicated, the organic constituents of wastes and receiving waters are poorly known.
5. Literature applicable to the AOSERP study area on the chemistry and toxicity of specific toxicant hazards, with

the exception of salinity, has not been extensively surveyed or reviewed. The trace element hazards of initial interest are those with high and moderate Toxicological Indices.

6. The dispersion of liquid discharges (zone of mixing) and their influence on natural watercourses has received relatively little attention.
7. To date, no projects have been carried out to identify and characterize, in a preliminary manner, the wastewaters, disposal methods, and effluents of in situ oil sands operations.
8. To date, no projects have examined concerns which may arise from wastes remaining on lease areas e.g. seepage from tailings ponds.

2.6.3.5 Monitoring. With the exception of inorganic water quality, suspended sediment and streamflow data, monitoring of the aquatic system (including regional biomonitoring) is underdeveloped. Complementary biotic and abiotic monitoring of major effluents are required to assess biotic changes in light of abiotic parameters. Abiotic monitoring data are needed on specific inorganic and organic contaminants (or classes of organic contaminants) in relation to point-sources.

2.6.4 Land System

Several information gaps relevant to toxicology in the Land system have been identified previously in Sections 2.6.2 and 2.6.3. The identified gaps in the Land System include:

1. The lack of suitable information on the identity, concentration, and loading of specific trace element constituents of emissions;
2. The lack of information on the organic constituents of emissions, in particular carcinogenic groups;
3. The lack of computerized storage and retrieval systems for data from monitoring and field projects; and
4. The lack of information on the effects of in situ oil sands extraction and upgrading operations on biological organisms.

2.6.4.1 Vegetation and soils. To date, toxicological studies in the Land System have focused primarily on the effects of sulphur dioxide, the major atmospheric contaminant by quantity, on vegetation and soils. As a result, research on the effects of other emission components has been restricted. It is necessary to redirect vegetation and soils research and biomonitoring to include the direct and indirect effects of other emission components, in particular, fly ash. To fill information gaps in the area of vegetation and soils the following recommendations for research should be considered:

1. Determination of the effects of fly ash on vegetation in native soil types;
2. Determination of the effects of fly ash on vegetation in native soil types exposed to sulphur dioxide;
3. Examination of the indirect effects of sulphur dioxide and other emissions on the chemistry and dynamics (e.g., mobilization) of potentially toxic trace elements in the soil;
4. Toxicological research and biomonitoring information (when and where possible) on a wider variety of forest communities and native soil types;
5. Determination of the physical and chemical properties and microflora of different soil types;
6. Determination of plant-available sulphur in native soil types;
7. Examination of the effects on forest vegetation of atmospheric pollutants at levels that occur within Alberta Ambient Air Quality Standards;
8. The use of fluctuating environmental parameters (light quality, temperature, darkness, etc.) in controlled fumigation experiments and an attempt to simulate AOSERP study area growing conditions (which vary throughout the area);
9. Determination, on intact seedlings, of whether previsual symptoms of sulphur dioxide toxicity are nonreversible and damaging to the metabolism of the plant; and
10. Design and establishment of networks to monitor abiotic parameters other than sulphur dioxide and their effects on specific forest communities and soil types.

2.6.4.2 Wildlife. As yet, no attempt has been made to determine the toxicological effects of oil sands development on wildlife in lease and surrounding areas. It is essential that information on the loadings and dynamics of potential toxicants be made available so that objectives may be established for the design of appropriate toxicological studies for wildlife. Until this information becomes available the development of biomonitoring networks should be given first priority. These should include the placement of biological specimens in an archives. These specimens could be examined at a later date once emissions and effluents have been characterized more completely.

2.7 USER SURVEY

2.7.1 Introduction

To aid the development of the research design for the AOSERP toxicology program, a survey of potential users of toxicological information was requested in the Terms of Reference. This survey was subsequently expanded to include researchers in AOSERP projects considered relevant to toxicology. A list of specific persons to be included in the survey was provided by AOSERP program management personnel (Meeting of 5 October 1977 with M. Falk, AOSERP, Edmonton, Alberta). A list of the persons contacted is presented in Appendix 5.5. These individuals, from within and outside Alberta, represented AOSERP managers and researchers, universities, consultants, the oil sands industry, and agencies of the federal and provincial governments. Each individual (or group) was asked to identify the major concerns and immediate research needs relative to existing and/or anticipated water, air, land, and human toxicological problems in the AOSERP study area.

The opinions expressed during the survey were used as part of the basis for developing the proposed research design and priorities for the research design. Each interview during the survey was conducted using an open question format. This section of the report presents the opinions of the persons surveyed.

2.7.2 Potential Users of AOSERP Toxicology Information

The potential users of AOSERP generated toxicological information can be divided into several groups. These are presented in Table 25.

It is probable that the extent to which government agencies use the toxicological information is determined by their regulatory and management responsibilities. Industry uses the information to set specific design objectives for particular projects. In Alberta, the major responsibilities for environmental protection and management lie with the Alberta government, specifically Alberta Environment and Alberta Parks, Recreation and Wildlife.

Table 25. Potential users of AOSERP toxicology information.

Federal Regulatory Agencies
Environmental Protection Service[a]
Federal Management Agencies
Environmental Management Services
Canadian Wildlife Service[a]
Canadian Forestry Service[a]
Fisheries and Marine Service[a]
Inland Waters Directorate[a]
Provincial Regulatory Agencies
Alberta Environment[a]
Provincial Management Agencies
Alberta Parks, Recreation and Wildlife[a]
Other Government Agencies
Alberta Labour
Alberta Social Services and Community Health
National Health and Welfare
Corporations Involved in Oil Sands Recovery
Great Canadian Oil Sands Ltd.[a]
Syncrude Canada Ltd.[a]
Shell Canada Ltd.[a]
Petrofina Canada Ltd.[a]
University Personnel[a]
AOSERP Personnel[a]
Public

[a]Contacted during survey of toxicological concerns and research needs in the AOSERP study area. For a list of individuals contacted see Appendix 5.5.

2.7.3 Toxicological Concerns

Only three main toxicological concerns were defined by the persons interviewed during the user survey. These were:

1. the direct and indirect effects of sulphur dioxide on terrestrial and aquatic systems;
2. the effects of saline groundwater (from mine depressurization) on aquatic systems; and
3. the development of efficient systems for the storage, retrieval and display of data pertinent to toxicology.

The effects of sulphur-containing compounds and saline groundwater were both regulatory and management concerns due to their known toxicity and their relatively high loadings in the AOSERP study area. The development of data management systems was considered important for the planning and interpretation of studies proposed as part of any toxicology program by all groups.

As well as the few clearly defined toxicological concerns, a number of broader problem areas were identified by users. These problem areas were identified because respondents felt that either existing knowledge or information was insufficient to adequately assess present conditions. Thus, toxicological concerns are implied. The problem areas regarded by the respondents as pertinent to toxicological studies in the AOSERP study area are as follows:

1. Physical and chemical characterization of effluents and emissions. This was perceived as a major toxicological problem area since all respondents felt that the identification and, in particular, the quantification of the constituents of effluents, wastewaters and emissions was incomplete and therefore a major area for further study. As a result of this gap, the potential effects of these contaminants as well as their cycling and deposition in terrestrial and aquatic systems were also of concern.
2. Assessment of toxicity. The assessment of the toxicity of specific effluents and emissions and their constituents was a major toxicological concern. Concerns regarding such toxicity were general due

to the perceived deficiencies in the analytical characterization (including loadings) of effluents and emissions.

2.7.3.1 <u>Research needs suggested by respondents</u>.

1. General. Government regulatory agencies focused on topics which would provide information for environmental quality criteria and industrial performance standards. Their primary concerns were contaminants discharged directly into the environment. Accordingly, the effects and toxicology of whole effluents and emissions on local biota were identified as major research needs. Industry which must maintain air and water quality within existing government regulations were concerned with the appropriateness of these regulations. Thus, they also identified whole waste toxicology as a high priority for study.

   Government management agencies were also concerned with discharges into the environment but stressed the importance of the acquisition of baseline data as a key to understanding the effects of oil sands development. These agencies tended to show more concern for component toxicology testing and evaluation than whole sample toxicology since it would identify the specific contaminant responsible for toxic effects and its mode of action. This would in turn enable management strategies to be developed. It was suggested by university personnel that since testing of constituents and components (groups of constituents e.g. phenols) was costly and time-consuming, factors such as carcinogenicity/mutagenicity/teratogenicity, persistance and biodegradability should be used in the selection of constituents (with similar toxicity) for further testing.
2. Physical and chemical characterization of effluents, emissions, and receiving environments.

   It was generally agreed that the characterization of the effluents and emissions, and determination of loadings (temporal) and distribution (geographic) of specific contaminants, should be given first priority in any toxicology program. In addition, government management agencies, universities, and individuals involved in existing AOSERP research projects consistently identified the development of suitable sampling and analytical techniques (in particular those for organic compounds) as a major research need.

a) Water System. It was agreed that characterization of the quality of receiving waters and effluents was further advanced than that of aerial emissions. On the other hand, gaps in the Air System research program may have been more easily identified because an inventory of information on sources and emissions has been completed (Shelfentook 1978). It was the consensus of the persons surveyed that the knowledge of the inorganic constituents of effluents and wastewater was greater than the knowledge of organic constituents. The identification, and quantification of organic components of wastewaters and receiving environments was identified as a major research need and given a higher priority than analytical studies of heavy metals.

b) Air System. All groups indicated that more information was required on the identity and quantity of main stack emissions and thus more intensive stack sampling was required. It was recognized that information gathering on sulphur dioxide emission was well in hand but information on other potential contaminants was lacking. Industry identified the study of the origin, distribution, and effects of vaporous and particulate heavy metal emissions as a concern and major research need. Government agencies ranked investigations of heavy metal and organic emissions approximately equal in importance. Studies of the indirect effects of gaseous emissions on particulate deposition and the increased mobilization of potentially toxic trace elements in the soil was recognized as a potential problem area.

All groups indicated that information was needed on the probable emissions and effluents of in situ oil sands plants but felt the priority for research should still be on the effects of wastes from existing technology.

3. Assessment of toxicity. All groups were ultimately concerned with determination of threshold toxicity levels of specific contaminants in order to avoid damage to critical biological systems or species. Long term, sublethal threshold levels were important to all groups in the survey but were most important to management agencies; determination of short term lethal threshold levels appeared to be ranked higher by industry and regulatory agencies than other groups. Short term lethal thresholds were considered necessary in order to develop preliminary environmental quality criteria.
   a) Water System. The knowledge of the short term toxicity of major whole effluents was considered adequate at this time. Hence, studies of the toxicity of liquid discharges to aquatic organisms were generally given a lower priority than studies of the effects of atmospheric emissions.

      The toxicology and disposal of groundwater from mine depressurization was a major management and regulatory concern to both government and industry. The effects of GCOS process wastewater, the other major effluent in the AOSERP area, was only a minor toxicological concern.
   b) Land System. In the Land System,

respondents stated that further characterization of emissions would be required before toxicological studies could be initiated. Land System researchers and government management personnel indicated that the design, establishment, and operation of suitable and analytically efficient biomonitoring networks should be given a high priority. The chemical parameters of interest to biomonitoring programs would be identified initially from a preliminary toxicological assessment of emission constituents.

3. PROPOSED TOXICOLOGY PROGRAM RESEARCH DESIGN

This section contains the basic research design, the priorities for research, brief comments on the implementation of the proposed design, and suggestions for individual research projects. The projects recommended for the proposed research design have been priorized.

3.1 BASIC DESIGN

The stated objectives of the Air, Water and Land research systems have a clear toxicological component (AOSERP 1977a; 1977b). An effective toxicology program requires abiotic and biotic information. Specific information is needed on the chemical and physical form and loadings of the contaminant(s) released to the environment; the transformation of the contaminant(s) by abiotic and biotic processes during transport from the point of release to receptor organisms; the effects of the contaminant(s) on individuals, populations and communities of organisms; and the consequences for the local and/or regional ecosystem.

As specified in the Statement of Work of the contract (see Appendix 5.1), the proposed toxicological program research design is intended to meet the objectives of AOSERP, taking into consideration the needs of government and industry, and the nature and probable magnitude of oil sands development. The basic design entails a scientific approach based on the identification, analysis, loading and impact of wastes (alone or in combination) as well as biomonitoring of receptor organisms. The design will provide information that can be used to minimize adverse effects of oil sands development wastes. It also allows for a continuous evaluation (through biomonitoring) of the receiving environment in order to evaluate the effectiveness of environmental protection measures.

The basic toxicological research design consists of five areas of activity.

1. Acquisition of abiotic and biotic baseline data.
2. Inventory of effluents and emissions and the identification of biological target systems.
3. Chemical and physical characterization of effluents and emissions.
4. Assessment of toxicity:
   a) In the laboratory; and
   b) In the field through biomonitoring.
5. Provision of information for environmental management.

3.1.1 Acquisition of Abiotic and Biotic Baseline Data

For the first three years of AOSERP, the acquisition of baseline data is a stated objective of each of the AOSERP research systems. Baseline data is of importance because:

1. It provides a basis for identifying concerns arising from emissions and effluents;
2. It provides a measure of the natural variability in the environment and a basis for measuring changes induced by oil sands development;
3. It provides information on background levels of contaminants occurring in the area and enables an assessment of loadings of the various constituents of effluents and emissions; and
4. It provides information on which groups of organisms might be affected by waste discharges in a specific locality.

3.1.2 Inventory of Effluents and Emissions and Identification of Biological Target Systems

An inventory of effluents and emissions is required to identify all sources of contaminants. From a list of actual effluents, emissions and other wastes and their disposition, it is possible to identify potential biological target systems, that is, biological systems that could be affected by a given waste.

3.1.3 Chemical and Physical Characterization of Effluents and Emissions

The chemical and physical characteristics of a waste must be known in order to assess its toxicological significance and potential effects on biological systems. To further understand the impact of a waste it is necessary to know the magnitude and temporal pattern of discharge and/or storage, as well as the spatial distribution of the waste within the receiving environment.

3.1.4 Assessment of Toxicity

This area of activity should be initiated when the activities of sections 3.1.1, 3.1.2, and 3.1.3 are in progress or have been completed. Without the data from these sections the planning of toxicological studies and an accurate assessment of the impact of a waste or waste constituent would be very difficult.

It is proposed that the toxicity of each waste be assessed in the laboratory and by biomonitoring studies in the field. The intent of these studies should be to determine if damage is likely to be negligible, slight, moderate or severe and to ascertain whether any effects observed are likely to be cumulative or reversed by natural processes.

The toxicological assessment of waste implies the evaluation of whole effluents and emissions and, when necessary, their constituents. These latter investigations are often referred to as "component toxicology".

3.1.4.1 Assessment of toxicity of whole wastes and constituents in the laboratory. This may be divided into four sections: preliminary evaluation; short term (acute) toxicity studies, long term (chronic) toxicity studies; and other tests or studies.

1. Preliminary evaluation.
   From the data obtained in sections 3.1.1, 3.1.2, and 3.1.3, it should be possible to determine the biological systems likely to be affected by a waste and the potential loadings of the constituents of a particular waste likely to be found in a given receiving area. Use of an index, such as the Toxicological Index presented in Section 2.5, would then enable the harmful potential of a particular waste to be assessed in a preliminary manner. It is recommended that particular attention should be paid to the 'loading factor', that is, the comparison between the background level of a particular constituent and the additional loading imposed by the discharge or storage of a waste.

   This preliminary evaluation of toxicity should identify information gaps, constituents of potential importance, the transfer pathways of the constituents and possible synergistic or antagonistic interactions between constituents and prepare the way for further laboratory studies. In addition, it may identify biological species to be used as 'indicators' in biomonitoring programs.

2. Short term (acute) toxicity studies. Short term tests on whole wastes constitute the first phase of toxicological assessments and form the basis for further work (e.g. component toxicity), if it is required. These studies determine whether a waste is toxic to a selected species and can be used to determine actual values of toxicity (e.g. LC50, LD50) for purposes of comparison between wastes or test species. They should include the examination of spatial-temporal variations in toxicity. Short term tests can provide information to design long term studies and may identify specific target species to be used as 'indicators' in biomonitoring. In addition, they can be used to set environmental quality criteria and industrial standards if appropriate application factors are used.
3. Long term (chronic) toxicity studies. Laboratory tests of this type are generally used to determine a dose or concentration of a waste, or waste constituent, that has 'no observable effect' (e.g. MATC - see glossary). The results of long term studies can provide a good data base for environmental quality criteria and industrial standards. They have also been used to ascertain if potential carcinogenic, mutagenic or teratogenic hazards exist. Such tests are time consuming and costly and it is recommended that they should be applied only when important informational gaps are identified.
4. Other tests or studies. Toxicological studies, particularly long term studies, are often slow to produce useful data, thus if a rapid 'screening' test exists for a particular property it should be used. An example of this is the Ames' test which can be used to determine the mutagenic, or carcinogenic, potential of a waste or its individual constituents.

Published scientific literature is a valuable tool for use in identifying potential hazards.

It is recommended that regular searches be conducted to identify potential new hazards and to confirm the validity of earlier assumptions. This data should be used to update the Toxicological Indices.

3.1.4.2 Assessment of toxicity in the field through biomonitoring. It is the stated objective in both Land system and Water system research to develop methods for biomonitoring and protecting biological systems in undeveloped portions of the AOSERP study area (AOSERP 1977b). Biomonitoring is defined as the observation of characteristics of a biological group (or groups) for the purpose of detecting temporal or spatial changes. It includes observations of natural populations, bioaccumulation studies, in situ bioassays (e.g. caging studies) and artificial substrate colonization studies. Ideally, these studies involve successive observations over time. As a complement to biological observations, biomonitoring may also include the repeated observations of abiotic parameters with the view to establishing temporal or spatial correlations with biological effects. It is anticipated that when biomonitoring systems are operational, they will be transferred to line agencies (AOSERP 1977a; 1977b).

Biomonitoring support is an essential component of the proposed toxicology program research design. It can identify wastes with ecological impacts as well as verify the effectiveness of management programs and environmental quality criteria (including regulatory standards). Biomonitoring can be a valuable technique in "investigative field research" and can be used to sort out which discharges have important biological effects on living systems, (letter dated 12 April 1978 from J. Sprague, Professor, Department of Zoology, University of Guelph, Guelph, Ontario). "This information should have a primary role in deciding which components of the waste, if any, require laboratory studies of toxicity or development of chemical and analytical techniques" (Ibid). From a toxicological viewpoint, only biomonitoring can provide proof of the effectiveness of environmental protection measures. In spite of its obvious advantages, biomonitoring has several disadvantages. Firstly, it measures an effect that will have already taken place. Secondly, the data may appear slowly and could represent only the tip of the iceberg as far as a particular contaminant is concerned. For example, by the time a contaminant has exerted an effect it may be present irreversibly. Thus, it may be difficult to select parameters to monitor that will provide comprehensive information at acceptable costs. Whenever possible biomonitoring networks should have standardized sampling designs, methods, and analytical toxicological procedures.

