A PLAN FOR THE IDENTIFICATION OF POTENTIALLY TOXIC MATERIALS IN THE AOSERP STUDY AREA

by

T.J. McCANN
T.J. McCann and Associates Ltd.

for

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ABSTRACT

A co-ordinated plan is proposed for the identification of toxic emissions from oil sand developments in the AOSERP study area.

Interviews with over 40 specialists in various fields relevant to this study developed essentially no confirmed awareness of existing biological stresses due to emissions from existing operations. However, there are appreciable concerns on the part of those interviewed relative to possible long-term biological degradation due to oil sand developments. These concerns may be grouped into the following classifications:

1. Sulphur dioxide emission impact;
2. In situ production groundwater and surface water contamination;
3. Compounds, generally in low concentrations, with possibly long-term toxicity implications; and
4. Containment of toxic materials.

The identification program recommendations have been broken into three segments covering the first three areas of concern:

1. Sulphur overview. To define the possible long-term implications of the sulphur emitted from these operations and to define further work required in this regard;
2. In situ overview. To define the potential for the release of toxic substances and to provide background for further AOSERP work in this regard; and
3. Trace compounds program. To determine the toxicity of materials emitted from conventional surface operations.

A parallel and equally important recommendation covers an aqueous sampling and biomonitoring program development study to define monitoring systems to indicate aquatic biological stess at its earliest stages.

Containment monitoring is in progress but more research may be warranted.

The proposed program is calculated to cost approximately $650 000 a year for two years with some continuity necessary beyond AOSERP's initial 5-year mandate.

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1. INTRODUCTION

1.1 TERMS OF REFERENCE

By his letter dated 22 September 1978 (received and accepted 27 September 1978), S.B. Smith, Program Director of the Alberta Oil Sands Environmental Research Program (AOSERP), confirmed arrangements for the preparation of a plan for the identification of potentially toxic materials released to the atmosphere and water in the AOSERP study area. The letter noted the following services were to be provided:

1. In the context of an overall program of toxicology-oriented studies, develop formal plans for projects which will identify pathways by which toxic compounds are introduced into the oil sands mining and refining processes and are released to the atmosphere; and
2. Recommend monitoring activities to define, measure, and validate predicted emissions and impact of toxic compounds.

The AOSERP letter requested that the report contain the following:

1. A statement of the problem relating to oil sands mining and refining;
2. A review of relevant toxicological work outside the AOSERP program;
3. A description of a system approach to toxicological studies;
4. Plans for individual projects with cost estimates and relevancy to overall program; and
5. A discussion of monitoring to validate projections.

For the purposes of this report, the AOSERP study area was assumed to start at the plant fence of specific oil sand developments.

1.2 STATEMENT OF THE PROBLEM

"The purpose of the Alberta Oil Sands Environmental Research Program is to provide information which can be used to minimize the occurrence of damage to the environment within and surrounding the oil sands region of northeastern Alberta" (AOSERP 1977).

Damage to the environment is often envisaged as being largely due to the "toxicity" of emissions from the various processing steps in the oil sands exploitation. In practice the various emissions may have a lesser effect than the various construction, transport, and community activities associated with them. However, emission toxicology normally has a longer range "damage" potential--both in space and time--than these other activities.

The plan presented defines "potentially toxic materials" as those materials not now considered inert (or beneficial) in the forms and concentrations emitted (as measured at the plant fence). Obviously such a classification will require continual correction as knowledge accumulates; hence, the emission toxicology program must be continually assessed and revised.

AOSERP has not had a co-ordinated thrust in toxicology, but rather the Air, Water, Land and Human sections have considered it in certain aspects of their separate programs. As the purpose noted above points out, toxic effects are very central concerns of the AOSERP program and this plan is an attempt to bring some focus on toxic emissions and to present a co-ordinated approach to future AOSERP work in this regard.

2. PROBLEMS AND CONCERNS

2.1 INTRODUCTION

The following sequence of activities was carried out in developing this report:

1. Updating the writer relative to AOSERP work to date and in progress;
2. Interviewing over 40 selected specialists in relevant disciplines and with specific oil sands regional expertise, to solicit their comments and recommendations; and
3. Preparing overall and individual plans for toxic substance identification.

In the interviews three basic questions were asked:

1. "What toxic effects can you now identify attributable to oil sands plant emissions?"
2. "What concerns do you have in this regard?" (i.e., potential toxic effects not now evident); and
3. "What monitoring programs do you recommend with regard to the identified problems or concerns?".

The problems and concerns expressed by those interviews form the bases for this section. As the views given were those of the individual and not necessarily those of his employer, references are cited in this section only in a few cases. The writer takes the responsibility for the interpretation and for the facts presented.

2.2 CURRENT PROBLEMS

Specific instances of damage or serious stress due to emission have been hard to find. Some very localized vegetation damage has resulted from various produce pipeline leaks, but without specifically toxic effects.

One oil-soaked beaver was humanely killed at the time of the large Great Canadian Oil Sands (GCOS) leak in 1970 (Alberta Department of Health 1970) and several oil-soaked birds were noted, but specific toxicity effects were not noted in these cases. One or two oily tasting fish caught in the winter just downstream of GCOS appear to be exceptions.