Two biomonitoring networks should be considered. These are:

1. Impact Biomonitoring Networks.
   Impact biomonitoring is the collection of biotic data and, if required, abiotic data in the vicinity of point sources of contaminants. Since these areas are likely to be exposed to the highest concentrations of wastes, any effects of these wastes on biological systems should appear in these areas first. As previously mentioned, this involves methodologies such as ecological surveys, bioaccumulation testing, in situ bioassays (caging studies), and artificial substrate colonization studies. It is probable that certain species can be used to monitor effects of specific wastes, e.g. lichens and sulphur dioxide emissions. Because of the potential costs, every effort should be made to identify potential "indicator" species.

   Impact biomonitoring will provide information on the local effects of wastes in situ and will be the first environmental check on the potential harmful effects of a particular waste. If a problem is identified, it is recommended that studies be carried out to determine the toxic agent(s) involved and its chemical form. The transformation of the agent(s) by abiotic and biotic processes during its transfer from the point of discharge to the receptor species should also be investigated. In conjunction with these studies, the overall residence time, or persistance of the toxic agent should be determined. It would also be advantageous (for planning, and data interpretation) if the results of industrial impact biomonitoring programs were available to AOSERP. A cooperative approach to the exchange of data is recommended.

2. Baseline Monitoring Networks.
   Data collected by baseline environmental studies should describe the status of the regional environment. It is recommended that the program of 'baseline' biomonitoring be extended temporarily to provide:
   a) A measure of changes which occur naturally in biological populations; and
   b) An additional system for the detection of long term changes brought about by oil sands development. This may, or may not, include the detection of overt toxic effects. Such a monitoring program provides the ultimate assessment of toxicity and the final check of the value of environmental controls and the effectiveness of the assessment procedures outlined in preceding sections.

By combining the data obtained both in the laboratory and in situ through impact biomonitoring and baseline biomonitoring and including the data generated in sections 3.1.1, 3.1.2, 3.1.3, and 3.1.4 a rational assessment of the toxicity or harmful potential of a specific waste can be made in the short term, in the medium term, and in the long term.

3.1.5 Provision of Information for Environmental Management

Information of relevance to environmental management will be generated as a result of the research studies described in the preceding four areas of activity (Sections 3.1.1 to 3.1.4). Figure 2 conceptualizes the proposed toxicology program research design. This diagram illustrates the integration of all five areas of activity in the basic research design, specifically: 1) acquisition of baseline data; 2) inventory of effluents and emissions and the identification of biological target systems; 3) chemical and physical characterization of effluents and emissions; 4) assessment of toxicity; and 5) provision of information for environmental management. On the basis of information generated in the first four activities, the ecological significance of wastes discharged in the AOSERP study area can be evaluated. With this evaluation, environmental quality criteria could be established.

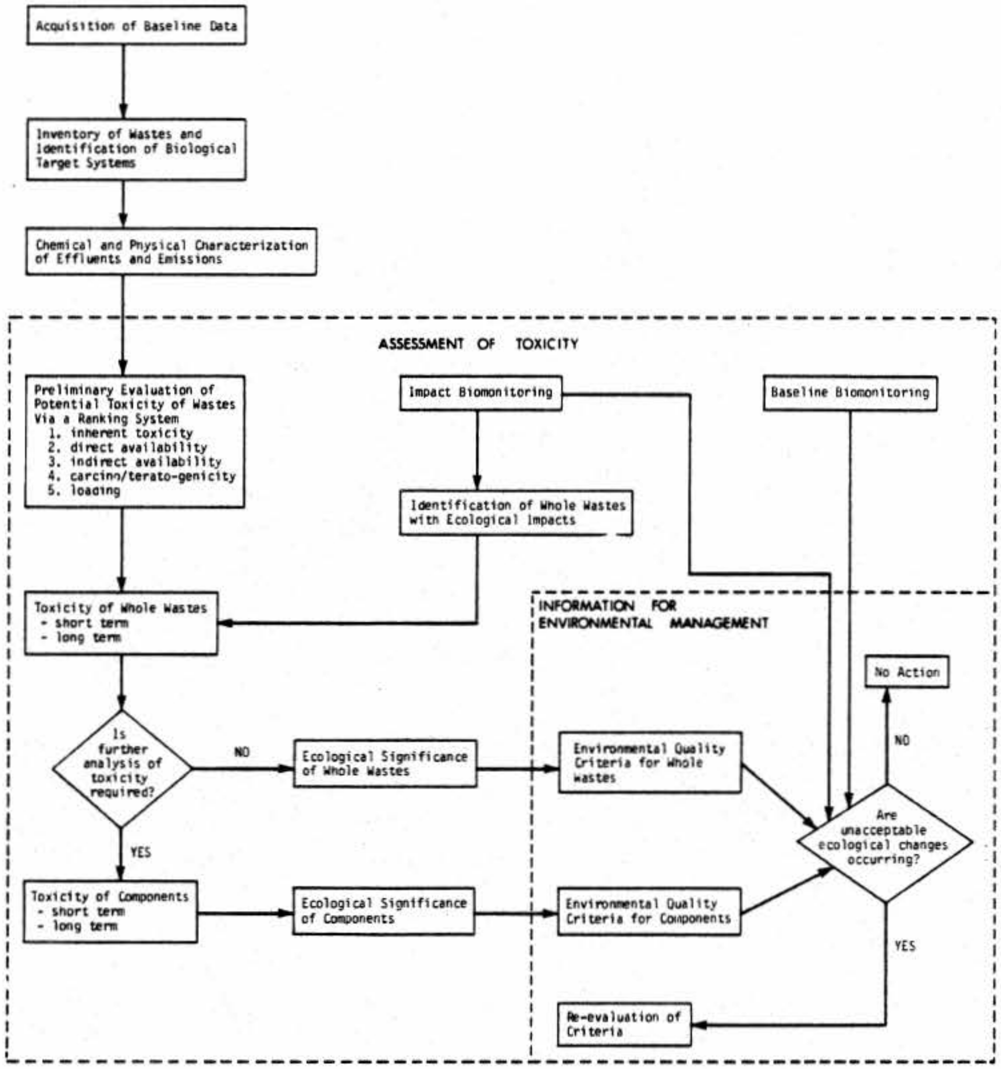

Figure 2. Proposed design for a program of toxicological research.

On the basis of information generated through the research design, industry and government should be able to develop management guidelines and strategies, including industry performance standards in order to meet the established criteria. In addition, the proposed research design will enable specific management decisions and predictions concerning the directions and rates of environmental changes to be evaluated and, where necessary, reformulated. Clearly, to realize the maximum benefits from the proposed research design and to avoid duplication of efforts, cooperative approach between industry, government and AOSERP is needed.

3.2 RESEARCH REQUIREMENTS IN THE AIR, WATER AND LAND SYSTEMS OF AOSERP FOR THE PROPOSED TOXICOLOGICAL PROGRAM RESEARCH DESIGN

3.2.1 Acquisition of Abiotic and Biotic Baseline Data

3.2.1.1 Abiotic baseline data. It will be useful to know the baseline states of air and water quality for the planning and interpretation of toxicology and related studies in all research systems. A high priority should be given to the development of rapid data storage and retrieval systems with appropriate display formats. This is recommended in order that ongoing air and water quality data collection can be rapidly integrated into the toxicological and related projects when it is required. The accuracy and precision of all analytical procedures should be determined and be available with the data.

3.2.1.2 Biotic baseline data. In the AOSERP study area, the description of biological communities at existing levels and configurations of air and water quality should be completed. To facilitate the planning, implementation, and interpretation of baseline and impact biomonitoring programs, information should be available on the composition, abundance (density), diversity, trophic interrelationships, and seasonal dynamics of major faunal components or indicator species. In addition, the results of parallel studies of biological change in areas directly affected by oil sand development activity and those remote from activity should be available.

3.2.2 Inventory of Effluents and Emissions and Identification of Biological Target Systems

An inventory of the atmospheric emissions associated with conventional oil sand technology (surface-mining) has been completed (Shelfentook 1978); however, a similar inventory (including existing analytical data) of liquid effluents is required to evaluate the potential toxicity of whole effluents and their constituents. An investigation of the potential atmospheric and liquid wastes associated with in situ extraction processes is recommended. Consideration should be given to concerns that may arise from wastes remaining on the lease area, for example, the potential of seepage from tailings ponds.

3.2.3 Chemical and Physical Characterization of Effluents and Emissions

The preliminary characterizations of specific emissions and effluents (including wastes such as extraction tailings and tailings sludge which represent potential effluents) have been presented in Section 2 of this report. In addition, the limitations of present knowledge concerning the inorganic and organic composition of specific liquid and aerial waste streams has been outlined. Considering these limitations, a more detailed characterization of existing and potential emissions and effluents is recommended. As indicated in Section 3.2.1.1, the accuracy and precision of analytical procedures should be determined and standardized methodologies established. Among complementary projects, an effort should be made to standardize analytical procedures as much as possible.

During the characterization of each effluent or emission a high priority should be given to the identification of known or potentially toxic inorganic and organic substances. Literature searches and ranking systems, such as the one described in Section 2.5, should be used to identify substances of potential concern.

3.2.3.1 Air, Water and Land systems. The analytical characterization of bitumen emissions, effluents/wastewaters and receiving environments should be completed to identify potential biological hazards, their loadings, and probable distribution. This involves:

1. Completion of the inventory and characterization of known and potential sources

(liquid and atmospheric) of contaminants;
2. Identification of the sources, methods and rates of entry of specific whole wastes or their constituents (e.g. known and possible hazards) to the AOSERP study area and their temporal variation;
3. Determination of the rates and patterns of dispersal and transport of significant (e.g. on the basis of size or toxicity) whole effluents and emissions, and of specific known and possible toxicological hazards as they are identified.
4. Identification of toxic forms of known and potential hazards and determination of the effects of ambient environmental conditions (e.g. variations in climate) and pollution control measures on the availability of toxic forms i.e. on the chemistry and dynamics of a specific constituent; and
5. Ultimately, the construction of mass balances of toxic substances entering and leaving oil sands plants (source, fluxes, transformations and sinks).

In the Air System the major emissions in each plant should be studied since each oil sands operation will have different emission characteristics. Studies of GCOS should be initiated before the new particulate control devices (electrostatic precipitators) are installed in order to establish accurately the environmental effects of GCOS. GCOS has been operating for years and baseline information collected under AOSERP prior to the Syncrude startup will be influenced to an unknown extent by the GCOS emission regime. A more detailed characterization of the emissions from GCOS (trace elements, organics) is necessary for the evaluation of this baseline information.

Since each oil sands operation will also likely have different effluent characteristics, the major effluents and wastewaters in each plant should be examined for known and potential hazards. A compilation of all existing analytical information on sources of potential aquatic contamination and effluents should be initiated during 1978/79. This study should include investigation of the composition and quantity of groundwater present on individual lease areas and its influence on the type of the mine dewatering discharge. The effects of climatic conditions (i.e. between seasons and years) on the dispersion of waste discharges should be considered in all studies of effluents, emissions and their constituents.

To aid in toxicological evaluations, the inorganic monitoring of major effluents (GCOS upgrading wastes and Syncrude saline groundwater), and particulate emissions (particularly in the vicinity of GCOS and Syncrude) should be expanded to include those waste constituents with high Toxicological Indices (Tables 20 and 22) if they are being released in significant quantities.

The toxicological evaluation and chemical examination of complex effluents and emissions requires the development of analytical methods for organic compounds. At this time, it does not seem practical to embark on a lengthy and costly program of comprehensive organic analysis of what are complex and probably highly variable materials. A program of complete organic analysis might have little relevance since it is possible that many of the organic compounds which might be isolated will have little or no toxicological significance. However, it would be reasonable to identify the major chemical groups of organic compounds (e.g. acids, bases, neutrals, phenols, etc.) in an effluent or emission and then test these groups for carcinogenicity, mutagenicity or teratogenicity (e.g. Ames' test). For example, there may be a link between carcinogenicity and compounds in the neutral fraction. As outlined in Section 2.6.3.2, a systematic separation of the organic components of wastes into the four groups (acids, phenols, bases, and neutrals) followed by gas chromatographic (GC) analyses of each group could also be valuable in monitoring-for-change. In the short term, it is necessary to develop techniques for monitoring of various samples (air, water, sediment/soil, biota). Initially, it should be verified that the separation scheme used is capable of extracting all the organic materials present in a sample. Further, if it is necessary to identify individual organic compounds, the method(s) selected should not only permit the efficient and cost effective separation of components but also, in the longer term, the accurate identification and quantification of specific compounds in any toxic fraction.

Initially, the development and testing of analytical techniques would be facilitated by the use of combined gas chromatography/mass spectrometry (GC/MS) and computerized data system. This system has been used successfully in identifying and quantifying organic components in the environment (Alford 1975). However, alternative methods should be reviewed through the literature to determine their possible merits. A small organic analytical program should be established to evaluate analytical techniques and investigate whole wastes which have been shown to be toxic.

3.2.4 Assessment of Toxicity

3.2.4.1 Evaluation of whole wastes and constituents in the laboratory.

1. Water System. Following the analytical characterization of an effluent or emission, the potential toxicological hazards in these wastes can be evaluated using Toxicological Indices such as those described in this report, searches of published literature, and contact with experts in the field. The Toxicological Indices in Table 22 present a preliminary evaluation of the toxicity to aquatic organisms of inorganic constituents of liquid wastes. Published literature and ongoing research projects on these and other constituents may be searched by computer using information services e.g. Hazmat (Environmental Contaminant Information System; published research), or NTIS (National Technical Information Service; published research), or SSIE (Smithsonian Science Informatin Exchange; ongoing research projects).

Several publications are relevant to the design and selection of methods for the toxicological evaluation of contaminants in aquatic systems. The United Nations Food and Agricultural Organization (1977) has presented a general guide to the toxicological evaluation of the potential risks arising from aquatic pollution sources. This publication is an excellent primer which outlines the basic types, characteristics and use of toxicity tests as well as a general strategy and procedures for the evaluation of contaminants from fixed-point, variable-point, and diffuse sources. It also discusses several factors to consider when selecting experimental organisms for various testing situations. Other references such as Davis (1975, 1977) and Sprague (1969, 1970,1971) give several guidelines for the design of aquatic toxicity studies.

In general, the first step is to obtain information on the short term lethal and sublethal toxicity of the whole effluent. Decisions can then be made concerning the necessity of further testing. Factors to be considered in these decisions include: the data provided by the screening test (e.g., short term LC50 value, shape of graphic concentration/response curve), the maximum anticipated concentration of the compound in the environment, and the chemical and physical dynamics (including transformation processes) of the compound in the environment. If the data from screening tests indicate that the margin of safety between concentration in the discharge and test organism sensitivity is likely to be small, further tests are required to identify the margin of safety with greater accuracy.

If the establishment of water quality criteria or industry performance standards are required, a second procedure is needed. Long term toxicological studies on appropriate organisms should be carried out on toxic whole wastes, or constituents identified by short term testing. Often a knowledge of the mode of action of a toxicant can help to identify the most sensitive organisms and physiological systems for testing during long term studies. To establish threshold levels of damage to aquatic organisms, all long term toxicology studies should include the determination of the Maximum Acceptable Toxicant Concentration (MATC - see glossary for definition). To reduce the number of toxicity studies required it may be necessary to establish the relative sensitivities of native and reference test species by literature reviews and, if necessary, research; and compare the sensitivities of one biological group to another (e.g. fish to invertebrates). Initially, in any biological group, the short term toxicity of whole wastewater samples can be determined using reference species. On the basis of these data, studies of the long term effects of whole effluents on native species can be planned, if necessary, and water quality criteria prepared.

The decision to seek additional information on the toxicity of waste constituents will be based on the results of short term toxicity studies of whole effluents. The criteria for the selection of constituents for further testing should include: the individual factors of the Toxicological Index i.e. inherent toxicity, direct and indirect availability and carcinogenicity/teratogenicity as well as the loading and distribution of the substance in receiving environments. For organic constituents, the persistence of the substance in the environment must also be included.

In toxicity testing situations involving the constituents of liquid or aerial wastes, the probable form(s) of an element, compound or chemical group involved should be determined by a review of its chemistry and behaviour under different environmental (or test) conditions. In addition, a review of the toxicity of specific chemical forms should be considered part of each of these toxicology experiments. In order to determine the chemical source of toxicity, the development of techniques for the systematic separation, identification, and quantification of individual effluent fractions (e.g. organics) may be required.

After the interpretation of laboratory-based toxicological studies, research on the effects of liquid wastes on biological systems in situ can be planned to confirm laboratory findings and establish requirements for biomonitoring. This research should commence on a small scale during the toxicological evaluation of whole effluents and should focus initially on toxic whole effluents.

The initial priority for toxicological assessments in the Water System should be studies to determine the long term effects of groundwater on aquatic organisms as well as MATC values for the saline discharges. This will enable rational discharge limits to be set.

2. Land System. To date, Land system research has centered on the determination of the baseline states of terrestrial ecosystems, the effects of sulphur dioxide on soil and vegetation, and studies related to the selection of suitable species and techniques for reclamation. A list of Land system projects and their major areas of activity is given in Table 17.

Vegetation and soils

To date, only the studies of the effects of sulphur dioxide on vegetation and soils can be considered as toxicological evaluations of emission constituents. These studies are well established (see Section 2.4.3.1) and should be continued. Only minor redirection of individual projects is recommended and these changes are discussed in the remainder of this section.

The effects of oil sands development on forest vegetation and forest soils, including forest soils microflora, will not be uniform through the Athabasca Oil Sands Area since emissions are expected to vary with plant design. In addition, the sensitivities and responses to pollution of different forest communities and soil types can be expected to vary.

Emissions (and in some cases effluents, such as groundwater) may cause changes in vegetation and soil systems. To recognize the early signs of any deviation from normal ranges of activity, baseline data from areas remote from and close to oil sands development is required. Baseline biological studies should provide this information. Therefore, the first priority of toxicology in the Land system is to complete the necessary descriptive and analytical baseline data on forest communities, forest soils, and forest soils microflora in the AOSERP study area.

a) Descriptive baseline data. Descriptive baseline studies are directed toward the general description of terrestrial ecosystems. A preliminary vegetation survey (project VE 2.2), has identified and described ten forest communities in the study area; however these communities have not been mapped. The mapping of these ten communities using existing black and white, Ektachrome, and infrared photography is basic to all field oriented toxicological research and must be considered a high priority.

The classification of soil types, surficial geology, land form, and hydrology is currently underway (project VE 2.1) and will be completed by 1980. It is recommended that an interim report be prepared, as soon as possible, describing surficial geology and representative soil types in the study area. Data on the physical and chemical characteristics of representative soil types in the study area and on soil types as substrates for soil microflora is essential for the planning of future research. Descriptive baseline data that can be used to design baseline studies of an analytical nature are being collected in projects VE 2.1 and VE 2.2.

b) Analytical baseline data. Analytical baseline studies are oriented toward the measurement of specific biological parameters and are required to establish a normal range of selected parameters in unpolluted environments. For example, measurement of the effects of atmospheric sulphur dioxide discharge on the carbon dioxide assimilation of a mature pine in a particular forest community and soil type, requires the establishment of normal fluctuations of assimilation in mature pine in unpolluted areas with the same forest and soil type. Another example of analytical baseline data would be the assessment of forest productivity in the area prior to alterations brought about through oil sands development. Analytical baseline studies on forest soils microflora may require the identification and quantification of the major genera and species of bacteria and fungi of each representative soil type defined in VE 2.1.