Anzac was evacuated on one occasion due to an in situ experimental program well blow out, but the system depressured quickly and the potentially toxic gases dissipated with no known effects. Fort MacKay has been receiving drinking water by truck since the 1970 GCOS spill, but the reasons today appear to be due to a problem in defining, funding, and building a proper system and not due to contamination by oil sand processing.

The required installation of electrostatic precipitators at GCOS is based on provincial emission standards with little or no evidence of any signficant damage to vegetation.

In summary, no confirmed evidence exists of major biological damage or stress.

2.3 FUTURE CONCERNS

All but one concern of those interviewed were relative to long-term considerations. The short-term concern is with regard to possible catastrophic breakage of a storage or tailings pond dike and the consequent dumping of toxic waters and clays into the river. This has a low probability and is generally outside the AOSERP mandate. Hence, we do not consider it further in this report.

For convenience, we have grouped the long-term concerns into six main categories:

1. Eastern Peace Athabasca Delta
   (Only the southeastern portion of the delta and the adjacent areas of Lake Athabasca are affected and when the term "Peace-Athabasca delta" is used in this report it refers only to the areas watered largely from the Athabasca River.)
   - Many of the "contaminants" emitted from the various operations pass into the river and, unless degraded within a few days, reside for appreciable periods in the delta region. The river is assumed to have appreciable resiliency to most potential contaminants,

but the same may not be true of the portions of the delta receiving Athabasca River water.

- The contaminants of most concern are trace organic and inorganic compounds that do not occur in nature. Long-term effects are of primary concern, as the various compounds enter and pass through various life cycles.

2. In Situ Production

- Contamination of ground and surface waters by in situ operations has also been widely noted as a potentially serious problem. Particularly of concern is the very wide range of soluble organic and organo-metallic compounds that may be produced during in situ operations.
- Containment of such materials in the production formation and on the surface is of major concern in at least parts of AOSERP study area.

3. Sulphur

- As Syncrude comes up to capacity and then expands, as GCOS expands, and as Shell builds its proposed plant, the area's emission rate of sulphur dioxide will likely increase. The problems at Sudbury and in northern Europe have been noted by many and by analogy concern has been expressed relative to oil sands development emission (Dotto 1978).
- Possible acidification of lakes on the Precambrian Shield (to the northeast and east) was a major concern expressed by many people. Dry deposition as opposed to "acid rain" has been noted as the predominant mechanism of deposition.
- There were other sulphur-related concerns in soil acidification, in natural sulphur/selenium ratios, and in biological growth rates.

- The particulate emissions from the various plants are of some concern (partly relative to inter-reaction with the sulphur released), even with the reduction of GCOS particulates with the building of electrostatic precipitators there.

4. Containment
   - Mine depressuring waterflows continue to be of concern due to high salinity and total dissolved solids.
   - Leakage and percolation of materials from waste ponds coupled with possible adsorption-leaching effects releasing toxic compounds in surges were noted.
   - The ability to sustain the zero discharge concept of Syncrude was questioned and the wide range of water balances of the various development proposals noted (e.g. Laycock 1974).
   - Oil on ponds was noted (although it appears more of a physical problem to birds than a toxicological one).
5. Human Health
   - Potentially carcinogenic compounds may exist in the air and water around at least the GCOS plant (Peake private communication October 1978). (This was the only toxicity-related human concern noted.)
6. Outside Developments
   - In situ oil and oil sands development in the Wabasca and Peace River areas and upstream on the Athabasca are specific examples of projects which may change the aquatic and aerial chemistry of the AOSERP region. Agricultural activities to the southwest may also affect the river chemistry (as traces of pesticides have already been noted).

3. SOURCES AND EMISSIONS

3.1 GENERAL

This section will provide a brief overview of the status of emission data with discussion, where appropriate, relative to "potentially toxic materials". It is not the intent to provide summaries of previous work in this regard, but to provide the setting for the toxic emission plans presented in the next sections.

Time factors are important in many aspects of plan development and Table 1 is a cursory overview of oil sand exploitation in the AOSERP study area as we now project it through 1987.

A metallurgical industry to recover nickel, vanadium, titanium and/or zirconium from various mineral streams from extraction and boiler particulate recovery systems may develop in the '80s. The individual plants will be small operations with different environmental concerns than plants such as Syncrude. While directly related to oil sands development, these potential activities have been excluded from study.

Virtually each oil sand development will be unique relative to emissions having different technology, regulatory pressures at time of "freezing" the design, as well as different operators with differing approaches to management, design and operations. But data from individual operators accumulate to the total for the area and, hence, even if unique, each plant must be considered individually in developing emission sources, rates and compositions.

The following subsections will consider individual segments of oil sands recovery and conservation by brief review of the introduction and/or production of man-made materials and the emission characteristics of each, again as related to "potentially toxic materials".

Shell's environmental impact assessment (included in their application to the Energy Resources Conservation Board) was not available at the time of this report and references to Shell are based on press reports.

Table 1. Development Scenario.

Year	GCOS MBPD[a]	Syncrude MBPD[b]	Shell MBPD[b]	AMOCO MBPD[c]	Texaco MBPD[d]	Petro-Canada[d]	Others[e]
1978	50	50	0	X	X	-	-
1979	50	100	0	X	X	X	-
1980	50	120	0	X	X	X	X
1981	60	120	0	P	P	X	X,X
1982	60	150	0	P	P	X	X,X
1983	70	180	0	P	P	X	X,X
1984	70	180	0	P	P	P	X,X
1985	70	180	60	P	P	P	P,X
1986	70	180	130	50[f]	P	P	P,X
1987	70	180	130	100	30[f]	P	P,X

Legend: X-Experimental P-Prototype (approx. 10 000 BPD) MBPD-Thousand barrels per day of product

[a] Delayed coking as principal process throughout.

[b] Fluid coking as principal process throughout--store coke during periods shown.

[c] In situ combustion.

[d] Steam injection in situ (or variation).

[e] Several in situ processes may be used.

[f] Residual hydrodesulphurization or flexicoking upgrading process.

3.2 SURFACE MINING

3.2.1 Processes

Surface mining operations are characterized by continually changing operational patterns geographically and, hence, varying emission patterns. Overburden is removed and reclamation is carried out during warm months whereas mining of oil sand and deposition of clean sand and other tailings continue year round.

Only physical operations are carried out with extraneous materials introduced via tailings disposal. There may be some chemical reaction between tailings components and natural materials but these are likely to be limited. (Tailings systems are considered under "extraction" below.)

Muskeg drainage is undertaken prior to its removal to permit mobile equipment operation.

Drainage of pressured groundwaters from under areas to be mined became a need first at Syncrude. Saline waters are released continuously at Syncrude after appreciable residence in holding ponds and blending with some runoff. Shell plans a similar system but may discharge such saline waters only at times of high water flows.

There may be some atmospheric emissions due to drying and aging of muskeg materials moved to permit overburden removal but these have not been considered of concern to date. Undisturbed natural materials including bitumen have been considered non-toxic by all those interviewed and that assumption is used throughout this study. Disturbed natural materials are considered inert unless they react with extraneous materials or are decomposed with heat or in other unnatural ways. Muskeg drainage may react with process and extraction wastes to enhance heavy metal solubility and muskeg drainage appears to have slightly enhanced heavy metal concentration.

3.2.2 Toxic Emissions

Atmospheric emissions covering all aspects of oil sand development have been summarized in an AOSERP report (Shelfantoock 1977) on a preliminary basis. Generally, we anticipate no significant toxic materials being emitted to the air from mining areas but note the recommendations of that reference for studies specific to natural emissions to the atmosphere.

There is no comparable survey of aqueous drainage. Concern has been expressed relative to greatly enhanced flows of saline water (largely mine depressuring water) with a large number of projects in the future. The organic content of that saline water has been noted as a possible trouble spot on a long-term basis. There will likely be local toxicity problems or concerns with mine depressuring water and muskeg drainage flows on most projects as the initial mine is opened, but we see that as a project-related problem and not of regional concern.

3.3 IN SITU PRODUCTION

3.3.1 Background

There has been very little work done in developing detailed vapor and liquid emission data from in situ operations. In such operations, air, steam and/or water are introduced into naturally bitumen laden formations. Some chemical additives may be added to reduce formation viscosities and to improve the percentage recovery.

There are underway in both Alberta and Saskatchewan several in situ combustion (air with and without water added) and thermal stimulation (steam/hot water mixture) projects to recover heavy oils but these are all relatively small compared to the Cold Lake proposals and the future commercial developments in the AOSERP region. Esso Resources Canada Ltd. is currently applying for permits to construct and operate a facility to produce over 140 000 BPD of upgraded synthetic crude oil via steam injection in the Cold Lake area. An appreciable amount of inhouse knowledge has built up over the past 15 years on heavy oil production generally.

Environmental concerns do not appear to have received the same attention as production. While produced waters (up to 4 or 5 times the oil rate) are generally reinjected into suitable formations, this approach may not be suitable on a very large scheme. At this time, the Cold Lake water utilization and disposal systems are still under experimental development. While no serious surface or groundwater toxicity problem has been identified in existing developments, it is noted that the Saskatchewan government is an intervenor at the Cold Lake hearings relative to possible contamination of groundwater aquifers which may extend into Saskatchewan.

3.3.2 AOSERP Area Projects

When steam is used, the formation temperatures reached may result in a very minor amount of hydrocarbon decomposition. Significant production of by-products has not occurred in the operations noted above. Steam is being used at the experimental program of Texaco near the Fort McMurray airport and a similar approach may be used by Petro-Canada at their Hangingstone experimental site west of Gregoire Lake. Some experimental work is now being done relative to a steam heating approach with the steam being introduced and oil drained out via holes drilled upward into oil sands from tunnels in the underlying limestone. But this latter approach is a very long way from economic development (Anonymous 1978).

AMOCO is using a COFCAW ("combination of forward combustion and water") at their Gregoire Lake site. The COFCAW approach produces a very wide range of oxygenated organics (with sulphur, nitrogen, and possibly even metal present in significant quantities). If the AMOCO program continues well, more COFCAW-type projects may be expected (Jenkins and Kirkpatrick 1978).