Baseline studies should describe the general pattern of forest communities and soil types in the AOSERP study area and characterize specific biological parameters. The tolerances of these varied ecological systems to emissions will vary greatly, and no broad generalizations with regard to resilience or susceptibility of vegetation and soil to specific toxicants can be made at this time.

To facilitate problem recognition and research design for toxicological studies the following categories of land affected by oil sands development have been identified:

a) Reclamation areas. These are the areas reclaimed after surface mining of the oil sands and are usually adjacent to emission sources.
b) In situ areas. These areas encompass the network of well sites, pipeline networks and processing plants associated with in situ oil sand developments.
c) Adjacent wilderness. Adjacent wilderness consists of forest communities not disturbed mechanically by oil sand extraction and processing but situated adjacent to surface mining and processing plants and in situ plants. Ambient concentrations of stack emissions and the deposition of sulphur-containing compounds and heavy metals are expected to be highest in these areas.
d) Remote wilderness. These areas are outside the direct influence of oil sands development. Environmental stress in remote wilderness areas should be limited to low level ambient

concentrations and depositions of stack emissions.

The planning and execution of vegetation and soil research will be facilitated by the satisfactory characterization of liquid and aerial wastes. Hazards can be identified by Toxicological Indices such as those proposed in this report, computer assisted searches of published literature, and interviews with experts. If suitable information is not available, research should be planned and implemented.

Following identification of a contaminant(s), research should be directed toward two major goals:

a) Establishment of threshold levels of damage to selected plant species. This requires information on the effects of a contaminant through direct exposure during a variety of types of fumigation episodes (e.g. conditions under thermal inversions) and via accumulation and transformation in the soil.
b) Establishment of the absorptive and regenerative capacity of each major soil type (including microflora) to a specific contaminant or mixture of contaminants. At present, very little information is available on microflora in the AOSERP study area. In addition, review articles on the effects of specific contaminants on soil microflora were found to be scarce.

As information is acquired and evaluated further research, if necessary, can be planned and initiated. The information generated in a) and b) could be used as the basis for environmental protection measures and industrial performance requirements. Research outlines for vegetation and soil studies are presented in Appendix 5.6 of this report; however, it is pertinent to suggest several guidelines:

a) The effects of contaminants on the receiving environment can only be understood when the availability and chemical reactivities of the toxic components are known. Therefore, it is recommended that the principal components of stack emissions be identified and their toxic forms and chemical dynamics be identified through published literature and/or research. The effects of wind-borne emissions including those from coke and sulphur stockpiles should also be investigated.

b) Studies of the effects of contaminants on forest vegetation are best conducted in fumigation chambers. There are several points to be made with regard to these experiments.

   i) It is important that specific emission components are investigated at levels in accordance with the Alberta Ambient Air Quality Standards (30 minutes, 1 hour, and 24 hours of exposure).

   ii) Experiments should be conducted under controlled conditions of temperature, relative humidity and light quality that simulate the conditions which might be expected in the AOSERP study area during the growing season. These conditions can be expected to vary throughout the area.

   iii) In determining the recovery of plant species from fumigation episodes, it is recommended that whole plants rather than excised portions of plants be used and that test plants be grown in representative soil types. The soil characteristics of the reclamation areas will likely be fairly uniform in their absorptive and regenerative qualities in response to pollution. However, in adjacent and remote wilderness areas, soils differ in origin, texture, physical characteristics, and chemical properties. For example, considerable differences in buffering capacity, nutrient status, and response to atmospheric pollution may be expected between the clays of glacio-lacustrine deposits and the post-glacial aeolian sand dunes (letter dated 24 January 1978 from G. Loman, Loman and Associates, Calgary, Alberta). General conclusions drawn from experiments on only a few soil types will be limited in terms of their relevance to toxicological evaluation.

c) Many heavy metals are associated with particulates, hence field and laboratory studies on the effects of heavy metals on vegetation and soil microflora should involve additions of fly ash to representative soil types.

d) There can be interactions in the soil between gaseous emissions and trace elements. For example, by the lowering of pH, acid rainfall via sulphur dioxide emissions could increase the availability of potentially toxic heavy metals associated with particulates. Naturally occurring elements can also be mobilized by lowering pH to such an extent that toxic effects appear. Hutchinson and Whitby (1976), for example, have reported the effect of acid rainfall in aluminum toxicity in the Sudbury area in Ontario. It should be determined if existing and future emissions in the AOSERP study area are likely to mobilize trace elements in soil to levels toxic to vegetation or soil microflora.

In the early phases of proposed research the following priorities for vegetation and soil toxicology are recommended.

a) The continuation of studies on the effects of sulphur dioxide, nitrogen oxides, and mixtures of sulphur dioxide and nitrogen oxides on vegetation (native and non-native). In these studies native soil types, intact plants, and growing conditions simulating the AOSERP environment should be emphasized.

b) Studies to determine the effects of fly ash (particulate emissions) on vegetation (native and non-native) in native soil types.

c) Studies of the effects of fly ash on vegetation in native soil types exposed to sulphur dioxide, nitrogen oxides, and their mixtures.

d) Determination of sulphur and nitrogen available to plants in selected native soil types using fertilizer trials.

In contrast to what was possible for mammals and aquatic organisms, it was not possible to derive Toxicological Indices for vegetation. However, Section 2.5 reviews the effects of inorganic substances and outlines the constituents most often associated with toxic effects. Individual references should be consulted for further information on the dose-response relationships of specific contaminants.

Wildlife

A large number of wildlife populations may be influenced by oil sands development. Included in this group are sedentary and highly mobile organisms as well as permanent (year-round) and migratory species. Toxicological investigations of both emissions and effluents will be necessary since the terrestrial fauna includes semi-aquatic mammals and birds as well as waterfowl.

Information on loadings of inorganic constituents of emissions, and data on the identity and loadings of organic constituents in effluents and emissions is insufficient to permit the planning of comprehensive toxicological studies for wildlife.

The first phase of the toxicology program for wildlife should be similar to that proposed for aquatic organisms i.e. analytical characterization of major effluents and emissions and identification of hazards. When substances of concern are identified their toxicology and dynamics must be investigated. Initially, literature surveys should be conducted and research planned, as required, to fill gaps. From a preliminary list of known and potential contaminents synoptic ecological and chemical surveys could be planned and conducted. The Toxicological Indices presented in Section 2 (Table 20) of the report could be considered as a preliminary assessment of potential hazards.

Since the characterization of emissions and effluents is incomplete, it is too early for laboratory-based assessments of the toxicity of specific waste constituents to selected wildlife species. Therefore, no toxicity testing studies are recommended at this time.

3.2.4.2 Assessment of toxicity in the field through biomonitoring.

1. Water System. Biomonitoring programs have been discussed previously. Both baseline and impact biomonitoring networks (see Section 3.1.4.2 for definitions) are recommended for aquatic-based toxicology.

   The United Nations Food and Agritural Organization (1977) describes four major types of bioevaluation procedures that can be used to monitor and assess the effects of fixed point, variable point, and diffuse discharges. These are:

   a) On-line early warning toxicity testing;
   b) In situ toxicity testing including artificial substrate colonization;
   c) Ecological surveys; and
   d) Bioaccumulation testing.

   To aid in the interpretation of biological observations, this document recommends that abiotic data be collected along with biological data in monitoring networks.

   It is expected that the biomonitoring techniques described by the Food and Agricultural Organization could be utilized in the AOSERP study area. It is recognized in the core activities of the Water system that biomonitoring methodologies and strategies may require investigation to determine appropriate organisms and evaluation procedures (AOSERP 1977b). The design of sampling programs and selection of suitable analytical techniques should be defined once a satisfactory list of contaminants (organic and inorganic) and their loadings (temporal and geographic) is available.

In biomonitoring, it is recommended that parallel biotic and abiotic monitoring be conducted to correlate biological effects with effluent discharge. This will be especially helpful in the assessment of the relative importance of contaminants from two or more sources which affect the same area. The selection of monitoring designs, monitoring procedures, and test organisms (or tissues) may vary with the specific objectives of each biomonitoring project. Because a satisfactory knowledge of known and possible toxicants and their dynamics is lacking, only ecological surveys (possibly including data acquired from previous baseline studies) in selected aquatic habitats are recommended for baseline biomonitoring in 1978/79. Locations such as the Muskeg River-Hartley Creek and MacKay River watersheds should be considered as possible areas for baseline biomonitoring since considerable abiotic and biotic data are already available; in addition these locations also represent probable sites for additional oil sands development.

Impact monitoring networks utilizing ecological surveys (benthic invertebrates) are recommended for Syncrude groundwater discharge and the final GCOS upgrading effluents and should be initiated immediately. As effluents become more fully characterized, studies of the accumulation by biota of the specific inorganic and organic constituents of effluents is recommended. Under the mandate of AOSERP, source oriented impact biomonitoring networks should most likely be operated by industry with AOSERP providing information (if required) on data requirements, techniques and designs.

The concepts involved in monitoring for the bioaccumulation of specific substances are discussed more fully in the following section on wildlife. At this time, only the establishment of an archives of biological material for future analysis is recommended.

2. Land System. In the Land system, there is a need for baseline and impact biomonitoring networks, regardless of what organization (industry, government, AOSERP) conducts the programs. The development of biomonitoring techniques and the establishment of biomonitoring networks for vegetation and terrestrial fauna is recognized by AOSERP as a high priority (AOSERP 1977a, 1977b). It is anticipated that ecological surveys and testing for bioaccumulation of specific compounds will form the basis of biomonitoring programs. The establishment of specific baseline and impact monitoring networks using ecological surveys and bioaccumulation techniques should be given immediate priority. Abiotic data to aid in network design, and later in the interpretation of biomonitoring results, will be supplied by air and water quality networks. Close cooperation between the groups responsible for these networks and various Land system researchers (vegetation and soils, terrestrial fauna) is highly desirable to ensure efficient and cost-effective monitoring. It is recommended that as long as the terrestrial ecosystems in the AOSERP study area are subjected to toxic contaminants, a system of biomonitoring should be used to detect and evaluate the effects of oil sands development.

   It is assumed that the baseline ecological surveys conducted to date, will provide much of the necessary information for planning and interpretation of the impact biomonitoring networks.

   In 1978/79, the selection of study organisms for ecological surveys and bioaccumulation research (in both baseline and impact monitoring networks) should be given a high priority. Tentative indicator organisms should be identified from data collected in baseline studies and if necessary, ecological surveys of these species undertaken in selected communities. Biomonitoring should be conducted at representative sites in reclamation areas, in situ areas, remote wilderness, and also wilderness adjacent to oil sand developments.

Analytical studies on the accumulation of specific constituents in vegetation and terrestrial fauna (including birds) is not recommended during 1978/79 since major emissions have been insufficiently characterized (including loadings). However, an archives of biological samples could be established.

As knowledge of the identity and loadings of emission constituents is expanded it is proposed that a biomonitoring program be established to examine selected mammals and birds to determine the baseline levels of inorganic elements in specific tissues. If toxic organic compounds are identified in effluents and emissions, the program should be expanded to include the determination of levels of these compounds.

The establishment of a biological archives would be useful in the evaluation of the long term effects of industrial development. During each year of the biomonitoring program, a certain number of samples should be collected for future reference. When parameters are identified as potential hazards, appropriate material in the archives could be recalled and analyzed. It is recommended that samples be collected during existing biological baseline studies and regularly thereafter.

Implicit in the establishment of a biological archive is the investigation and development of sampling designs and collection methods for specific biological groups and chemical constituents. As well, appropriate preservation methods for specimens and specific contaminants must be investigated. It will be important to examine the effects of storage (techniques and duration) on contaminant levels in preserved samples. It will also be important to determine which potential contaminants or groups of contaminants other than volatile organics are not amenable to study using specimens from a biological archives.

For the 1978/79 fiscal year, priority should be given to the establishment of appropriate sampling and preservation techniques. A combined study approach of literature searches, personal interviews, and small scale experiments is recommended. Analysis of samples collected during 1978/79 is recommended only on an experimental basis since suitable lists and loadings of specific effluent and emission components are not available at this time.

3.3 TOXICOLOGY IN THE HUMAN SYSTEM

As stated in AOSERP Policy and Direction (1977a), "Research in the Human System is oriented to establishing baseline states for demographic patterns and social conditions in the study area and the changes which may occur in these as a result of oil sand development". The stated objectives and core activities of the 1977-80 system research plans for the Human system make no direct mention of human toxicology or human health (AOSERP 1977b).

In the terms of reference of this study, an assessment of the toxicological implications of oil sands wastes to humans was requested. Computerized literature searches of Biological Abstracts, Index Medicus, and Toxindex, were carried out and generated 38, 59, and 67 citations respectively. None were directly relevant to human toxicology in the oil sands area. It is current practice to assess the potential for harm of a substance to humans by conducting toxicity experiments on animals and then extrapolating to humans. Therefore, the information in Section 2.5 on the toxicology of wastes and waste constituents can be used as a preliminary assessment of parameters of potential toxicological concern to humans. In addition, the National Institute of Occupational Safety and Health (NIOSH) produces and updates registries of the toxic effects of chemical substances (Christensen 1976) and suspected carcinogens (Christensen 1975).

3.3.1 Air

Possible harmful effects to the health of humans could arise in several ways. Presently available data (Section 2) indicate that stack emissions are likely to account for a large quantity of the potential atmospheric contaminants leaving the plant and entering the environment. In addition, each plant will discharge, locally, low altitude emissions which could be harmful (see Section 2.6). Both stack and low altitude emissions rely on dilution to minimize environmental damage and adverse dispersion conditions could result in higher than average concentrations of potential toxicants. This may be especially true of stack emissions because of their large volumes.

The possible effects of emissions on humans could include:

1. Offensive odours;
2. Potential carcinogens, e.g. benzopyrenes;
3. Potentially toxic gaseous materials, e.g. hydrogen sulfide, sulphur dioxide, nitrogen dioxide, arsenic, mercury, selenium;
4. Particulate matter containing toxicants (e.g. heavy metals) and dusts; and
5. Toxic substances which can accumulate in human tissues.

3.3.2. Water.

Adverse effects on humans arising from liquid effluents should be minimal. Problems which could arise from liquid effluents include:

1. Loss of recreational amenities:
2. Exposure to offensive odour and taste;
3. Ingestion of water contaminated with potential toxicants, e.g. arsenic; and
4. Ingestion of contaminated fish (may include problems of offensive odour or taste); these could be contaminated from the water directly or indirectly through their food chain.

3.3.3 Land

The remoteness of many of the lease areas and their surroundings suggests that any impact on humans will be small. It seems probable that most effects on human health would arise from ingestion of contaminated vegetation or wildlife. Biomonitoring data obtained by projects in other research systems should detect substances that could accumulate in humans through food consumption.

3.3.4. Emergencies

A potential hazard to human health exists if any emergency arises at a plant. This hazard could exist within and/or outside the plant. An example of an emergency situation would be a fire in the sulphur stockpile or the flooding of an industrial site.

3.3.5 Toxicological Studies

Since it is assumed that all oil sands plants will adopt high standards of industrial hygiene and safety, it is recommended that AOSERP should decide whether a human toxicology program is necessary. In regard to human health, occupational safety, and industrial hygiene, several existing government departments and agencies (Alberta Environment, Alberta Labour, National Health and Welfare) already have large responsibilities. It is felt that a review of all data on atmospheric emissions and liquid wastes to determine their potential for causing human health problems is not the responsibility of AOSERP (letter dated 31 March 1978 from AOSERP Program Management, letter collated by M. Falk, Assistant Director, AOSERP). Nor is it AOSERP's responsibility to review the health hazards associated with emergency situations *(Ibid.)*. Further, several significant gaps in the inorganic and organic characterization (composition and loading) of effluents, wastes and emissions have been identified (Section 2) and thus it would be somewhat difficult to determine the potential for toxicological effects of wastes to humans on the basis of existing information.

The research design proposed in this report should provide information on changes occurring in the environment, and it should be possible to detect and avert any possible danger to man. Fish, mammals, birds, invertebrates, and vegetation, being directly exposed to potential toxicants, should be sensitive indicators of the toxic potential of whole emissions and effluents to humans. If biomonitoring studies indicate that specific contaminants are accumulating in biota, the implications and consequences of these levels to humans could be investigated.

Since the role of the Human system in the overall area of human toxicology and human health in the AOSERP study area is poorly defined in relation to other government agencies and since human toxicology studies could be outside the scope of research for the Human system, no recommendations or priorities for human toxicology studies have been set.

3.4 IMPLEMENTATION OF THE PROPOSED TOXICOLOGICAL PROGRAM RESEARCH DESIGN

In Section 3.1, the proposed toxicology research design has been described. The design is based on the systematic investigation of the toxicological concerns associated with oil sands development. The research requirements for the proposed toxicological program research design and a general discussion of their implementation have been presented in Section 3.2. To aid in the implementation of the proposed research design, certain priorities and specific projects are recommended.

3.4.1 Research Direction

The integration of toxicology projects with other research projects of AOSERP will be necessary if the short and long terms effects of oil sands development are to be assessed successfully. As well as the cooperative planning and evaluation of many projects, close coordination of projects in progress in various AOSERP research systems will be required. It should be recognized that there are problems in processing the large amounts of information generated by ambitious programs such as AOSERP. To facilitate this process, the flow of information (print and non-print) to AOSERP and other potential users should be maximized. At this date the majority of AOSERP research information relevant to toxicology is unavailable for general distribution and the results of specific studies are often delayed in draft or status reports. The successful integration of toxicological information into the overall AOSERP program will also be facilitated by the establishment of efficient data analysis, storage, and retrieval systems in all AOSERP research systems. This process will further enhance the rapid reporting of research findings within AOSERP and to the external scientific and industrial community. To aid in the development of a toxicology program and to facilitate the planning and integration of studies in other research system core activities with toxicology, a high priority is recommended for the establishment of data management systems in all AOSERP research systems.

The priorities for general direction of research activity within the implementation phase of the proposed research design are:

1. Acquisition, in all research systems, of baseline information pertinent to toxicology including the review, evaluation, and redesign (if necessary) of existing programs collecting abiotic data (e.g. ambient air and water quality data);
2. Completion of inventories of effluents and emissions and identification of biological target systems;
3. Completion of the chemical and physical analysis and characterization of effluents and emissions;
4. Completion or modification of the preliminary evaluation of the potential toxicity of wastes and waste constituents; and
5. Design and initiation of biomonitoring programs in the Land and Water systems.

Information on the relative importance, relative size and duration of research effort within the proposed research design is given in Table 26.

The anticipated trend in research effort, assuming a third oil sands plant does not commence production before 1984, is as follows. Following completion of the research mentioned in the prevous paragraph, it is anticipated that biomonitoring will increase substantially and maintain a relatively high level of effort (both in numbers of studies and levels of funding) for the duration of the Program. It is also expected the toxicological assessment of whole wastes and waste constituents will be restricted to known hazards with effects in the AOSERP study area. These studies will likely maintain a relatively constant, but low level of effort for the remainder of the Program.

To provide critical appraisal, it is recommended that the progress of the toxicology program be reviewed annually and evaluated by an independent group every two years.

Table 26. A summary of priorities for the implementation of the proposed toxicology program research design.

Program Activities	Relative[a] Importance of Research	Relative Size[b] of Initial Research Effort	Duration[c] of Research Effort
I ACQUISITION OF ABIOTIC AND BIOTIC BASELINE DATE	1	small	long
II INVENTORY OF EFFLUENTS AND EMISSION; IDENTIFICATION OF BIOLOGICAL TARGET SYSTEMS	1	small	short
III CHEMICAL AND PHYSICAL CHARACTERIZATION OF EFFLUENTS AND EMISSIONS	2	medium	short
IV ASSESSMENT OF TOXICITY			
Preliminary evaluation of potential toxicity	1	small	short
Toxicity of whole wastes	2	medium	short
Toxicity of components of wastes	3	small	short
Biomonitoring			
Impact biomonitoring	2	large	long
Baseline biomonitoring	2	medium	long

[a]Relative importance of research effort at present time

1 - of highest priority, research effort indispensible or fundamental to design

2 - of secondary priority, but still indispensible or fundamental

3 - of lowest priority, a definite need but not indispensible or fundamental

[b]Relative size of initial research effort

small - less than 10% of research resources

medium - 10 to 25% of research resources

large - greater than 25% of research resources

(Since some aspects of I-IV are outside what are traditionally thought of as "Toxicology Studies" research effort may ultimately exceed $ 100,000 per annum)

[c]Duration of research activity (assuming a third oil sands plant does not commence operation prior to 1984)

short - less than 18 months

medium - 18 to 36 months

long - greater than 36 months

3.4.2 Project Details

In this section, the projects considered necessary to initiate the proposed AOSERP toxicology program research design are briefly outlined. A list of the proposed projects (twenty five) and their relation to the proposed toxicology program research design is presented in Table 27. Studies in technically non-toxicological disciplines also have been described so that suitable information for toxicological planning and data interpretation can be acquired from baseline studies and/or analytical studies of emissions and effluents. For each project, a "detail sheet" has been prepared outlining objectives, a general research outline, cost, timing, and coordination of the project. These sheets are presented in Appendix 5.6. They are not intended to be Terms of Reference for specific projects. It should be noted that several detail sheets are for existing or proposed AOSERP research projects: on these sheets, suggestions have been made which could improve the quality of toxicological information they will generate. The integration of the proposed projects is discussed on the project detail sheets and illustrated in Figure 3.

Table 27. Projects recommended for the implementation of the proposed design of the AOSERP toxicology research program.

Program Activities and Project Title	Relative Importance[a]	Size of Proposed Project[b]	Duration of Proposed Project[c]	Starting Date[d]
I ACQUISITION OF ABIOTIC AND BIOTIC BASELINE DATA (Sections 3.1.1, 3.2.1)				
In the Land, Water and Air Systems				
1. Design and implementation of data storage and retrieval systems	1	small	short	immediate
2. Analysis of organic compounds in air, water, sediment/soil and biota	3	medium	short	early
2.1 Literature review of methods used to extract organic compounds from various samples	3	small	short	immediate
2.2 A comparative study of methods of extracting organic compounds from water	3	small	short	early
2.3 Monitoring of organic compounds in water and sediment - selection of methods	3	small	short	early
In the Water System				
3. Review of abiotic monitoring programs - water	1	small	short	immediate

continued . . .

Table 27. Continued.

Program Activities and Project Title	Relative Importance[a]	Size of Proposed Project[b]	Duration of Proposed Project[c]	Starting Date[d]
In the Land System				
4. Biophysical land classification of forest land	1	small	short	immediate
5. Detailed mapping of forest communities	1	small	short	immediate
6. Soils inventory of the Oil Sands Area - preliminary mapping	1	small	short	immediate
7. Physical and chemical analysis of soil types in the Oil Sands Area	2	medium	short	early
8. Physical and chemical properties of tailings sand	2	medium	short	early
9. Preliminary survey of soil microflora in Oil Sands Area	3	small	short	early
10. Coordination of vegetation and soils projects	1	small	long	immediate
II INVENTORY OF EFFLUENTS AND EMISSIONS AND IDENTIFICATION OF TARGET SYSTEMS (Sections 3.1.2, 3.2.2)				
In the Land, Water and Air Systems				
11. In situ Oil Sands development: technology and potential effects on the environment	3	small	short	early

continued . . .

Table 27. Continued.

Program activities and Project Title	Relative Importance[a]	Size of Proposed Project[b]	Duration of Proposed Project[c]	Starting Date[d]
In the Water System				
12. Inventory of effluent and wastewaters	1	medium	short	immediate
III CHARACTERIZATION OF EFFLUENTS AND EMISSIONS (Sections 3.1.3, 3.2.3)				
In the Air and Water Systems				
13. Trace elements: mass balance around an Oil Sands Plant	1	large	moderate	immediate
13.1 Trace elements entering an Oil Sands Plant	1	medium	short	immediate
13.2 Trace elements: balance around the extraction process in an Oil Sands Plant	1	small	short	later
13.3 Trace elements: balance around the upgrading process in an Oil Sands Plant	1	medium	short	later
13.4 Trace elements: balance around power plant and water treatment plant in an Oil Sands Plant	1	medium	short	later
13.5 Trace elements: balance around tailings pond in an Oil Sands Plant	1	medium	short	later
14. Characterization of organic emissions and effluents from an Oil Sands Plant	1	small	short	immediate

continued . . .

Table 27. Continued.

Program Activities and Project Title	Relative Importance[a]	Size of Proposed Project[b]	Duration of Proposed Project[c]	Starting Date[d]
In the Air System				
15. Characterization of particulates near Oil Sands Plants	1	small	short	immediate
In the Water System				
16. Effects of water chemistry on the dynamics of known or potential aquatic hazards	2	small	short	early
17. Investigations of the chemistry and dynamics of groundwater in small drainages	2	small	short	early
18. Mixing characteristics of the Athabasca River	2	small	short	early
IV ASSESSMENT OF TOXICITY (Sections 3.1.4, 3.2.4)				
In the Water System				
19. Effects of industrial effluents on aquatic organisms	1	medium	moderate	immediate
19.1 Long term effects of saline groundwater on fish and invertebrates - laboratory study	1	medium	moderate	immediate

continued . . .

Table 27. Continued

Program Activities and Project Title	Relative Importance[a]	Size of Proposed Project[b]	Duration of Proposed Project[c]	Starting Date[d]
19.2 Guidelines for reporting fish bioassay results	3	small	short	immediate
20. Biomonitoring of the effects of major industrial effluents on aquatic organisms	1	medium	long	immediate
20.1 Biomonitoring of Syncrude mine depressurization water discharge	1	medium	long	immediate
20.2 Biomonitoring of GCOS process effluent	1	medium	long	immediate
20.3 Rapid monitoring techniques - preliminary evaluation	3	small	short	later
20.3.1 Literature review	3	small	short	later
20.3.2 Assessment of selected techniques	3	small	short	later
In the Land System				
21. Effects of industrial emissions on vegetation	1	large	moderate	immediate
21.1 Effects of sulphur dioxide and nitrogen oxides on vegetation - laboratory study	2	medium	moderate	ongoing

continued . . .

Table 27. Continued.

Program Activities and Project Title	Relative Importance[a]	Size of Proposed Project[b]	Duration of Proposed Project[c]	Starting Date[d]
21.2 Effects of particulate emissions on vegetation - laboratory study	2	medium	moderate	immediate
21.3 Effects of sulphur dioxide, nitrogen oxides and particulate emissions on vegetation - laboratory study	2	medium	moderate	early
21.4 Identification of species intolerant to Alberta Ambient Air Quality Standards - literature review	3	small	short	early
21.5 A literature review of the toxicology of trace elements to vegetation	3	small	short	early
22. Biomonitoring of the effects of sulphur dioxide, nitrogen oxides and particulate emissions on vegetation	1	medium	long	immediate
23. Effects of industrial emissions on soil systems	3	medium	moderate	immediate
23.1 Effects of sulphur, nitrogen and particulate emissions on soil microflora - laboratory study	3	medium	moderate	later

continued . . .

Table 27. Concluded.

Program Activities and Project Title	Relative Importance[a]	Size of Proposed Project[b]	Duration of Proposed Project[c]	Starting Date[d]
23.2 A preliminary study of the availability of sulphur and nitrogen to plants	3	small	short	immediate
23.3 A literature review of toxicology of trace elements to soil systems	1	small	short	early
24. Biomonitoring of the effects of sulphur, nitrogen and particulate emissions on soil microflora	3	medium	long	later
25. Biomonitoring of the effects of industrial activity on wildlife	1	medium	long	immediate

[a]Relative importance for research <u>at the present time</u>
1 - of highest priority, indispensible or fundamental
2 - of secondary priority but still indispensible or fundamental
3 - of lowest priority, a definite need but not indispensible or fundamental

[b]Size of the proposed project
small - annual budget less than $ 40,000
medium - annual budget of $ 40,000 to $ 100,000
large - annual budget of greater than $ 100,000

[c]Duration of initial research project
short - less than 18 months
moderate - 18 to 36 months
long - longer than 36 months

[d]Starting date
immediate - required for first phase of program
early - could be delayed for up to one year
later - could be delayed for greater than one year or requires prerequisite data from other studies before beginning

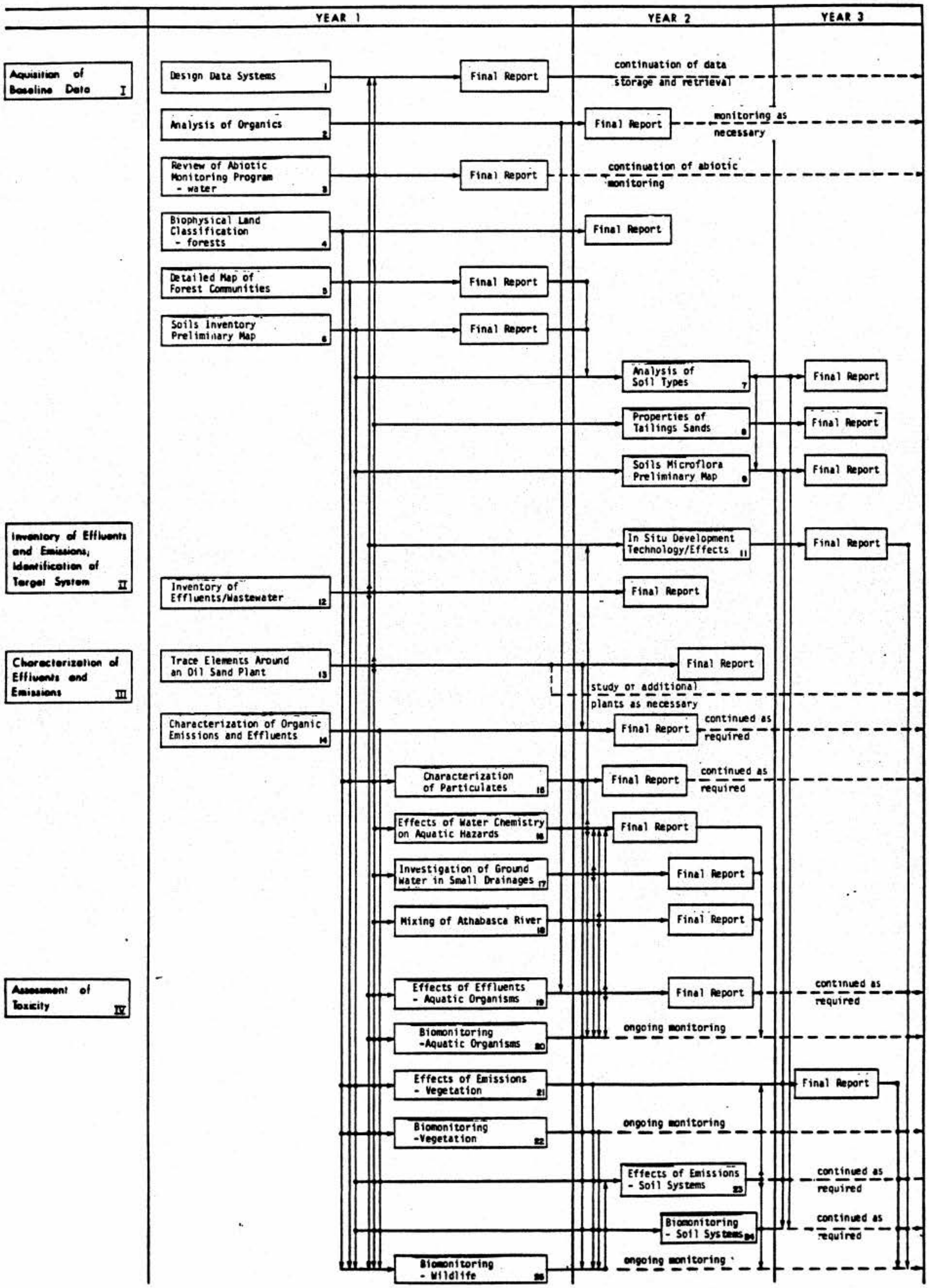

Figure 3. Integrated schedule of projects recommended for implementation of proposed research design.

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5.0 APPENDICES

5.1 TERMS OF REFERENCE

1. Objective. A program of toxicology research for the Alberta Oil Sands Environmental Research Program (AOSERP).
2. Statement of Work.
   a) Review and evaluate the nature and magnitude of present and proposed oil sands development effluents (liquid) and emissions (aerial) within the AOSERP study area.
   b) Review and evaluate the results of previous and ongoing waste and receiving water quality and air quality studies undertaken by or for government agencies, oil sands industry, and AOSERP.
   c) Review and evaluate the results of previous and ongoing toxicology studies undertaken by or for government agencies, oil sands industry, and AOSERP.
   d) Describe the physical and chemical characteristics of oil sands development wastes and outline the toxicological significance of these wastes to each of the following groups:
      - bacteria
      - algae
      - aquatic invertebrates
      - fish
      - semi-aquatic mammals
      - terrestrial mammals
      - waterfowl
      - other birds
      - terrestrial vegetation
      - aquatic vegetation
      - soil micro-organism
      - humans
   e) From points a to d above and a search of the literature, prepare a preliminary list of parameters judged to be of environmental concern and describe the toxicology of each parameter.

f) Through personal contact with users (government agencies, oil sands industry, sectors of AOSERP, etc.), determine the needs of a toxicology research program. Prepare a tabulation of contacts and defined needs.

g) On the basis of point a to f above, design an integrated toxicology research program for AOSERP appropriate to the objectives of AOSERP; the needs of government, the oil sands industry and the sectors of AOSERP; and the nature and magnitude of oil sands development.

   i) The research design will be presented in chart and written form and will be described in a modular or component format.

   ii) Each component of the research design will be described as to objective, detailed outline of work, duration, approximate cost, and suggested contractors (government, industry and university).

   iii) The research design will be appropriate to the three, five and ten year Program objectives as outlined in the Policy and Direction Document.

   iv) The research design will address the entire spectrum of toxicology as appropriate and will include:
      - acute, lethal, sub-acute and chronic toxicology
      - fish, aquatic invertebrates, plankton, bacteria, higher plants, birds, plants, soil micro-organisms, mammal and human toxicology
      - whole effluents and emissions and components thereof
      - pathways and sinks of contaminants in the environment
      - synergistic, antagonistic and additive aspects of components
      - persistence or half-life of substances

- potential for bioaccumulation
- toxicity of breakdown products

v) Each component of the research design will be priorized as the relative significance in terms of the objectives of AOSERP, defined needs from users, the nature and magnitude of oil sands development, and as judged from a search of the literature.

vi) The research program design is to reflect an expenditure of funds by AOSERP between $200,000 and $400,000 annually from 1977 to 1985.

5.2 GLOSSARY

BASELINE BIOMONITORING: The collection of biomonitoring data (see next definition) to determine the status of regional environment.

BIOMONITORING: The systematic collection of biological data for the purpose of detecting temporal or spatial change. As a complement to biological observations, biomonitoring may also include the repeated observation of a contaminant with the view to establishing temporal or spatial trends in its biological effects.

CARCINOGENIC: The ability of a substance or group of substances to produce malignant tumours.

CONTAMINANT: A substance present at elevated levels (compared to background) in the environment which may or may not have observable adverse effects. Thus a contaminant may refer to a substance found at elevated concentrations but with unknown or undetermined toxicity.

IMPACT BIOMONITORING: The source-oriented (i.e., waste source) collection of biomonitoring (see definition above) data for the purpose of measuring changes in the status of the environment.

INCIPIENT LETHAL LEVEL (ILL): The concentration of a toxic substance or group of substances beyond which 50 percent of the experimental organisms can live for an indefinite time.

LONG TERM TOXICOLOGY STUDIES: Toxicological studies which last longer than 30 days. Long term studies may be conducted over several complete life cycles of certain organisms and may include effects on all stages of survival, growth and reproduction of the organism. As well, the carcinogenic, teratogenic, and mutagenic potential of the substance or group of substances may be evaluated.

MAXIMUM ACCEPTABLE TOXICANT CONCENTRATION (MATC): The highest concentration of a toxicant that has no observable adverse effect on survival, growth, or reproduction of a species based on the results of a life-cycle or partial life-cycle toxicity test.
A life-cycle or partial life-cycle test cannot produce

an actual value for the MATC: a test can only produce limits (i.e., effect and no effect levels) within which the MATC must fall.

MEDIAN LETHAL DOSE (LD50): The amount (ingested or injected) of a toxicant or group of toxicants which cause the death of 50% of a group of experimental animals exposed to it for a specified period of time.

MEDIAN LETHAL CONCENTRATION (LC50): The concentration of a toxicant in water which is lethal to 50% of the organisms of a particular species under a given set of conditions in a specified length of time (i.e. 24-, 48-,96-hours, etc.).

MONITORING: The systematic collection of information on environmental variables (biotic and abiotic) for the purpose of detecting temporal and/or spatial change.

MUTAGENIC: The ability of a substance or group of substances to cause adverse genetic changes.

PHARMACODYNAMICS: The study of the biochemical and physiological effects as well as the mechanisms of action, of toxic substances.

SHORT TERM TOXICOLOGY STUDIES: Toxicological studies which last no longer than 30 days.

TERATOGENIC: The ability of a substance or group of substances to cause embryological changes that result in abnormal offspring.

THRESHOLD LEVEL: The lowest level of a toxic substance or group of substances at which a specific adverse effect (lethal or sublethal) just begins to be detected.

TOLERANCE: The ability of an organism to resist or adapt to stress, this ability being a combination of the genetic and environmental history of the organism. Tolerance to a particular agent or substance usually is not constant and varies with many factors (e.g., age, sex, diet, acclimation, synergisms, antagonism, etc.).