One of the major problems in all heavy oil development is to get communication between the injection and the production holes. At Surmount Lake south of Gregoire Lake, Gulf, Numac and Alberta Oil Sands Technology and Research Authority (AOSTRA) carried out one of the largest experimental fracturing programs ever, in an attempt to get such communication. All of the pilot schemes are attacking this problem. Nichols and Luhning (1977) provided a summary of in situ oil sand experimental projects.

AOSTRA also funded a study of Russian underground mining approaches to heavy oil recovery but no active consideration of that approach is reported at this time. Steam and in situ combustion approaches are now the only processes anticipated to be used in the AOSERP study area over the next 5 years.

3.3.3 Composition Data Availability

All AOSERP study area projects are at an experimental stage and, as with similar developments elsewhere, are being attacked on a step-by-step approach. After the initial experimental program, a larger program is undertaken to debug the various systems developed earlier. Only when this "prototype" is successfully operating is a full scale plant commissioned. Hence, 15 years is not an abnormal time span from first experimentation until a full scale production facility is complete.

As most production know-how and data are confidential, obtaining data on possible emissions is difficult, especially so in the case of combustion approaches with their vast range of by-products (Barbour et al. 1977). For compositional data--gases, liquids, water--on combustion tests it is possible to use laboratory test facilities such as in Dr. Bennion's laboratory at the University of Calgary to provide an indication of the potential products for toxicity screening. The mixture of gases and liquids produced in the formation is best estimated from actual field samples or, if they are not available, from a laboratory test.

3.3.4 Toxic Gases

In practice the produced gases will be recovered in surface facilities similar to gas processing plants and we see few toxic vapour emission possibilities other than those in any oil refinery or in a sour gas field. The range of gaseous components may be broader than in a gas plant with significant nitrogenous compound concentrations and higher molecular weight sulphur compounds concentrations will be enhanced, but hydrogen sulphide will be the main toxicant of concern. The wellhead and the piping from the wellhead to the plant will be areas subject to minor leakages and even blowouts. The amounts of toxic gases present will very seldom lead to more than local toxic situations with some minor vegetation damage at most. The Anzac blowout, which might not occur today with better well monitoring and control equipment, does show that there is potential for blowouts, especially when the tens of thousands of wells ultimately in use are considered.

The upgrading facilities for in situ production are similar to those at surface mines and, hence, are discussed in a later subsection covering all upgrading.

3.3.5 Underground Containment of Toxic Materials

As noted above under "concerns", there is major concern about containing oil and by-products in the formation at all times. However, the operators are very interested as well, as any product leakage away from the well will lead to heat losses and thus reduce the thermal efficiency of the project. Large leakages of heat may be expected to lead to quick stoppage of air injection allowing the formation to cool off and seal itself. But smaller leakages may go undetected.

While steam injection projects may have thermal and product leaks, they are not considered to have any serious potential for leakage unless there are aquifers in or very close to the production zone. The produced oil may be assumed to freeze once it is out of the heated area, thus sealing itself off. Production of toxic compounds will likely be very low in steam production approaches minimizing the hazard of leakage to ground waters.

But many of the "new" compounds formed in in situ combustion operations will be acutely toxic at high concentration levels and others may have long-term mutagenic effects. Hence, even minor leakage may be of serious concern.

In the area of Gregoire Lake, Surmount Lake and the Petro-Canada site there are suggestions of faults and other leakage paths through the Clearwater shale overlaying the oil sands. Appreciable groundwater upwelling may occur in the area and there may be a long fault running from Anzac through Fort McMurray to at least Fort MacKay (Hackbarth 1977). Hence, there may be ready means of egress for at least part of the combustion products which leak out of a production formation through an accident.

3.3.6 Aboveground Containment of Toxic Materials

The large quantities of water produced in both combustion and steam processes must be injected into suitable formation or treated for recycling and/or disposal. For the Fort McMurray area, full scale developments work on water systems is probably at a very early stage or not yet started. Experimental schemes are reinjecting their produced water--an acceptable practice due to its small volume. The need for special casing to protect near-surface waters is a point of contention at the current Cold Lake hearings.

Composition and flow data on the produced and treated water can only be roughly estimated at this time for the Fort McMurray area as experimental programs do not fully duplicate expected commercial practices relative to water reuse and disposal.

3.3.7 Summary of In Situ Toxic Emission Concern

There is major concern about possible ground- and surface-water contamination from in situ production operations, but generally AOSERP region development is at an early stage and there are little public data to use in any evaluation. Some water rates, and water, gas and organic product compositions can be estimated from literature and laboratory tests. It is likely to be 3 to 5 years before any significantly improved data are available.

3.4 EXTRACTION AND TAILINGS

3.4.1 Extraction Process

In the first stages of the extraction process, the raw oil sand is contacted with hot water, some caustic soda and (at GCOS) a surfactant. The water used is largely from tailings ponds which may contain some effluent water from the upgrading system (Syncrude).