TOXICANT: A substance which causes observable toxicological effects and which by definition must have a harmful effect.

TOXICITY: The ability of a substance or group of substances to cause death, measurable damage, altered behaviour, and/or observable changes in the normal life cycle of an organism and/or its constitute cells.

TOXICOLOGY: The study of the ability of a substance or group of substances to cause death, measurable damage, altered behaviour, and/or observable changes in the normal life cycle of an organism and/or its constituent cells.

5.3 REVIEWS OF INDIVIDUAL TOXICOLOGY STUDIES

5.3.1 Water System

McMAHON, B., P. McCart, A. Peltzner and G. Walder 1977. Toxicity of Saline Groundwater from Syncrude's Lease 17 to Fish and Benthic Macroinvertebrates. Syncrude Environmental Research Monograph 1977-3. 99 pp.

This is one of three reports available on the short term toxicity of mine depressurization water (MDW). It has no abstract or conclusions, most of the useful information being contained in the discussion. No attempt was made in this study to monitor possible changes in the concentration of the various constituents of MDW. Since storage is known to bring about changes in the concentration of many of the constituents of MDW, this is a serious deficiency and may account for the wide variation in toxicity which was observed. The study assumes that the MDW examined forms a representative sample of all MDW and many of the comments made depend on this being a fact. It is unlikely, however, that MDW will have a constant composition when sampled from a single well, from separate wells, or from wells on different leases.

Of the eight fish species studied, lake chub and white sucker were found to be the most resistant to the toxic actions of MDW, flathead chub showed an intermediate response, and trout-perch, arctic grayling, rainbow trout, yellow walleye and mountain whitefish were the most sensitive species. At 96 and 168 hours, the LC50 of the least sensitive species, lake chub, was seven to eight times that of the most sensitive species, walleye.

Egg-alevin experiments with rainbow trout showed that fry are generally more sensitive than eggs to the toxic actions of MDW. Similar effects have been noted with most toxicants. The data on the four invertebrate species studied is useful but contains nothing unusual. Of the species of invertebrates tested, the plecopteran Isogenus sp. was by far the most resistant. In comparison with juvenile fish, invertebrates had a short term (to 48 hours) tolerance which exceeded that of the most tolerant fish; by 168 hours, values for benthic invertebrates began to overlap the upper ranges of value for fish. Unlike juvenile fish, mortalities of benthic macroinvertebrates were greater at 15 degrees C than at 5 degrees C.

The recommendation that 'values for the threshold level can only be determined by experiments involving long term exposure' is an important one for the toxicology program.

SPRAGUE, J.B., D.A. Holdway and D. Stendahl. 1978. Acute and Chronic Toxicity of Vanadium to Fish. Prepared for the Alberta Oil Sands Environmental Research Program by the University of Guelph. AOSERP Project AF 3.5.1 Draft Final Report, Oct. 1977. 88 pp.

This draft final report presents the results of a short and long term study of the toxicity of vanadium to trout and flag fish respectively. The authors have also included a brief review of the probable chemical forms of vanadium under a variety of experimental conditions.

The report concludes that vanadium is a moderately toxic element, that it does not appear to accumulate in fish and that it is unlikely that this element represents a serious environmental hazard. These findings are important because of the high concentrations of vanadium in raw oil sand and in some effluents and emissions.

The report contains a model for future long term toxicity studies with either MDW or its various constituents.

GILES, M.A., J.F. Klaverkamp, and S. Lawrence. in review. The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates. Prepared for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada Freshwater Institute. AOSERP Project AF 3.2.1 Draft Final Report, Jan. 1978. 205 pp.

This is the only report reviewed that has examined the physiological and histopathological actions of MDW or vanadium.

The report includes data which shows that the composition of MDW changes on storage and that this alters its toxicity, indicating that this factor has to be considered in all studies of MDW. The acute toxicity studies show that MDW is toxic to both fish and invertebrates but that invertebrates can tolerate higher concentrations of MDW over the time period studied.

The study of the toxicity of vanadium provides results which agree with those of Sprague et al. (1978).

The histopathology is interesting in that both MDW and vanadium appear to produce similar gill lesions in fish. The mechanism by which MDW or vanadium causes death is, however, still undetermined and, presumably, this was not included in the statement of work for this project. In general, the report contains much potentially valuable histological data but the usefulness of the physiological and behavioural data to the AOSER Program is questionable.

LAKE, W. and W. Rogers. in prep. Acute Lethality of Mine Depressurization Water on Trout-Perch (Percopsis omiscomaycus) and Rainbow Trout (Salmo gairdneri). Prepared for the Alberta Oil Sands Environmental Research Program by Alberta Environment. AOSERP Project AF 1.1.2 Draft Report. June, 1977. 107 pp.

This report presents data on the composition of MDW and the variations in composition likely to be encountered from samples taken from a single well and from well to well within a sampling period. Data is also presented which show that the toxicity of MDW is altered by storage. This was the first study to demonstrate that MDW was toxic to fish.

The report contains several recommendations for further work including the suggestion that field bioassays should be used to monitor the toxicity of MDW. The report has demonstrated that toxicological studies, in situ, are feasible.

MACHNIAK, K. 1977. The Impact of Saline Waters Upon Freshwater Biota (A Literature Review and Bibliography). Prepared for the Alberta Oil Sands Environmental Research Program by Aquatic Environments Ltd. AOSERP Report 8. 258 pp.

This report contains a comprehensive review of the published literature on the impact of saline waters on biota. The author reaches several important conclusions from this survey perhaps the most important being the conclusion that toxicity is related to cation, rather than anion, content of the water. Other important conclusions derived from this study include the possibility that diatoms may be useful as indicators of salinity, that the yellow walleye (<u>Stizostedion vitreum vitreum</u>) is probably the species of fish most likely to be affected adversely by saline water and that it is unlikely that saline water will have a significant impact on amphibia, birds or mammals.

LUTZ, A. and M. Hendzel. 1977. Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area. Prepared for Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Fisheries and Marine Service. AOSERP Report 17. 51 pp.

This report provides background data on the levels of several potential toxicants (12 metals) in water, sediment, fish (8 species) and a few phytoplankton and invertebrate samples in the AOSERP area. Fish were also examined for four pesticides. The authors concluded that despite limitations caused by sampling difficulties, the reported values reflect baseline levels of trace metals in the area. No natural sources of contamination were noted for fish and their was no correlation between levels of contaminant and weight of fish. There did not appear to be any accumulation of metals in the food chain.

In general, the report contains valuable information on baseline levels of contaminants. It also contains practical recommendations for future studies. However, because the data represents conditions in 1975, it now represents an isolated study. Clearly there is a need for continuous data acquisition.

5.3.2 Land System

STRINGER, P.W. 1976. A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area. Project VE 2.2.

This report provides basic vegetation information for the AOSERP study area. It is highly recommended that the "Conclusions and Recommendations" section on pages 41-45 be carefully studied and implemented. It is further recommended that all future field-oriented vegetation studies use the classification of forest communities as recognized by Dr. Stringer. This approach will permit comparisons to be made between the results of different subprojects involving work in forest vegetation.

CCRS. Vegetation Inventory of the AOSERP Study Area. Project VE 2.3.

It is advised that Dr. Stringer's recommendations with regard to the use of aerial photography be implemented and that the inventory of vegetation be described in terms of the ten forest communties recognized by Dr. Stringer.

MALHOTRA, S.S. Symptomology of Sulphur Dioxide to Vegetation. Project VE 3.1.

The intent of this project was to induce visible sulphur dioxide symptoms on the foliage of intact seedlings of representative species in a fumigation chamber, under carefully controlled environmental conditions. Results will be of great interest to persons involved in environmental management and impact assessment. Estimates of ambient sulphur dioxide concentrations and exposure times that resulted in the three categories of symptoms that have been observed in the Whitecourt Study Area are still unavailable.

MALHOTRA, S.S. Physiology and Mechanisms of Sulphur Dioxide Injury to Vegetation (Pre-visual). Project VE 3.3.

This sub-project was conducted entirely in the laboratory. Excised lodgepole pine needles were immersed in aqueous solutions of sulphur dioxide of various concentrations, and allowed to photosynthesize for 22 hours at 23^{o}C under 64,000 lux illumination. Extrapolation of the results of this experiment to conditions in nature are not possible for the following reasons:

1. It is extremely unlikely that self-repair mechanisms are as efficient in excised foliage as in foliage attached to trees.
2. The assumption is made that at 23^{o}C the ratio of dissolved (aqueous) sulphur dioxide to gaseous sulphur dioxide is

1000 to 1. Slight to significant changes in the ultra-structure of chloroplasts and the structure of thylakoids were observed respectively at 100 and 500 ppm aqueous sulphur dioxide (0.1 and 0.5 ppm gaseous sulphur dioxide equivalent) after 22 hours of exposure at 23°C under 64,000 lux illumination. Equivalent conditions for gaseous sulphur dioxide (assuming the above mentioned 1000:1 ratio) never occur in nature.

3. At 250 ppm and 500 ppm aqueous sulphur dioxide (0.25 and 0.5 ppm gaseous sulphur dioxide equivalent) exposure of 22 hours at 23°C, visible symptoms were induced *in vitro*. With the exception of changes in the levels of glycolipids, no significant changes in previsual symptoms occurred below the aqueous sulphur dioxide concentrations that induced visual symptoms. No information is available on whether the levels of glycolipids might not revert to normal levels after cessation of short term exposure to gaseous sulphur dioxide in foliage attached to trees.
4. Experimental conditions of sulphur dioxide exposure in the laboratory (0.25 and 0.5 ppm gaseous sulphur dioxide equivalent for 22 hours) that induced changes in ultrastructure and biochemistry and induced visible symptoms, were considerably above Alberta Ambient Air Quality Standards for this compound (0.06 ppm sulphur dioxide exposure for a 234 hour period). These results on visible symptoms are in line with Dreisigner's and GmGovern's

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[1]Dreisinger, B.R. and P.E. GmGovern. 1970. Monitoring atmospheric sulphur dioxide and correlating its effects on crops and forests in the Sudbury area. *In* "Proceedings Impact of Air Pollution on Vegetation; Specialty Conference", Toronto, Ontario Section, Air Pollution Control Association, Toronto.

(1970) observations of twenty years in the Sudbury area, where Pinus banksiana developed visible symptoms at a minimum of 0.22 ppm after an 8 hour exposure (observed) and 0.20 ppm after a 24 hour exposure (curved value), Malhotra's results also agree with field observations by Loman (letter dated 17 January, 1978 from G. Loman, Loman and Associates, Calgary, Alberta) that no symptoms were ever found on forest vegetation in the immediate vicinity of continuous air quality monitoring trailers which recorded Alberta Ambient Air Quality Standard violations. Loman's conclusion was that visible symptoms are induced by ambient sulphur dioxide levels considerably in excess of AAAQS standards.

ADDISON, P.A. and J. Baker. Ecological Benchmarking and Biomonitoring for Detection of Sulphur Dioxide Effects on Vegetation and Soils. Project VE 3.4.

The results of this excellent field-oriented subproject will hopefully result in a useful contribution to impact assessments in the oil sands area. Results of chemical analyses of soils and foliage and of lichen studies conducted eight years after the first oil sands processing plant went on stream, confirm the results of impact assessment work conducted in the GCOS area.

MacLEAN, A.H. Studies of Physical Properties of Soils and Mined Materials in Relation to Reclamation. Project VE 4.1.

It is recommended that this study be continued in close cooperation with projects VE 5.2, 6.1, 7.1, 7.2, 7.3. The primary objective would then be to determine the physical properties of tailing sands which have already been successfully planted or seeded with native forest species.

TURCHENEK, L.L., and W.B. McGill. Studies of Chemical Properties of Soils and Methods of Improving Mined Materials for Plant Growth. Project VE 4.1.

It is recommended that chemical analyses be conducted on soils supporting successful regeneration, and on undisturbed sandy soils with healthy vegetative growth. Close cooperation with project VE 5.2 and subprojects VE 7.1, 7.2, 7.3 is recommended to ensure that research efforts focus on successful combinations of tailings sands and peat that support desirable regeneration.

TAKYI, S.K., and M. Nyborg. Sulphur Deposition and Acidification of Soils in the Oil Sands Area. VE 4.2.

The results of acidification on homogenized agricultural soils in plastic cannisters should not be considered as directly applicable to soils in the AOSERP study area. Imported homogenized agricultural soils do not have a network of roots capable of absorbing aqueous solutions of nutrients, including sulphate ions and nitrate ions as sources of sulphur and nitrogen for growing vegetation in the soils. Neither does a plastic cannister allow for the leaching of excess sulphate out of the rooting zone of the soil. Therefore, sulphur levels and pH in the experimental cannisters are not comparable to sulphur levels and pH values in undisturbed soils.

LINDSAY, J.D. Characterization and Utilization of Peat in the Oil Sands Area. Project VE 5.2.

The objectives of this project are well conceived, and valuable results can be expected. It is recommended that ongoing research be coordinated with subprojects VE 7.1, 7.2 and 7.3 to test growth of selected species on peat at various stages of its changes in characteristics during handling and storage.

BLISS, L.C. Long Term Prediction of Vegetation Performance for Dike Management. Project VE 6.1.

It is recommended that the emphasis of research in this project be changes from detailed studies of a mature forest to detailed studies of the microenvironment of successful regeneration on sandy soils and tailings sands.

SELNER, J. and R. Thompson. Reclamation for Afforestation by Suitable Native and Introduced Tree and Shrub Species. Project VE 7.1.

This practical project has yielded valuable information. It is recommended that future work be coordinated with projects VE 7.2 and 7.3 to avoid duplication of species testing. Practical experience gained by personnel of the Alberta Forest Service in afforestation of the reclamation areas in the oil sands area must be considered to have top priority. Coordination with project 5.2 is also recommended.

Appendix 5.4 Rankings of Individual Factors in the Toxicological Indices of Inorganics

5.4.1 Rankings for mammals (including humans)

5.4.2 Rankings for aquatic organisms

Appendix 5.4.1. Rankings of individual factors[a] in the Toxicological Indices of inorganics for mammals (including humans).

Constituent	Inherent Toxicity	Direct Availa-bility	Indirect Availa-bility	Carcinogenicity/ Teratogenicity	Total
Aluminum	1	1	1	4[b]; 2[c]	7
Antimony	2-3	1-2	1	0 ; 0	4-6
Arsenic	3-4	3-4	4	2 ; 4	14-16
Barium	2	2-3	U	0 ; 0	4-5
Beryllium	3	4	4	4 ; 2	15
Bismuth	2-3	1-2	1	0 ; 0	4-6
Boron	1-2	3-4	1	0 ; 0	6-7
Cadmium	3	2-3	4	4 ; 4	13-14
Calcium	1	2-3	1	0 ; 0	4-5
Cesium	U	3	U	0 ; 0	3[e]
Chromium	1-2	1-2	1	4 ; 0	7-9
Cobalt	2-3	2-3[d]	1	4 ; 0	9-11
Copper	2-3	2-3	4	4 ; 0	12-14
Gallium	1	1	U	2 ; 0	4[e]
Germanium	1	1	U	0 ; 0	2[e]
Gold	1	1	1-2	0 ; 0	3-4
Hafnium	1-2	1-2	1	0 ; 0	3-5
Indium	1	1	U	0 ; 4	6[e]
Iodine	1-2	1-2	1	0 ; 0	3-5
Iridium	1	1	U	0 ; 0	2[e]
Iron	1	4	3	4 ; 0	12
Lead	2	1-2	3-4	4 ; 4	10-12
Lithium	2	4	1	0 ; 4	11
Magnesium	1	2-3	1[d]	0 ; 0	4-5
Manganese	1	1	1	2 ; 0	5
Mercury	3	3	3	0 ; 4	13
Molybdenum	2	2-3	1	0 ; 4	9-10

continued . . .

Appendix 5.4.1. Continued.

Constituent	Inherent Toxicity	Direct Availa- bility	Indirect Availa- bility	Carcinogenicity/ Teratogenicity	Total
Nickel	2-3	1-2	2-3	4 ; 0	9-12
Niobium	1	1	1	0 ; 0	3
Osmium	1	1	U	0 ; 0	2[e]
Palladium	1	1	U	2 ; 0	4[e]
Platinum	1	1	U	0 ; 0	2[e]
Potassium	1[d]	2-3	1	0 ; 0	4-5
Rhenium	1-2	2	1	0 ; 0	4-5
Rhodium	1	1-2	1	2 ; 0	5-6
Rubidium	1-2	3	U	0 ; 0	4-5
Scandium	1	2	U	2 ; 0	5[e]
Selenium	2-3	2-3	1	4 ; 4	9-11
Silicon	1	1	1	2 ; 0	5
Silver	3	1-2	3	4 ; 0	11-12
Sodium	1[d]	2-3	1	0 ; 0	4-5
Strontium	1	2-3	1	0 ; 0	4-5[e]
Sulphur	2	3	4	0 ; 0	9
Tantalum	1	1	1	0 ; 0	3
Tellurium	1-2	1-2	1-2	0 ; 4	7-10
Thallium	3	4	4	0 ; 4	15
Tin	1-2	1	3	4 ; 0	9-10
Titanium	2[d]	1	3-4	2 ; 0	8-9
Tungsten	1	1	1	0 ; 0	3
Vanadium	2-3	2-3	2	0 ; 0	6-8
Yttrium	1-2	2-3	U	2 ; 0	5-7[e]
Zinc	1-2	2-3	1	4 ; 4	8-10
Zirconium	1	1-2	1	4 ; 0	7-8

continued . . .

Appendix 5.4.1. Concluded.

[a]Rankings:

	Inherent Toxicity	Direct Availability	Indirect Availability	Carcinogenicity/ Teratogenicity
4	high	high	high	known
3	moderate	moderate	moderate	
2	slight	slight	possible	suspected
1	practically non-toxic	low	none reported	
0				none reported

[b]Carcinogenicity ranking

[c]Teratogenicity ranking

[d]Indicates an estimate was made

[e]Indicates at least one of the individual factors was unknown or estimated

Symbol: U = ranking unknown

Appendix 5.4.2 Rankings of individual factors[a] in the Toxicological Indices of inorganic elements for aquatic organisms.

Constituent	Inherent Toxicity	Direct Availa-bility	Indirect Availa-bility	Carcinogenicity/ Teratogenicity	Total
Aluminum	3	1-2	2-3	4[b];2[c]	10-12
Antimony	2-3	2[d]	2[d]	0 ; 0	6-7[e]
Arsenic	3	2-3	4	2 ; 4	13-14
Barium	1-2	2	4	0 ; 0	7-8
Beryllium	2	1-2	4	4 ; 2	11-12
Bismuth	U	1	U	0 ; 0	U
Boron	1	3-4	1	0 ; 0	5-6
Bromine gas	1-2	3[d]	U	0 ; 0	4-5[e]
Cadmium	4	3-4	4	4 ; 4	15-16
Calcium	1-2	3-4	1	0 ; 0	5-7
Cesium	1	3-4	1	0 ; 0	5-6
Chloride	1	3	1	0 ; 0	5
Chlorine gas	4	1	4	0 ; 0	9
Chromium	2-4	2	4	4 ; 0	12-14
Cobalt	2	2-3[d]	4	4 ; 0	12-13[e]
Copper	3	2-3	4	4 ; 0	13-14
Fluorine gas	2-3	2[d]	1-2[d]	0 ; 0	5-7[e]
Gallium	U	U	U	2 ; 0	U
Germanium	U	U	U	0 ; 0	U
Gold	4	1	U	0 ; 0	5[e]
Hafnium	U	U	U	0 ; 0	U
Indium	U	U	U	0 ; 4	U
Iodine	U	U	U	0 ; 0	U
Iridium	U	1-2	U	0 ; 0	U
Iron	1-3	1	3	4 ; 0	9-11
Lead	2-3	1	2[e]	4 ; 4	9-10[e]

continued . . .

Appendix 5.4.2 Continued.

Constituent	Inherent Toxicity	Direct Availa-bility	Indirect Availa-bility	Carcinogenicity/ Teratogenicity	Total
Lithium	1-2	3	U	0 ; 4	8-9[e]
Magnesium	1	3-4	1	0 ; 0	4-6
Manganese	2	2	2	2 ; 0	8
Mercury	4	2-3	4	0 ; 4	14-15
Molybdenum	1	U	2	0 ; 4	7[e]
Nickel	2-3	3	U	4 ; 0	9-10[e]
Niobium	U	U	U	0 ; 0	U
Osmium	U	1-2	U	0 ; 0	U
Palladium	U	U	U	2 ; 0	U
Platinum	2-3	1	U	0 ; 0	3-4[e]
Potassium	1-2	3-4	1	0 ; 0	5-7
Rhenium	U	U	U	0 ; 0	U
Rhodium	U	U	U	2 ; 0	U
Rubidium	1	3-4	U	0 ; 0	4-5[e]
Scandium	U	U	U	2 ; 0	U
Selenium	2	2-3	2	4 ; 4	10-11
Silicon	1	1-2[d]	1	2 ; 0	5-6[e]
Silver	4	2	U	4 ; 0	10[e]
Sodium	1-2	3-4	1	0 ; 0	5-7
Strontium	U	U	U	0 ; 0	U
Sulphur	2	3	4	0 ; 0	9
Tantalum	U	U	U	0 ; 0	U
Tellurium	U	U	U	0 ; 4	U
Thallium	2-3	3-4	2	0 ; 4	11-13[e]
Tin	2	2	U	4 ; 0	8[e]
Titanium	2	2-3	2[d]	2 ; 0	8-9[e]
Tungsten	1	2-3	U	0 ; 0	3-4[e]

continued . . .

Appendix 5.4.2 Concluded

Constituent	Inherent Toxicity	Direct Availa-bility	Indirect Availa-bility	Carcinogenicity/ Teratogenicity	Total
Vanadium	2-3	3	U	2 ; 0	5-6
Yttrium	U	U	U	2 ; 0	U
Zinc	2-3	2-3	4	4 ; 4	12-14
Zirconium	1-2	2	U	4 ; 0	7-8[e]

[a]Rankings:

	Inherent Toxicity	Direct Availability	Indirect Availability	Carcinogenicity/ Teratogenicity
4	high	high	high	known
3	moderate	moderate	moderate	
2	slight	low	possible	suspected
1	practically non-toxic	practically non-available	none reported	
0				none reported

[b]Carcinogenicity ranking

[c]Teratogenicity ranking

[d]Indicates an estimate was made

[e]Indicates at least one of the individual factors was unknown or estimated

Symbol: U = ranking unknown

Appendix 5.5 Participants in AOSERP Toxicology User Survey

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Appendix 5.6 'Detail Sheets' of proposed projects for for AOSERP toxicological research program design.

<u>Legend</u>

[a]Budget of project

small - annual budget less than $ 40,000
medium - annual budget of $ 40,000 to $ 100,000
large - annual budget of greater than $ 100,000

[b]Duration of initial research project

short - less than 18 months
moderate - 18 to 36 months
long - longer than 36 months

[c]Starting date of project

immediate - required for first phase of program
early - could be delayed for up to one year
later - could be delayed for greater than one year or requires prerequisite date from other studies before beginning

PROPOSED PROJECT DETAILS FOR AOSERP
TOXICOLOGICAL RESEARCH PROGRAM DESIGN

SYSTEM: Land, Water, Air BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 1
TITLE: Design and Implementation of Data Storage and Retrieval Systems

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OBJECTIVES:

1. To design and implement data storage and retrieval systems for each of the three research systems within AOSERP.

2. To review similar data storage systems in use elsewhere e.g., by Alberta Environment, Ontario Ministry of the Environment, Fisheries and Environment Canada and the U.S. Environmental Protection Agency; and those offered "off the shelf" by computer supply and service companies.

RESEARCH OUTLINE:

1. Needs within each system should be determined through discussion with the system manager, government employees, universities and consultants.

2. Costs for alternative systems should be compared in detail for both capital investment and annual operating costs.

3. Upon approval from AOSERP the selected system should be installed and implemented using all currently available data from each of air, water, and land systems.

TO BE UNDERTAKEN BY:

Consultants

SYSTEM: Land, Water, Air BUDGET: Medium (All projects)

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Immediate DURATION: Moderate

PROJECT NUMBER: 2
TITLE: Analysis of Organic Compounds in Air, Water, Sediment/Soil and Biota.

OBJECTIVE:

1. To develop, test, and evaluate techniques for the study (including monitoring) of the organic constituents in air, emissions, wastewaters, sediment/soil and biota.

RESEARCH OUTLINE:

1. Only four subprojects have been recommended initially.

2. The basic outline of an analytical program for organic substances is presented prior to the details of each project.

Initially, an analytical program should be devised which can be implemented quickly and which will almost immediately permit the monitoring of water, sediment/soil, and air for their organic components e.g., organic acids, phenols, organic bases, neutral organic compounds and water-soluble, non-extractable organic compounds.

The optimum method of extracting organic compounds from water, sediment/soil and air samples should be determined. For water and sediments, either a solvent extraction or absorption procedure could be used. If the former was chosen, the best solvent would have to be determined while if the latter procedure was used the best absorbent would have to be determined. For air samples it would be necessary to find the best absorbent. After extraction and separation, gas chromatography (GC) would be used to record each isolated group of organic compounds after suitable chemical derivatization. The comparison of GC traces with previous ones would indicate the presence of new compounds in the extracts and thus monitoring for change will be possible.

During the examination of a water or sediment sample, it should also be possible to toxicologically evaluate the organic constituents in samples. During such an evaluation emphasis should be placed on:

a) Short term toxicity testing of the various fractions prior to further separation. Unless another fraction is significantly more toxic the fraction containing neutral materials should be systematically investigated first. This fraction containing aldehydes, ketones, nitrites, amides, alcohols, quinones, aliphatic and aromatic hydrocarbons may be important since potential carcinogenic compounds such as polyaromatic hydrocarbons would be found here.

b) Identification of the organic components:
   i) in the fractions which are most toxic as shown in a) above
   ii) in the fraction containing neutral organic compounds since carcinogenic compounds, if present, would probably be found in this fraction (e.g. polyaromatic hydrocarbons)
   iii) other fractions

In the longer term (Year 5-8 of AOSERP), the isolation, separation, identification and quantitative analysis of the major individual organic constituents in water, sediment and air samples may be required. Until a toxic organic fraction is identified, the identification and quantification of organic compounds should be given a relatively low priority.

During 1978/79, three subprojects are recommended. These are described on the detail sheets which follow.

TO BE UNDERTAKEN BY:

Universities under direction of a coordinator

SYSTEM: Air/Water BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 2.1
TITLE: Literature Review of Methods Used to Extract Organic Compounds from Various Samples

OBJECTIVES:
1. To determine, if possible, the methods which are considered best for the extraction of organic compounds from various water, air and sediment samples.

2. To gather data on the efficiencies of extraction methods.

3. To determine the strengths, and limitations of the possible extraction methods.

This project should be coordinated with other sub-projects in 2 as well as project 14.

TO BE UNDERTAKEN BY:

University and research institutions

SYSTEM: Water BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 2.2
TITLE: A Comparative Study of the Methods of Extracting Organic Compounds from Water.

OBJECTIVES:

1. To determine the extraction method which gives the best yields of organic materials present in a water sample.

2. To determine whether a solvent extraction method (which is tedious and may not be complete) is necessary or whether the use of the non-ionic adsorbents and/or anionic or cationic exchange resins would be more appropriate.

3. To determine what, if any, water-soluble organic compounds (e.g., amino acids, simple organic acids) are not extracted by either method 1 or 2 above.

RESEARCH OUTLINE:

1. A solution containing known environmental chemicals in quantities approximating to what is found in nature (e.g., 1 part in 100 million parts = 10 μg/litre) should be made. Typical components might be: phenol, propionic acid, glutamic acid, an aromatic hydrocarbon (e.g., benzo(a)pyrene), an aliphatic hydrocarbon (e.g., octadecane), a basic material (e.g., phenethylamine) and an insecticide. The quantities of each compound added will be accurately known.

2. One litre quantities of the solution will be extracted by the following methods:
    a) solvent extraction - benzene, ethyl acetate, methylene chloride will each be separately used.

b) an ionic exchange resin (to remove acids) followed by a cationic exchange resin (to remove bases) followed by a neutral resin (to remove other organic compounds except very water-soluble compounds). Elution of the columns with suitable solvents will recover the acidic, basic, and neutral components. Evaporation of the final aqueous solution will yield the non-extractable organic compounds

c) purified activated charcoal

3. The organic compounds extracted by methods a), b) and c) will be separated into major chemical groups using the method outlined in the attached figure. Each separated compound will be quantitatively analyzed by gas chromatography and mass spectrometry. The amounts of the compounds remaining in the aqueous portion will also be determined by lyophilization followed by derivatization and combined gas chromatography/mass spectrometry.

Coordination is recommended with projects 2.1 and 2.3.

TO BE UNDERTAKEN BY:

University

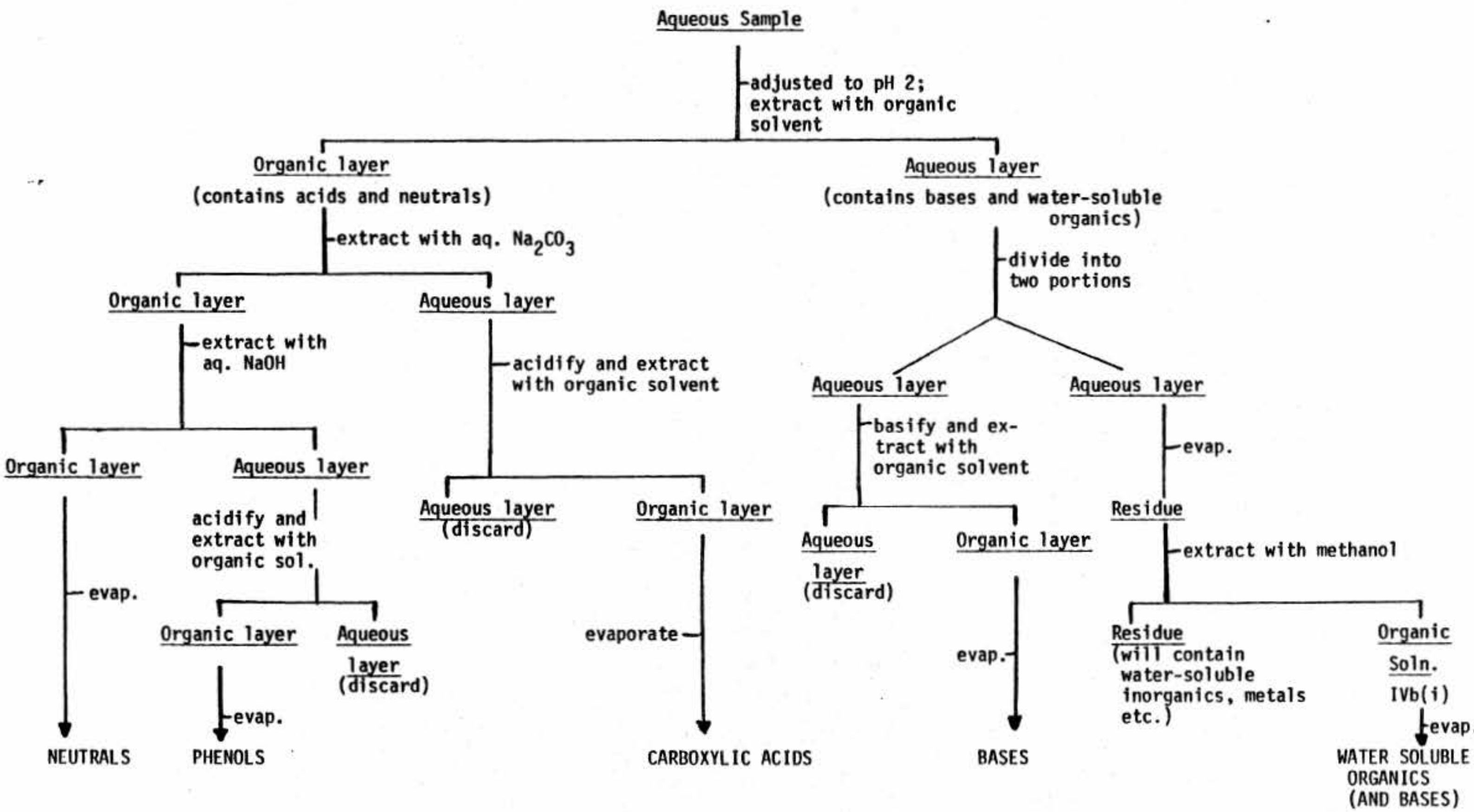

Figure 4. Separation Scheme for Organic Constituents.

SYSTEM: Water BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 2.3
TITLE: Monitoring of Organic Compounds in Water Samples and Sediments - Selection of Methods

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OBJECTIVES:

1. To devise a method, capable of rapid implementation, of monitoring samples for organic components.

   A suitable method could be one utilizing chromatographic (GC) traces of:
   a) weak acid components e.g., phenols,
   b) strong acid components,
   c) basic components,
   d) neutral components, and
   e) water-soluble, non-extractable components

   all suitably derivatized. These traces could be obtained on a regular basis and compared regularly to determine what changes are occurring in the components (concentration and number of components). Such a system can be quickly established, but the <u>identities</u> of even the major components will take time and will require an efficient GC/mass spectrometer/data system and expertise in this technique. Identification of components, if required, should be a separate project.

RESEARCH OUTLINE:

A solvent extraction technique, using benzene as solvent, will be used initially. (This methodology may be replaced later if an alternative extraction technique (e.g., XAD-2 resin, activated charcoal etc.) is found to be superior in project 2.1 or 2.2). The components in the extract (a - e above) will be isolated using the procedure outlined in the project 2.2. Each fraction, a - e, will be examined by

SYSTEM: Land BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 4
TITLE: Biophysical Land Classification of Forest Land in the AOSERP Area.

OBJECTIVES:
1. To prepare maps delineating major land forms, and physiognomically distinct vegetation types as identified by Dr. P.W. Stringer (VE 2.2).

2. To prepare a preliminary map from existing photographs and the most recent forest cover maps.

RESEARCH OUTLINE:
1. Existing black and white panchromatic photographs (1:25,000) should be utilized.

2. Ground surveys should be conducted during the summer of 1978 to verify air photo mapping.

3. Provide a report that can be used by research workers in the field.

4. Coordination of this project with project 15 is recommended to ensure the proper site selection. The results of this study should also be used in the planning of studies for the biomonitoring of vegetation (22) and wildlife (25).

TO BE UNDERTAKEN BY:

To be defined

SYSTEM: Land BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 5
TITLE: Detailed Mapping of Forest Communities in the AOSERP Area.

OBJECTIVES:

1. To intensively map representative vegetation types (as recognized in VE 2.2) in conjunction with surficial geological features and soil types (as defined in VE 2.1). Information should also be included on basic hydrology and topography.

RESEARCH OUTLINE:

1. Ektachrome and Infrared color photography (1:7,000-12,000), flown in June or July 1978, will be required.

2. Preliminary maps should be verified by ground surveys.

3. The results of this project should be used in the planning of vegetation (22) and wildlife (25) biomonitoring programs.

TO BE UNDERTAKEN BY:

To be defined

SYSTEM: Land BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 6 (VE 2.1)
TITLE: Soils Inventory of the Oil Sands Area (VE 2.1) - preliminary mapping

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OBJECTIVES:

1. To provide a preliminary land systems map of the Athabasca Oil Sands Area that will give data on soils and land forms.

RESEARCH OUTLINE:

1. It is strongly recommended the primary investigator of VE 2.1 (Mr. J. Lindsay) be asked to prepare an interim report (including map) describing and defining representative soil types.

2. Data from this project should be used in the planning and interpretation of projects 7, 9, 21, 22, 23, 24, and 25.

SYSTEM: Land BUDGET: Medium

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 7
TITLE: Physical and Chemical Analysis of Soil Types in the Oil Sands Area.

OBJECTIVES:
1. To determine the physical and chemical characteristics of each of the soil types classified in VE 2.1.

RESEARCH OUTLINE:
1. To immediately acquire descriptions of all soil types completed to date in VE 2.1.

2. Samples of each major soil type should be collected in 1978.

3. The physical characteristics of each representative soil type should be determined.

4. The major elements that determine the nutrient status of each soil type should be investigated and the major heavy metals in each soil type identified and if possible their availability determined. Trace elements of interest could be defined from the results of projects 13.1, 13.3, and 13.4.

5. Coordination with other projects involving the chemical analysis (including heavy metals) of soil types will be necessary to ensure standardized procedures and the use of the same analytical data.

TO BE UNDERTAKEN BY:

To be defined

SYSTEM: Land BUDGET: Medium

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 8
TITLE: Physical and Chemical Properties of Tailings Sands

OBJECTIVES:

1. To determine the physical and chemical properties of tailings sands.

2. To identify and quantify any contaminants which may be present.

3. To assess the significance of these contaminants to the development of vegetation and soil.

RESEARCH OUTLINE:

1. Research design - to be defined.

2. This project should include studies of the microflora in tailings sand.

3. Coordination is recommended with project 6 and 7 as well as reclamation studies.

TO BE UNDERTAKEN BY:

To be defined

SYSTEM: Land BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 9
TITLE: Preliminary Survey of Forest Soils Microflora in Oil Sands Area

OBJECTIVES:

1. To identify the major genera and species of soils bacteria and fungi that inhabit each of the soil types classified in VE 2.1.

2. To determine the biological activity, function and optimum environmental conditions for growth and reproduction of the most common genera and species.

3. To design a sampling and analytical program to meet the two objectives listed above.

COORDINATION:

1. Information from projects 6 and 7 should be useful in planning this project.

2. Data from this study will be used to plan studies in projects 23 and 24 and may be useful in interpreting the results of studies in project 21, 22, 23, and 24.