In the last stage of the extraction system a light hydrocarbon (diluent) is added before centrifuging to remove most of the remaining clay minerals from the recovered oil. The operations are largely physical in nature with the raw sand being fully exposed to the water phase to release all possible oil.

Extraction and related processes are still under development in a variety of areas. As new technology develops, tailings ponds should get smaller (as clay settles more quickly) and caustic use will likely decrease. A close watch will be needed in this area relative to the possible introduction of new chemicals.

3.4.2 Toxic Materials in Extraction and Tailings

While there is no reaction of the raw bitumen per se or the diluent there are some water soluble organic compounds present in the oil sands which are released into the water layer (Moschopedis et al. 1977).

The waters from extraction are toxic to fish but are fully (Syncrude) or partially (GCOS) recycled. There is also a suggestion that, at the pH of the extraction process, the natural acids form relatively stable compounds with vanadium and nickel, compounds which may be biodegradable introducing the metal into biological cycles (Korchinski private communication 1978).

However, other heavy metals, such as zirconium (Kramers and Brown 1976) and hafnium, that are toxic in certain forms (Rulka and Risby 1976) pass out to the clay storage areas with no apparent problems being created.

Some benzene and other slightly soluble light hydrocarbons are dissolved from the diluent but probably evaporate in the tailings pond. More diluent is absorbed in unrecovered bitumen carried out to the sand and clay tailings areas with its lighter fractions again vaporizing over time. The AOSERP inventory of air emissions (Shelfantoock 1977) notes very sizable hydrocarbon losses (through evaporation) in the extraction system. It is doubtful if any of these is of toxic concern. (Benzene, toxic in signficant concentrations, is present but only in very low concentration.) These vapors may contribute to atmospheric reactions, but the quantities are small when compared to natural emissions. The GCOS expansion program includes a scheme to recover 500 barrels a day of diluent from tailings systems (GCOS 1978) to further reduce hydrocarbon evaporation losses.

The large oil coverage of the Syncrude tailings pond the week of 6 November 1978 was noted by two people. While of concern to birdlife and water balances, bitumen per se is considered to be non-toxic. The oil effectively stops evaporation in the area it covers and reduced evaporation might necessitate some discharge of ponded waters by Syncrude in the future.

The Syncrude design indicates some percolation into groundwaters of impounded waters and these may be assumed to reach the river, probably well diluted with natural groundwaters. The presence in the tailings ponds of some wastes from upgrading and utility operations should be noted at Syncrude. While certain of the toxic materials from upgrading probably biologically degrade in tailings and other ponds, these man-made compounds need to be watched for in percolation drainage.

3.5 UPGRADING

3.5.1 General

Except for in situ combustion production, virtually all production of man-made compounds in an oil sands complex takes place in the various upgrading processes. In converting bitumen to marketable products, the sulphur, nitrogen, oxygen, vanadium, nickel and other minerals of the original bitumen are largely removed regardless of the upgrading processes used. Water and mineral matter carried over from the extraction step are also removed. Hydrogen is added usually after most of the undesirable materials and part of the carbon are removed in a coking step. Shell now proposes the same sequence Syncrude has--fluid coking followed by hydrotreating in fixed-bed catalytic reactors. GCOS uses a delayed coking (batch) process, but with similar hydrotreating. Other processes may be considered in future plants as noted in Table 1, but this discussion covers only those plants in operation (GCOS and Syncrude) or are at the approval stage (Shell).

Auxiliary processes consist of the production of hydrogen from natural gas, the recovery of H_2S and its conversion to elemental sulphur--operations common to all three plants. Gases produced are used as fuel (after H_2S removal) in the process furnaces. Natural gas for hydrogen production and supplemental fuel needs (in both upgrading and utility areas) is the only imported feedstock.

3.5.2 Coking

In the cokers a wide variety of new organic molecules are formed, generally smaller than the original ones except for coke which collects most of the minerals and metals present and a significant quantity of sulphur. In the Syncrude fluid cokers, part of the recovered coke is burned to produce enough heat for the coking reaction. The flue gas from this combustion contains some CO, appreciable SO_2, and some fly ash (partially burned coke plus minerals) as well as some trace compounds. The flue gas passes through boilers where natural gas is burned as well as the CO and any other trace combustibles. The sulphur recovery plant tail gas and some gases (H_2S and NH_3 mostly) from a water cleanup operation are also incinerated in the boilers. Excess coke is disposed of in storage areas.

GCOS's delayed coking operation does not make any in-process use of the coke deposited in large "drums" in their process, but the coke is jetted out with water, drained, and about 80% of it is used in the utility plant. The remainder is accumulated in a storage area.

Except for the various flue gases, gases are contained within process equipment and vent to flare stacks if high pressures build up. While the coking operation produces a variety of toxic gases (H_2S, NH_3, CO, COS, etc.) these are fully contained and the operation is comparable to most refinery process units from an acute toxicity standpoint.

Water drained from coke contains some phenols, a variety of other oxygenated organics, sulphur, and nitrogenous products. There is some benzene, probably some polycyclic aromatics and other potentially carcinogenic compounds present in low concentration. Except for tankage, pump leaks, and similar abnormal situations, these liquids are normally completely confined.

At GCOS the coke from the drums is coated with a thin layer of oil and by-products which may be partially removed into the water used to clean out the drums. (There is a small amount of gas and hydrocarbon vapor lost, as well, when the coke drum and coke are first exposed to air.)

Aside from the GCOS decoking operation, there are several sources of contaminated waters from the coking processes, waters with various oxygenated and sulphur compounds present. These wastes are normally "stripped" of hydrogen sulphide before discharge to effluent treatment systems.

3.5.3 Hydrotreating and Sulphur Recovery

The liquids from the coking operations are treated with hydrogen in the hydrotreaters where the bulk of sulphur and nitrogen compounds present are converted to H_2S and NH_3, respectively. (Oxygenated compounds are converted to water and hydrocarbons.) Some hydrogen is added to reactive hydrocarbons to produce a "stable" product. GCOS has three separate hydrotreating systems and Syncrude two. Again all gases are fully contained. The liquid products go to storage for blending to the final synthetic crude product.

All off gases from coking and hydrotreating are chemically scrubbed to remove H_2S which is converted to sulphur in a Claus sulphur unit. Liquid sulphur is piped to large blocks of sulphur where it is solidified (and stays until a buyer is found). Hydrogen is produced from natural gas and steam at Syncrude and GCOS but Shell may use part of all of their coke product for hydrogen some time after the plant is started up (using gas in the interim). Shell will be using a "tail gas" unit or units to increase Claus unit sulphur recovery to nearly 100% compared to GCOS's 96% for their expanded plant.

Both the H_2S removal system and the hydrogen plant use chemicals common to most natural gas treating plants. Inert solid catalysts are used in the hydrotreaters, sulphur recovery plant, and the hydrogen units. Natural gas is the only extraneous raw material.

3.5.4 Toxic Emissions

As noted, the upgrading plant is very much like a refinery--indeed there has been a delayed coker/hydrotreater complex upgrading heavy California crudes for over 20 years. The Edmonton Gulf and Texaco and the Regina Consumers Co-op refineries have delayed cokers similar to those of GCOS. (GCOS's coker is larger by a factor of about 6 in terms of coke production than the largest of these.) Imperial in Sarnia currently has a fluid coker and for 30 years operated a delayed coker.

Sulphur dioxide is the principal gas emitted that is of concern and it leaves largely from the sulphur plant off gas incinerator stack (or boiler stack at Syncrude) with some from the flare stack (less than 10% of the SO_2 emission from upgrading per se). Sulphur dioxide emission rates are calculated daily (and are probably within 5 or 10% of the actual). Technology exists to reduce sulphur recovery system SO_2 losses to the atmosphere by about 70% over the current Syncrude and GCOS losses and such a process is proposed by Shell. GCOS's expansion plans currently a third reactor in their Claus unit to increase recovery efficiency from 94 to 96%.

A concern was noted above with polycyclic aromatics and other possible carcinogens. These may get into the air from miscellaneous process leaks and from tank vents. GCOS is eliminating most tank vent losses of hydrocarbons over the next few years. The utility plant boiler stack, however, likely contributes some of these as does the oily water separator through evaporation. At this time, there are no data relative to the quantities of potentially carcinogenic compounds.

Other gases are emitted only intermittently and we do not foresee any significant toxicity problems resulting outside the plant fence.

3.5.5 Aqueous Waste Toxic Compounds

At Syncrude, upgrading waste waters go to the tailings pond and not to the Athabasca River and Shell is expected to do the same. GCOS thus contributes (and will continue to contribute) virtually all planned man-made organics going from surface oil sand exploitation to the river.

Treatment at both GCOS and Syncrude consist of steam stripping to remove H_2S (and most NH_3) and oily water gravity separation. The GCOS process effluent meets Alberta and Canadian refinery standards but the treatment system is not as complex as at most refineries (Alberta Department of the Environment 1976). GCOS uses a once through cooling system; hence, the river is heated slightly near their discharges.

The GCOS process effluents are causing no apparent stress to the river beyond its outfalls (the reported oily fish appear to have been exceptions). But the trace organic and possible organometallic compounds are a major concern relative to long-term mutagenicity aspects in the delta as noted previously. A significant portion of the organics at least is probably biodegraded in the waste ponds and adjacent river and thus does not enter into the main body of the river. The long-term toxicity aspects of such wastes are largely unknown, but are not considered potentially serious.

3.6 UTILITIES PLANT

3.6.1 General

On site power generation is normal for oil sands plants as it integrates well the steam needs for the hot water extraction process. GCOS burns delayed coke and gas; Syncrude burns natural gas (plus some process off gases as noted above); Shell's plans are not known at this time.

3.6.2 Sulphur Dioxide

The main stack at the utility plant in both cases carries off the bulk of the SO_2 emitted at both GCOS and Syncrude as well as fly ash from the coke burning (after electrostatic precipitators now at Syncrude and in the future at GCOS).

The reduction of fly ash losses at GCOS may reduce neutralization of SO_2 deposited in the immediate vicinity of the plant, thus decreasing soil pH in that area (but a high soil pH at the plant compared with adjacent areas is not uncommon at natural gas processing plants). There has been a suggestion raised that low soil pH tends to permit the solution of vanadium and other heavy elements present in the fly ash (Dotto 1978). While GCOS's stacks emitted some 40% of all the particulates in the AOSERP study area in 1976 there is no confirmed evidence of any resulting environmental stress due to these materials at this time.