TO BE UNDERTAKEN BY:

To be defined

SYSTEM: Land BUDGET: Small

ACTIVITY: Acquisition of Baseline Data

STARTING DATE: Immediate DURATION: Long

PROJECT NUMBER: 10
TITLE: Coordination of Vegetation and Soils Projects

OBJECTIVES:
1. To ensure that all vegetation and soils projects utilize standardized techniques (when feasible) for the sampling, storing and chemical analysis of vegetation, soils, and microflora.

2. To ensure that procedures are standardized between laboratory and field oriented work in vegetation, soils, and soil microflora.

3. To ensure that the results of one project, for example VE 2.1 or VE 2.2, be transmitted to and used by all related projects so that cooperated planning is facilitated and duplication of effort is minimized.

RESEARCH OUTLINE:
1. It is recommended that a person with no active research interest be appointed as coordinator.

SYSTEM: Land, Water, Air BUDGET: Small

ACTIVITY: Inventory of Effluents and Emissions; Identification of Target Systems

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 11
TITLE: In situ Oil Sands Development: Technology and Potential Effects on the Environment

OBJECTIVES:

1. From existing information determine the potential effects of in situ oil sands development on the environment.

2. To describe the process technology of in situ methods and their implications for air and water quality.

RESEARCH OUTLINE:

1. The design of the project should be developed through discussions with government, industry, universities and consultants.

2. Emphasis should be placed on comparison of in situ development with conventional technology in relation to effluents and emissions, water needs, and toxicological concerns.

3. Data collected in project 13 should be useful to this project.

TO BE UNDERTAKEN BY:

Consultants

SYSTEM: Water BUDGET: Medium

ACTIVITY: Inventory of Effluents and Emissions; Identification of Target Systems

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 12
TITLE: Inventory of Effluent and Wastewaters

OBJECTIVES:
1. To review existing government, industry, and AOSERP information in order to:
    a) identify contaminants discharged to aquatic systems via effluents
    b) determine the loadings (concentration and quantity) of individual contaminants
    c) determine the background loadings (concentration and quantity) of contaminants in natural water courses receiving effluent discharges
    d) determine the background loadings (concentration and quantity) of contaminants entering and leaving the AOSERP study area
    e) determine (estimate) the composition and quantity of groundwater on specific leases in relation to the potential availability of such water for discharge to surface water.

RESEARCH OUTLINE:
1. Close cooperation with industry will be essential during this project in order that all available information can be gathered.

2. A computerized data storage and retrieval system should be established to store and summarize the data collected. The system should be capable of handling additional data as other projects (industry, government and AOSERP) are completed, e.g., proposed projects 2.3, 13.3, and 13.5. The

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system should be able to summarize information on both organic and inorganic constituents of effluents.

3. The progress and results of this project should be of interest to researchers planning and evaluating projects 1, 3, 11, 19, and 20.

TO BE UNDERTAKEN BY:

Consultant. In addition, joint industry/AOSERP funding is recommended.

SYSTEM: Air, Water BUDGET: Large (All projects)

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Immediate DURATION: Moderate (All projects)

PROJECT NUMBER: 13
TITLE: Trace Elements: Balance Around an Oil Sands Plant

OBJECTIVES:

1. To identify and quantify the rate at which trace elements enter a plant. To relate this inlet rate to a production rate and bitumen recovery efficiency.

2. To quantify the distribution of selected trace elements, following input to the plant, to various process streams.

3. To quantify the rate at which selected trace elements leave a processing plant in the major output process streams.

RESEARCH OUTLINE:

1. This project is divided into five major subprojects which are described on subsequent pages. To gather suitable information on conditions prior to the "start up" of Syncrude, GCOS should be examined prior to the installation of the new particulate control devices.

2. Each subproject should describe the process examined, evaluate alternative sampling and analytical methods and use the recommended and/or approved procedures. The investigators should carry out inter-laboratory analytical checks, report on the accuracy of results and make recommendations.

3. This project should provide important information for the planning and interpretation of many baseline and toxicology projects including projects 1, 3, 7, 8, 11, 15, 16, 17, 18, 21.2, 21.3, 21.5, 22, 23, 24 and future studies in projects 19, 20, and 25. The data from this project should also be incorporated into projects 11 and 12.

TO BE UNDERTAKEN BY:

Consultants, universities, government, and industry under direction and coordination of an overall project manager. In addition, joint funding by AOSERP and industry is also recommended.

SYSTEM: Air, Water BUDGET: Medium

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 13.1
TITLE: Trace Elements Entering an Oil Sands Plant.

OBJECTIVES:

1. To identify and quantify the trace elements in the raw oil sands and supply water or produced water (in situ process) entering both surface mine-based in situ plants.

2. To relate this inlet to the overall production rate and bitumen recovery efficiency.

3. To determine the variation of trace element concentrations in the Athabasca oil sands deposit with emphasis on areas of the deposit which have high potential for recovery over the next 20 years.

RESEARCH OUTLINE:

1. Evaluate alternative methods for sampling and analyzing raw oil sands with consideration for surface mined, in situ produced or in-place oil sands.

2. Carry out a sampling and analysis program to meet the three objectives.

3. Provide a report which gives the methods and results, sources of error and inlet rates for both surface and in situ mining schemes related to production rates and efficiency.

TO BE UNDERTAKEN BY:

Consultants, universities, government, and industry under direction and coordination of an overall project manager. In addition, joint funding by AOSERP and industry is also recommended.

SYSTEM: Air, Water BUDGET: Small

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Later DURATION: Short

PROJECT NUMBER: 13.2
TITLE: Trace Metals - Balance Around the Extraction Process in an Oil Sands Plant

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OBJECTIVES:

1. To carry out a trace element balance around the extraction process. The trace elements of interest will be defined following subproject 13.1.

2. To determine the trace element concentrations in the raw oil sands and water (fresh and recycled) fed to the extraction process.

3. To determine the trace element concentrations contained in the bitumen, sand, silt, and clay fractions and the primary and secondary tailing streams.

4. To relate the data obtained to production rate and efficiency of bitumen recovery for the extraction process.

RESEARCH OUTLINE:

1. Evaluate alternative methods for sampling and analyzing extracted bitumen and final tailings.

2. Carry out a sampling and analysis program to meet the objectives given above.

3. Provide a report giving the methods used, results, sources of errors and the balance related to bitumen recovery efficiency and production rate.

TO BE UNDERTAKEN BY:

Consultants, universities, government, and industry under direction and coordination of an overall project manager. In addition, joint funding by AOSERP and industry is also recommended.

SYSTEM: Air, Water BUDGET: Medium

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Later DURATION: Short

PROJECT NUMBER: 13.3
TITLE: Trace Elements - Balance Around the Upgrading Process in an Oil Sands Plant

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OBJECTIVES:

1. To carry out a trace element balance around the upgrading process. Trace elements of interest will be defined following subproject 13.2.

2. To determine the trace element concentrations in the bitumen feedstock; and the products: coke, sulphur, synthetic crude, internal fuels and naptha; and the major process wastewaters and emissions.

3. To relate the data obtained to the production rate and efficiency of bitumen conversion to synthetic crude.

RESEARCH OUTLINE:

1. Evaluate alternative methods for sampling and analyzing the identified process streams.

2. Carry out a testing program to meet the above objectives.

3. From a knowledge of the operation of each process unit examined, provide an estimate of the trace element balance for other oil sands plants (i.e., those not tested).

4. Provide a report giving the methods used, results, sources of error, estimates for the other plants, and the balance related to production rates and conversion efficiency.

TO BE UNDERTAKEN BY:

Consultants, universities, government, and industry under direction and coordination of an overall project manager. In addition, joint funding by AOSERP and industry is also recommended.

SYSTEM: Air, Water BUDGET: Medium

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Later DURATION: Short

PROJECT NUMBER: 13.4
TITLE: Trace Elements - Balance Around the Power Plant and Waste Treatment Plant in an Oil Sands Plant

OBJECTIVES:

1. To carry out a trace element balance around the power plant and water treatment plant complex. The elements of interest will be defined following subprojects 13.1 and 13.3.

2. To determine the trace element concentrations in the power plant fuel (coke and other), fly ash and stack emissions. Stack trace element emissions should be characterized so that vapours and particulate size fraction emissions can be identified.

3. To determine the trace element concentrations in the raw water, treated water, treatment plant sludges, and power plant blowdown water.

4. To relate the data obtained to steam and generation rates and water supply rates.

RESEARCH OUTLINE:

1. Evaluate alternative methods for sampling and analyzing the streams of interest.

2. Carry out a testing program to meet the above objectives.

3. Provide a report giving the methods used, results, and sources of error.

TO BE UNDERTAKEN BY:

Consultants, universities, government, and industry under direction and coordination of an overall project manager. In addition, joint funding by AOSERP and industry is also recommended.

SYSTEM: Air, Water BUDGET: Medium

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Later DURATION: Short

PROJECT NUMBER: 13.5
TITLE: Trace Elements - Balance Around the Tailings Pond of an Oil Sands Plant

OBJECTIVES:

1. To carry out a trace element balance around the tailings pond. The trace elements of interest will be defined following subproject 13.2.

2. To determine the concentration and accumulation of trace elements in the pond sediment, concentration in supernatant (both dissolved and total) and the concentration in the recycle stream. Analysis of pond sediments should be carried out at predetermined depth intervals down to the natural pond base.

3. To relate the data obtained to the tailings production and recycle rates and relate data on the accumulation of trace elements to years of operation and total tons of bitumen produced.

RESEARCH OUTLINE:

1. Evaluate alternative methods for sampling and analysis.

2. Carry out a testing program to meet the above objectives.

3. Provide a report giving the methods used, results, and sources of error.

TO BE UNDERTAKEN BY:

Consultants, universities, government, and industry under direction and coordination of an overall project manager. In addition, joint funding by AOSERP and industry is also recommended.

SYSTEM: Water BUDGET: Small

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 14
TITLE: Characterization of Organic Emissions and Effluents from an Oil Sands Plant.

OBJECTIVES:
1. To identify and quantify the rate at which organic compounds are emitted from the main stack and major effluents.

2. To identify the fraction of organics measured in emissions that are released in particulate and vaporous form.

RESEARCH OUTLINE:
1. Sampling design and analytical methods should be requested as part of a proposal.

2. The methods for sampling and analysis should be evaluated prior to carrying out the work.

3. Two separate sampling programs should be carried out; the first for method and source familiarization, the second for production of valid data.

4. Emphasis should be placed on screening for carcinogenic organics including polycyclics such as Benzo(a)pyrene.

5. Each oil sands plant should be investigated.

6. This project should be coordinated with subprojects 2.1 and 13.4. The data should be of interest to projects 19, 20, 21, 22, 23, 24, and 25.

TO BE UNDERTAKEN BY:

Consultants, research institutions and government agencies.

SYSTEM: Air BUDGET: Small

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 15
TITLE: Characterization of Particulate Matter Near Oil Sands Plants

OBJECTIVES:

1. To design, install and operate (initially for one year) a network to sample settleable and suspended particulate matter near the Syncrude and GCOS mine sites.

2. To collect and archive the samples pending the results of stack emission characterization (Project 13.3, 13.4).

RESEARCH OUTLINE:

1. The network should be designed taking into account fugitive and stack particulate emissions, meteorology and local topography. Sites in representative forest communities (as identified in projects 4 and 5) should also be included in the sampling design.

2. High-volume sampling should be carried out on a six day schedule.

3. Store the samples in such a way that chemical reactions or changes are minimized.

4. Provide all sampling records and notes to AOSERP.

5. Samples should be analyzed following interpretation of the results of Project 13.1, 13.3, and 13.4.

6. The network should be evaluated after one year of operation and redesigned or discontinued.

7. Information should be of interest to projects 19, 20, 21, 22, 23, 24, and 25.

TO BE UNDERTAKEN BY:

Government agencies and AOSERP field staff.

SYSTEM: Water BUDGET: Small

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 16
TITLE: Effects of Water Chemistry on the Dynamics of Known or Potential Aquatic Hazards

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OBJECTIVES:

1. To determine the rate of dissolution of selected trace elements under controlled conditions simulating the AOSERP aquatic environments.

2. To determine the effect of changes in water chemistry such as pH on the rate of dissolution of elements.

3. To determine, if necessary, the effects of specific effluent discharges on the release of elements established in objective 1 and 2.

RESEARCH OUTLINE:

1. The objectives and design of this project and its several anticipated subprojects should be reviewed and re-formulated following the interpretaton of data collected in project 2.3, 13.1, and 13.3.

2. The trace metals of interest will be defined by project 13 and the Toxicological Index.

3. Studies should be restricted to the chemistry of toxic forms of metals. This may require literature reviews on their chemistry and the development of selective analytical techniques.

4. Initially emphasis should be placed on chemical conditions simulating existing AOSERP water quality.

5. Studies of specific effluents such as GCOS and Syncrude mine water should be initiated after the completion of projects 12 and 13.

6. This project should be coordinated with projects 11, 17, 18, 19, 20.1 and 20.2. The data should be of use to projects 19 and 20.

TO BE UNDERTAKEN BY:

Government

SYSTEM: Water BUDGET: Small

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 17
TITLE: Investigations of the Chemistry and Dynamics of Groundwater in Small Drainages

OBJECTIVES:

1. To identify the constituents of groundwater and determine their loadings and distribution in small drainages receiving discharges of mine depressurization water e.g., Beaver Creek Diversion System.

2. To monitor selected inorganic components (both heavy metal and non-heavy metal) in order to determine the size and shape of the discharge plume during various seasons.

3. To provide information to water quality modelling studies.

4. To aid in interpretaton of the results from biomonitoring studies of saline discharges.

RESEARCH OUTLINE:

1. Study design - to be defined.

2. Coordination with project 2, 3, 12, 16, 19, and 20 is recommended. The data should be of use to projects 19 and 20.

TO BE UNDERTAKEN BY:

Consultant
Joint AOSERP/industry funding

SYSTEM: Water BUDGET: Small

ACTIVITY: Characterization of Effluents and Emissions

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 18
TITLE: Mixing Characteristics of the Athabasca River

OBJECTIVES:
1. To determine the seasonal mixing characteristics of the Athabasca River in the AOSERP area.

2. To determine the influence of the Athabasca River on the size and shape of the GCOS plume at different seasons of the year.

RESEARCH OUTLINE:
1. Study design - to be defined.

2. Coordination is recommended with project 2.3, 3, 16, and 20. Project 20 could use the preliminary results of this study to locate biomonitoring stations in the Athabasca River.

TO BE UNDERTAKEN BY:

Consultant

SYSTEM: Water | BUDGET: Medium (All projects)

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate | DURATION: Moderate

PROJECT NUMBER: 19
TITLE: Effects of Industrial Effluents on Aquatic Organisms

OBJECTIVES:

1. To determine the effects of whole effluents on selected aquatic species.

2. To determine the contaminant concentrations and loadings required to cause lethal and sublethal levels of damage to selected species.

3. To determine what toxicant concentrations and durations of exposure cause levels of damage which are irreversible.

4. To determine the MATC for each toxic whole effluent and/or individual toxicant.

RESEARCH OUTLINE:

1. Initially this project is divided into 2 major subprojects which are described on following pages.

2. Information from projects 2, 3, 11, 12, 13, and 14 may be useful in planning future projects.

3. Coordination is recommended with projects 16, 17, and 20. The data should be of interest to project 20.

TO BE UNDERTAKEN BY:

Universities, government, and consultants

SYSTEM: Water BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate DURATION: Moderate

PROJECT NUMBER: 19.1
TITLE: Long Term Effects of Groundwater to Fish and Invertebrates - Laboratory Studies

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OBJECTIVES:
1. To determine the relative sensitivities to, and the maximum acceptable toxicant concentration (MATC) of, saline groundwater discharges to selected fish and invertebrates.

2. To determine temporal variation in the toxicity of saline groundwater testing.

3. To determine the storage effects of samples collected for toxicity testing.

RESEARCH OUTLINE:
1. Short term experiments (10 to 30 days in length) should be undertaken:
   a) to determine the most sensitive species and life history stages of native fish and invertebrates
   b) to compare the relative sensitivity of selected native species with reference to species such as flag fish, *Daphnia magna* and *D. pulex*.
   c) to provide other information for the planning of long term studies.

2. On the basis of information collected from Objective 1, long term experiments (greater than 30 days) should be planned. Data to be determined include:
   a) Onset, duration and nature of any toxic signs
   b) Effects on fertility
   c) Effects on all stages of life cycle

MATC - See glossary (Appendix 5.2 for definition)

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d) Effects on growth and onset of maturity
e) Mutagenic or carcinogenic effects
f) Effects on food intake
g) Routine blood studies
h) Routine organ function tests
i) Complete autopsies of those organisms that die and those which survive. Attention could be given gills, liver, kidney, reproductive systems and other target organ systems as defined. Autopsies should include:
  i) Macroscopic examination of tissues
  ii) Microscopic examination of tissues
  iii) Organ weights
j) Information on the pharmacodynamics of the toxicant. Probably evidence of the absence or presence of accumulation would be sufficient.

3. The MATC should be defined by ensuring that both an "effect" and a "no effect" level are included in the studies.

4. The following species should be considered for native test organisms:

a) Fish
  - fathead minnow (also as reference species)
  - trout perch
  - lake whitefish
  - mountain whitefish
  - longnose sucker
  - white sucker
  - goldeye
  - walleye

b) - Invertebrates
  - cladocerans (particularly daphnids)
  - calanoid and cyclopoid copepods
  - larval <u>Chironomus</u>
  - <u>Gammarus</u> <u>lacustris</u>
  - <u>Hyalella</u> <u>azteca</u>
  - locally abundant dragonfly nymphs

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5. Coordination is recommended with projects 3, 16. 17, and 20.1.

TO BE UNDERTAKEN BY:

Universities and government under the direction of a coordinator

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SYSTEM: Water BUDGET: Small

ACTIVITY: Toxicology

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 19.2
TITLE: Guidelines for the Reporting of Fish Bioassay Results

OBJECTIVES:
1. On the basis of a literature review and personal interviews, prepare standardized guidelines for the reporting of fish bioassay results.

RESEARCH OUTLINE:
1. Guidelines will facilitate the comparison of toxicity results between different projects and subprojects and aid in the interpretation of bioassay results.

2. The following factors should be considered.
   a) definition of recommended terminology
   b) listing of routine analytical water quality parameters
   c) standardized reporting of biological factors
      - species, genetics
      - size of fish: range and mean of length, weight
      - conditioning factor
      - loading density
   d) standard features for description of experimental design and apparatus
      - size
      - volume of effluent (% replaced)
      - dosing apparatus
      - light conditions
      - feeding schedules
      - replications
      - controls
      - storage time and conditions of effluent storage

e) Standardization of statistical protocols
- confidence limits
- LC50 calculation at specified intervals 24, 48, 96, hours, etc. to allow comparison between experiments of varying lengths
- a reference method of LC50 calculation to be common in all experiments; however more than one method could be used.

f) methods to evaluate the incidence and severity of pathology. Standard histopathological screening methods should be considered.

TO BE UNDERTAKEN BY:

To be defined.