There likely are some polycyclic aromatics ("pyrogens") in the flue gas from the boiler stacks resulting from partially burned coke. (In fact, the writer would expect some peak above-background levels of this type of compound around refineries and similar operations.) Also noted by one person were possible inorganic carcinogens from the flue gas, but there is no supporting evidence.

Sulphur dioxide appears the main concern in the case of utility plant emissions to the air (although NO_x and particulates may enhance its environmental impact). GCOS's stack is significantly lower than that of Syncrude's and influenced by river valley air movements. Shell's stack will likely be as high as Syncrude's. Long-range transport to the Precambrian Shield on easterly flowing wind currents may be expected to increase appreciably with time due to increased emissions.

Sulphur dioxide emissions and stack conditions are well defined with data available. Stack gas desulphurization technology is available to remove in the order of 90% of the SO_2 emitted as well as virtually all the particulate matter, but at a very high cost as noted in GCOS's recent application for its proposed expansion program (GCOS 1978).

3.6.3 Other Utility Wastes

The boiler feedwater makeup systems involve the use of extraneous chemicals for ion exchange and other water treatment operations and these systems result in significant blowdown--at Syncrude to the tailings pond and to the river at GCOS. Generally the chemicals used and the blowdown itself, although high in solids and likely acutely toxic to fish in high concentrations, are not considered of concern when properly flushed to the river. These wastes are similar to those from major boiler operations elsewhere in the province.

Disposal of recovered fly ash with tailings may lend to leaching of slightly soluble vanadium and nickel compounds. (Both elements are normally in very low concentration coal and, hence, the oil sand fly ash is unique.)

3.7 OTHER OPERATIONS

3.7.1 Atmospheric Emissions

The release of hydrocarbon vapours from storage tanks, separators, and leaks may include some mutagenic and carcinogenic compounds. Product pipelines present the potential for spills, but various synthetic products have been considered inert from a toxic standpoint, and no toxic effects from any product spill has been reported.

3.7.2 Aqueous Wastes

There may be some potential long-term leaching of heavy metals (vanadium and nickel) from coke storage and recovered fly ash disposal areas (Sullivan et al. 1978). Delayed coke piles have existed for ten years with no specific evidence of a problem. Delayed coke does have some hydrocarbons and other organics on its surface as it is dumped from the coke drums which likely leach off in storage, but the amount is likely small relative to aqueous wastes from processing operations.

Sulphur piles are subject to very slow leaching, but the amount of acid produced is low and of concern only as it may dissolve metals with which it comes in contact.

3.8 SOURCES AND EMISSIONS SUMMARY

3.8.1 General

The above identification of sources of possible toxic compounds is very preliminary. In any case, more analysis is needed than provided above.

3.8.2 Introduced Chemicals

Only caustic soda and a minor amount of surfactant and water soluble gas treating chemicals are introduced into the oil sands mining and refining processes. Some chemicals are used in water treating and boiler conditioning. Solid catalysts are used, but these can be considered inert from a toxicity standpoint with normal handling and utilization procedures. Spills of the various chemicals are possible, but their toxicity effect will be local due to the small quantities involved. None of the chemicals or catalysts currently used is unique to oil sands processing. Generally, these chemicals are not toxic themselves, but may enter into reactions creating compounds with long-term toxic implications. Alberta Environment receives information on the consumption of these chemicals on a regular basis and notes any new compounds.

3.8.3 Atmospheric Toxicants

The above discussion has covered briefly a review of major toxic air emission possibilities. The inventory of atmospheric emissions (Shelfantoock 1977) projected quantities of various emissions and described their sources. The data provided in the Inventory require regular updating and source list correcting as better data become available and as processes change and new facilities are built. In situ production is a particular area needing further source and emission definition. That inventory, however, does not provide sufficient toxic emissions analysis except in the case of SO_2 and more up to date SO_2 data are available on a regular basis and backed by a strong series of monitoring stations. Some data are in the support files for the inventory but further analyses are needed to complete the picture.

An SO_2 emission projection for 1985 of 654 long tons per day is made up of 252 long tons per calendar day from GCOS, 282 tons from Syncrude (permit figure), and 120 long tons from Shell (estimated by writer).

3.8.4 Aqueous Toxicants

No water equivalent of the air inventory has been undertaken. The number of man-made source emissions to the river is quite small by comparison with natural flows. However, the variety of potentially toxic compounds present in certain of these flows is very large. Some analytical data are available but seasonal and process variations may not be well defined even for existing flows.

4. PROGRAM RECOMMENDATIONS

4.1 INTRODUCTION

This paper is oriented to the identification and quantifying of potentially toxic emissions to provide sound bases for predictive modelling of man-produced environmental stresses and their effects.