SYSTEM: Water BUDGET: Medium (All projects)

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate DURATION: Long

PROJECT NUMBER: 20
TITLE: Biomonitoring of the Effects of Industrial Effluents on Aquatic Organisms

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OBJECTIVES:
1. To determine the effect of industrial wastewater discharges on fish, benthic macroinvertebrates, algae and bacteria in receiving waters.

2. To determine the magnitude and spatial extent of the influence of individual discharges during different seasons of the year.

RESEARCH OUTLINE:

1. This project is divided into two subprojects which are described on the following pages.

TO BE UNDERTAKEN BY:

Consultant

SYSTEM: Water BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate DURATION: Long

PROJECT NUMBER: 20.1
TITLE: Biomonitoring of Syncrude Mine Depressurization Water Discharge

OBJECTIVES:

1. To determine the effects of Syncrude water discharge on the fish, benthic macroinvertebrates, algae and bacteria in the Beaver Creek Diversion System.

2. From a preliminary study, select the best techniques and indicator organism(s) for specific monitoring objectives.

RESEARCH OUTLINE:

1. Factors for consideration should include: species distribution, biomass, abundance and richness (number of taxa); community composition and diversity (information theory); and the seasonal dynamics of species and communities.

2. Stations will be established to provide adequate controls.

3. Both bottom sampling and appropriate artificial substrates should be used in the program.

4. Coordination with project 17 is recommended.

5. The project could be expanded to include mine depressurization discharges from other plants as they become operational.

TO BE UNDERTAKEN BY:

Consultant

SYSTEM: Water BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate DURATION: Long

PROJECT NUMBER: 20.2
TITLE: Biomonitoring of GCOS Process Effluent

OBJECTIVES:
1. To determine the effects of the GCOS process effluent on the fish, benthic macroinvertebrates, algae and bacteria in the Athabasca River.

2. From a preliminary study, select the best techniques and indicator organism(s) for specific monitoring objectives.

RESEARCH OUTLINE:
1. Factors for consideration will include: species distribution, biomass, abundance and richness (number of taxa); community composition and diversity (information theory); and the seasonal dynamics of species and communities.

2. Stations will be established to provide adequate controls.

3. Both bottom sampling and appropriate artificial substrates should be used in the program.

4. Coordination with project 18 is recommended.

TO BE UNDERTAKEN BY:

Consultant

SYSTEM: Water

BUDGET: Small (All subprojects)

ACTIVITY: Assessment of Toxicity

STARTING DATE: Later

DURATION: Short

PROJECT NUMBER: 20.3

TITLE: Rapid Monitoring Techniques - Preliminary Evaluation

OBJECTIVES:

1. To develop a rapid, cost-effective toxicity test (lethal or sublethal) suitable for the routine monitoring of waste streams, whole effluents, or mine drainage waters.

2. To integrate such a bioassay into an in situ monitoring system as an automated procedure.

3. To utilize the test as an early warning device which will provide information as to the need for further toxicological studies.

RESEARCH OUTLINE (GUIDELINES):

1. This project is divided into two subprojects which are described on the following pages.

2. It is recommended that both subproject be carried out by the same researcher or group.

TO BE UNDERTAKEN BY:

Consultant

SYSTEM: Water BUDGET: Small

ACTIVITY: Assessment of Toxicity

STARTING DATE: Later DURATION: Short

PROJECT NUMBER: 20.3.1
TITLE: Rapid Monitoring Techniques - Literature Review

OBJECTIVES:

1. To review the various types of existing and developmental bioassays (fish, invertebrates, bacteria, and algae) with respect to their potential to provide a fast, meaningful, and cost-effective test for use as a monitoring device.

2. To select and priorize the types of bioassays considered most likely to fulfill the objectives of the project.

3. To determine the costs of development of a suitable monitoring procedure and to estimate the eventual cost on a per sample basis.

RESEARCH OUTLINE (GUIDELINES):

1. Computerized information retrieval systems such as NTIS and SSIE would be utilized to search published and unpublished literature.

2. Since a bioassay is needed that is suitable in both theory and practice, some travel and consultation with experts outside Alberta may be required and sufficient travel funds should be provided.

3. At all stages, searches should be directed at the identification of suitable test organisms as well as bioassay procedures and apparatus.

TO BE UNDERTAKEN BY:

Consultant

SYSTEM: Water BUDGET: Small

ACTIVITY: Assessment of Toxicity

STARTING DATE: Later DURATION: Short

PROJECT NUMBER: 20.3.2
TITLE: Rapid Monitoring Techniques - Assessment of Selected Techniques

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OBJECTIVES:

1. To determine the sensitivity, reliability, ease of operation and cost of each technique identified in subproject 20.3.1.

2. To assess the suitability of the techniques selected to meet the needs of this project e.g. a technique for the rapid monitoring of effluents.

3. To estimate the costs of developing a chosen technique.

RESEARCH OUTLINE (GUIDELINES):

1. The sensitivity of procedures identified in subproject 20.3.1 should be determined using known toxicants and effluents and comparing the results with the existing fish (rainbow trout) bioassay. The sensitivity of different test organisms in similar experimental designs should also be compared.

2. The design of procedures and test apparatus should be directed toward methods which can be most easily automated.

3. A recently developed bacterial bioluminescent assay may fulfill the criteria of a rapid monitoring test as outlined. Preliminary work indicates that this test is sensitive, rapid (2-5 minutes), and adaptable to automation. Since this technique has already received considerable study, the amount of development work needed should be less than some other techniques.

TO BE UNDERTAKEN BY:

Consultant

SYSTEM: Land | BUDGET: Large (All projects)

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate | DURATION: Moderate

PROJECT NUMBER: 21
TITLE: Effects of Industrial Emissions on Vegetation

OBJECTIVES:

1. To determine the effects of single contaminants or groups of contaminants on selected physiological and biochemical parameters in selected forest species.

2. To determine contaminant concentrations and fumigation times required to cause sublethal and lethal levels of damage to selected forest species.

3. To determine what ambient contaminant levels and fumigation times cause levels of damage which are irreversible.

RESEARCH OUTLINE:

1. This project is divided into 6 major subprojects which are described on the following pages.

2. Information from projects 4, 5, 6, 7, 10, 13, and 14 may be useful in the planning for this project.

3. Coordination is recommended with projects 5, 6, 7, 22, 23, 24, and 25. The data should be useful to projects 22, 23, 24, and 25.

TO BE UNDERTAKEN BY:

Universities and government; appointment of coordinator is recommended

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SYSTEM: Land BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Ongoing DURATION: Moderate

PROJECT NUMBER: 21.1
TITLE: Effects of Sulphur Dioxide and Nitrogen Oxides on Vegetation - Laboratory Study

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OBJECTIVES:

1. To determine the physiological and biochemical effects of sulphur dioxide on selected plant species (native and introduced) in native soil types.

2. To determine the physiological and biochemical effects of nitrogen oxides on selected plant species (native and introduced) in native soil types.

3. To determine the physiological and biochemical effects of mixtures of sulphur dioxide and nitrogen oxides on selected plant species (native and introduced) in native soil types.

4. To determine the resilience of selected plant species (and recovery time) following fumigation episodes of selected characterization and deviation.

RESEARCH OUTLINE:

1. This project will utilize controlled environment chambers with fumigation capabilities.

2. The effects of environmental factors such as temperature, relative humidity, light quality and soil moisture on selected physiological and biochemical parameters should be determined to establish a normal range of control values.

3. Light quality, day length, temperature range and relative humidity simulating AOSERP growing conditions should be tested.

4. As essential references, ambient sulphur dioxide and nitrogen oxide levels and fumigation times as well as Alberta Ambient Air Quality Standards (concentrations and fumigation times) should be tested.

5. Tests should utilize intact plants to preserve the repair mechanisms in plant cells. After cessation of fumigation episodes, the time required for normalization of selected physiological and biochemical parameters under controlled environmental conditions will be determined e.g., the recovery or resilience of selected plant species must be determined.

6. Tests should be conducted in representative native soil types (VE 2.1).

7. Coordination is recommended with projects 4, 5, 6, 7, 21.2, 21.3, 21.4, 22, 23, 24, and 25.

TO BE UNDERTAKEN BY:

Universities or government

SYSTEM: Land BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate DURATION: Moderate

PROJECT NUMBER: 21.2
TITLE: Effects of Particulate Emissions on Vegetation - Laboratory Study

OBJECTIVES:

1. To determine the physiological and biochemical effects of particulate emissions (e.g., fly ash) on selected plant species (native and introduced) in native soil types.

2. To determine the effects of particulate emissions from GCOS (before and after particulate controls).

3. To determine the effects of particulate emissions from Syncrude.

RESEARCH OUTLINE:

1. This project will utilize controlled environmental growth chambers. Effects of particulate emissions should be determined on selected plant species grown on soil containing various levels of fly ash.

2. The effects of environmental factors such as temperature, relative humidity, light quality, and soil moisture on selected physiological biochemical parameters should be determined to establish a normal range of control values. Conditions must also be tested which simulate the AOSERP growing season.

3. As essential references, ambient levels (loadings) of fly ash as well as the levels specified by Alberta Ambient Air Quality Standards (concentration and duration) should be tested.

4. The repair mechanisms and recovery of plants to experimental conditions should be tested using intact plants.

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5. Tests should be conducted in representative native soil types (VE 2.1).

6. During each series of tests a broad analytical screening of fly ash samples should be carried out to determine the trace metal content. Parameters of interest will be defined in project 13.

7. This project should be coordinated with 5, 6, 21.1, 21.3, 21.4, 22, 23, 24, and 25.

TO BE UNDERTAKEN BY:

Universities or government.

SYSTEM: Land BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Early DURATION: Moderate

PROJECT NUMBER: 21.3
TITLE: Effects of Sulphur Dioxide, Nitrogen Oxides, and Particulate Emissions on Vegetation - Laboratory Study

OBJECTIVES:

1. To determine the physiological and biochemical effects of particulate emissions (e.g., fly ash) on selected plant species (native and introduced) in native soil types exposed to sulphur dioxide and/or nitrogen oxides.

2. To determine the resilience of selected plant species (and recovery time) following fumigation episodes of selected characteristics and duration.

RESEARCH OUTLINE:

1. Controlled environmental chambers with fumigation capabilities will be utilized to determine the effects of sulphur dioxide and nitrogen oxides and sulphur dioxide/nitrogen oxide on selected plant species grown in soil containing various levels of fly ash.

2. The effects of environmental factors such as temperature, relative humidity, light quality, and soil moisture on selected physiological and biochemical parameters should be determined to establish a normal range of control values.

3. Light quality, daylength, temperature range, and relative humidity simulating AOSERP growing conditions should be tested.

4. As essential references, ambient levels of fly ash, nitrogen oxides and sulphur dioxide as well as the levels specified by Alberta Ambient Air Quality Standards (concentration and duration) should be tested.

5. Certain tests should utilize intact plants to preserve repair mechanisms in plant cells.

6. Tests should be conducted in representative native soil types (VE 2.1).

7. Tests should include particulates from GCOS (before and after new particulate controls), Syncrude and in situ projects. During each series of tests a broad analytical screening of fly ash should be carried out. Parameters of interest will be defined in project 1.

8. Coordination of this project with projects 5, 6, 21.2, 21.4, 22, 23, 24, and 25 is recommended.

TO BE UNDERTAKEN BY:

Universities or government.

SYSTEM: Land BUDGET: Small

ACTIVITY: Assessment of Toxicity

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 21.4
TITLE: Identification of Species Intolerant to Alberta Ambient Air Quality Standards - Literature Review

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OBJECTIVES:

1. From the results of research in previous subprojects (21.1, 21.2, 21.3) and project 22 identify the forest species that are intolerant to existing Alberta air quality standards.

2. To define and describe (with input from previous subprojects) levels of impact to vegetation resulting from oil sands industrial emissions.

RESEARCH OUTLINE:

1. To be defined.

TO BE UNDERTAKEN BY:

To be defined.

SYSTEM: Land BUDGET: Small

ACTIVITY: Assessment of Toxicity

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 21.5
TITLE: A Literature Review of the Toxicology of Trace Elements to Vegetation

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OBJECTIVES:

1. To prepare a comprehensive review of the function of selected trace elements in the physiology, biochemistry, and toxicology of vegetation. The metals of interest should be defined from the results of project 13.

TO BE UNDERTAKEN BY:

To be defined.

SYSTEM: Land BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate DURATION: Long

PROJECT NUMBER: 22
TITLE: BioMonitoring of the Effects of Sulphur Dioxide, Nitrogen Oxides and Particulate Emissions on Vegetation

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OBJECTIVES:
1. To determine the physiologial and biochemical effects of natural fumigation episodes (groups of contaminants) on selected forest species under ambient environmental conditions.

2. To determine the sulphur dioxide, nitrogen oxides, and fly ash concentrations and fumigation times required to cause irreversible physiological or biochemical changes in selected plant species under ambient environmental conditions.

RESEARCH OUTLINE:
1. Monitoring stations (abiotic and biotic) should be established and located at various distances from emission sources.

2. Stations should include examples of the representative forest communities (VE 2.2) and soil types (VE 2.1).

3. Initially stations could be located adjacent to each air quality monitoring trailer and each sulphate cylinder. If vegetation and soil types are unknown at these locations, they should be described in accordance with the existing descriptions of VE 2.1, VE 2.2.

4. The effects of sulphur dioxide, nitrogen oxides, and/or fly ash under varied environmental conditions (temperature, light quality, relative humidity, etc.) should be compared with the effects

of similar environmental factors in control areas e.g., fumigation effects on a parameter under low temperature and overcast skies will be compared to the same parameter under low temperature - overcast skies in a control area.

5. The effects of heavy metal accumulations in specific soil types (VE 2.1) on vegetation exposed to ambient fumigation episodes can be determined by controlled additions of fly ash (of known composition) to test sites.

6. A high priority should be given to the physiological and/or biochemical recovery of vegetation following fumigation episodes.

7. Field studies should include both temporal (change at a site over time) and spatial (a similar site in an "uncontaminated" area) controls.

8. In conjunction with this project changes in the physical and chemical characteristics of the soil at each site should also be monitored.

9. Coordination of this project with projects 5, 6, 21.1, 21.2, 21.3, 23.1, 24, and 25 is recommended. The data should be useful to projects 23, 24, and 25.

TO BE UNDERTAKEN BY:

Government or universities with assistance from AOSERP field staff.

SYSTEM: Land | BUDGET: Medium (All projects)

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate | DURATION: Moderate

PROJECT NUMBER: 23
TITLE: Effects of Industrial Emissions on Soil Systems

OBJECTIVES:

1. To determine the effects of single contaminants or groups of contaminants on selected soil characteristics.

2. To determine the effects of single contaminants or groups of contaminants on soil microflora.

RESEARCH OUTLINE:

1. This project is divided into three subprojects which are described on the following pages.

2. Information from projects 6, 7, and 10 may be useful in designing this project.

3. Coordination is recommended with projects 6, 7, 21, 22, and 24. The data should be useful to projects 21, 24, and 25.

TO BE UNDERTAKEN BY:

To be defined.

SYSTEM: Land BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Later DURATION: Moderate

PROJECT NUMBER: 23.1
TITLE: Effects of Sulphur, Nitrogen, and Particulate Emissions on Soil Microflora - laboratory study

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OBJECTIVE:
1. To determine the effects of sulphur, nitrogen, and fly ash (heavy metal) deposition on the dominance, vigor and reproduction capacity of specific soil microflora (VE 2.1).

RESEARCH OUTLINE:
1. The design of the project should be defined following assessment of the results of projects 10, 21, 22, and 24.

TO BE UNDERTAKEN BY:

To be defined.

SYSTEM: Land BUDGET: Small

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate DURATION: Short

PROJECT NUMBER: 23.2
TITLE: A Preliminary Study of the Availability of Sulphur and Nitrogen to Plants

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OBJECTIVES:

1. To determine the response of representative soil types to additions of sulphur and nitrogen.

2. To estimate the quantities of sulphur and nitrogen that can be deposited per hectare of soil type without detrimentally effecting forest vegetation.

RESEARCH OUTLINE:

1. This study would utilize a series of fertilizer trials to determine the response of soils (as indicated by plant growth) to additions of sulphur and nitrogen.

2. Major representative soil types (VE 2.1) should be tested.

TO BE UNDERTAKEN BY:

To be defined.

SYSTEM: Land BUDGET: Small

ACTIVITY: Assessment of Toxicity

STARTING DATE: Early DURATION: Short

PROJECT NUMBER: 23.3
TITLE: A Literature Review of the Toxicology of Trace Elements in Soil Systems

OBJECTIVE:

1. To prepare a comprehensive review of the function of selected trace elements in the physiology, biochemistry, and toxicology of soil micro-organisms. The elements of interest should be defined from the results of project 13.

TO BE UNDERTAKEN BY:

To be defined.

SYSTEM: Land BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Later DURATION: Long

PROJECT NUMBER: 24
TITLE: Biomonitoring of the Effects of Sulphur, Nitrogen, and Particulate Emissions on Soil Microflora

OBJECTIVE:
1. To determine the absorptive and regenerative capacity of native soil types (including reclamation soils) to the deposition of sulphur, nitrogen, fly ash (heavy metal deposition) and accompanying changes (if any) in soil chemistry.

RESEARCH OUTLINE:
1. The design of the project should be defined following assessment of the results of projects 10 and 21.

2. Changes in microflora should be determined and compared with temporal and spatial controls.

3. Monitoring stations established in project 22 should be used in this project to insure:
    a) representative soil types
    b) adequate abiotic monitoring data

4. Test soils should remain as undisturbed as possible.

TO BE UNDERTAKEN BY:

To be defined.

SYSTEM: Land BUDGET: Medium

ACTIVITY: Assessment of Toxicity

STARTING DATE: Immediate DURATION: Long

PROJECT NUMBER: 25
TITLE: Biomonitoring of the Effects of Industrial Activity on Wildlife Populations

OBJECTIVES:

1. To design and implement baseline and impact biomonitoring programs for each of the major wildlife groups in the AOSERP area.

2. To incorporate, in the design, principles of biomonitoring as well as information from similar programs in use elsewhere in the world.

3. To design a biological archives and commence collection of specific biological material as defined by studies in objectives 1 and 2.

RESEARCH OUTLINE:

1. The needs of specific biomonitoring networks should be determined through discussion with AOSERP personnel, government employees, universities and consultants.

2. Networks should include:
   a) monitoring of various trophic levels
   b) monitoring of population structure, abundance and seasonal dynamics of specific groups
   c) studies of the accumulation of specific contaminants. Contaminants of interest should be those defined by projects 2.3, 13, and 14.

3. The effects of storage (techniques and duration) on levels of contaminants in specific samples may require investigation.

TO BE UNDERTAKEN BY:

Government or consultant

6. 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 whithin 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.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 4.2.1	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

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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.		An Overview Assessment of In Situ Development in the Athabasca Deposit
64.	LS 21.6.1	A Review 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 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
-	--	Interim Report to 1978
74.	AS 4.5	Air Quality Modelling and User Needs

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

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