From the above discussions the following general grouping of work to be done emerges as far as toxic emissions are concerned:

1. Sulphur. How serious are the concerns noted and what needs to be done to analyze and monitor the biological stresses induced by sulphur;
2. In Situ Operations. How to define the potential emissions and develop suitable programs to monitor their effects; and
3. Trace Compounds. How do we select the proper compounds--both organic and inorganic--for detailed physical study and biomonitoring? And how will we monitor to insure that all serious biological degradation is identified in time for action?

All toxicological work should fit together not only with itself but other work relative to predictive modelling, regulation setting, and problem mitigation. The last two areas are outside group activities but it is essential to mesh with these as it is for AOSERP to co-ordinate its own internal work.

Monitoring suggestions are summarized in a later section and are touched on here only as they pertain to the definition of potentially toxic material emissions. As both the sulphur and in situ situations appear to warrant detailed problem definition at this time, initial overviews are recommended in the next two subsections in these areas. A further subsection will discuss trace compounds. This section will conclude with notes on management of the recommended activities.

4.2 SULPHUR PROGRAM RECOMMENDATIONS

Very significant data and studies have been developed by AOSERP, Syncrude, and others relative to meteorology, air chemistry, and ground level sulphur and particulate concentrations. Some work has started both in AOSERP and by others in the area of biological stresses due to airborne emissions. Serious concerns expressed about potential problems due to sulphur emissions have been noted above.

At this time a review of the data collected and assessment of possible implications are recommended along the lines of the following questions:

1. Where does all the sulphur go;
2. Will enough reach the Precambrian Shield to adversely affect that region's lakes in the foreseeable future;
3. Will the sulphur that settles in the region reduce forest growth rates directly or indirectly;
4. Will there be enough deposition at any one point to cause irreversible biological stress;
5. Will the sulphur deposition increase soil leaching and contaminate surface and ground waters with leached materials;
6. Is there toxicity related synergism between SO_2 emissions, NO_x emissions, particulate emissions, and other atmospheric components; and
7. What biological monitoring approaches are optimum relative to the AOSERP study area and sulphur and other airborne emissions?

The sulphur overview is intended to provide specific guidelines and programs for further AOSERP work in order to reach some degree of stress predictability in the next two years. Long-term biomonitoring will be needed to correct the models in any case and should also be an area where recommendations are provided.

The following is our recommended sulphur overview program:

General Management - AOSERP

Project Management - A senior specialist in sulphur emissions.

Other Participants - Meteorologist
- Vegetation specialists
- Chemist (air and surface reactions)
- Chemist (lake chemistry)

Terms of Reference - Prepare overview of SO_2 and related emissions in the AOSERP study area and their possible detrimental effects inside and outside the region:

1. Develop sulphur inventory.
2. Estimate sulphur transport patterns.
3. Estimate aerial chemical transformations as appropriate.
4. Estimate sulphur (and related elements and compounds) ground level balances at representative points through the AOSERP study area and on the adjacent areas of the Precambrian Shield. Possible heavy metal (e.g., vanadium) solubilizing is a specific aspect to be considered as is the selenium/sulphur balance.
5. Estimate assimilative capacity of groundwaters, soils, and vegetation at such places.
6. Identify possible biological stresses induced by this sulphur and related materials.

- Recommend further work by AOSERP relative to SO_2 and related emissions.
- Review existing monitoring programs and recommend changes and/or additions.

Costs - A budget of $40 000 has been estimated for this overview.

Timing - This overview is estimated to require six months, with an interim report required after two months (relative to other AOSERP work then in progress).

Generally no field or laboratory work is anticipated in this overview.

Low level emission work discussed below should be co-ordinated with the sulphur overview.

The sulphur overview should be viewed as an intermediate step--it will put the current concerns in perspective and may recommend an integrated ongoing program covering areas of AOSERP activity other than emission toxicology per se.

4.3 IN SITU PROGRAM RECOMMENDATIONS

Broadly based concerns relative to in situ production have been noted above. Data are not readily available to analyze these concerns and it appears likely that it will be some time before such data become available. However, some AOSERP activity (beyond the current air monitoring program) is warranted to define potential toxicity related problems and to develop suitable monitoring systems.

The following is the recommended In Situ Overview program:

General Management - AOSERP.

Project Management - In situ production technology specialist.

Other team members - Geologist knowledgeable in specific region.
- Groundwater hydrologist knowledgeable in specific region.

- Chemist with sound geo-organic knowledge.
- Scientist involved on the University of Calgary in situ pilot test program.

Study Focus - Area 20 km^2 to side with northeast corner at Anzac as shown in Figure 1.

Terms of Reference -
1. Define from available data geological parameters of study area relative to potential pathways for toxic compounds to exit the normal production zone and to move to areas where toxic effects may occur.
2. Develop lists of types of compounds to be expected from various steam stimulation and in situ combustion production approaches. Define toxic compound possibilities. (One or more tests in the University of Calgary pilot plant are anticipated as necessary to develop the necessary data.)
3. Estimate the potential movement of toxic compounds from the original formations into surface waters and/or into the atmosphere (other than in the oil recovery system).
4. Recommend surface and groundwater baseline definition and monitoring programs for regions of in situ development and possible in situ developments in the AOSERP study area.

Timing - 6 months.

Cost - $50 000 estimated.

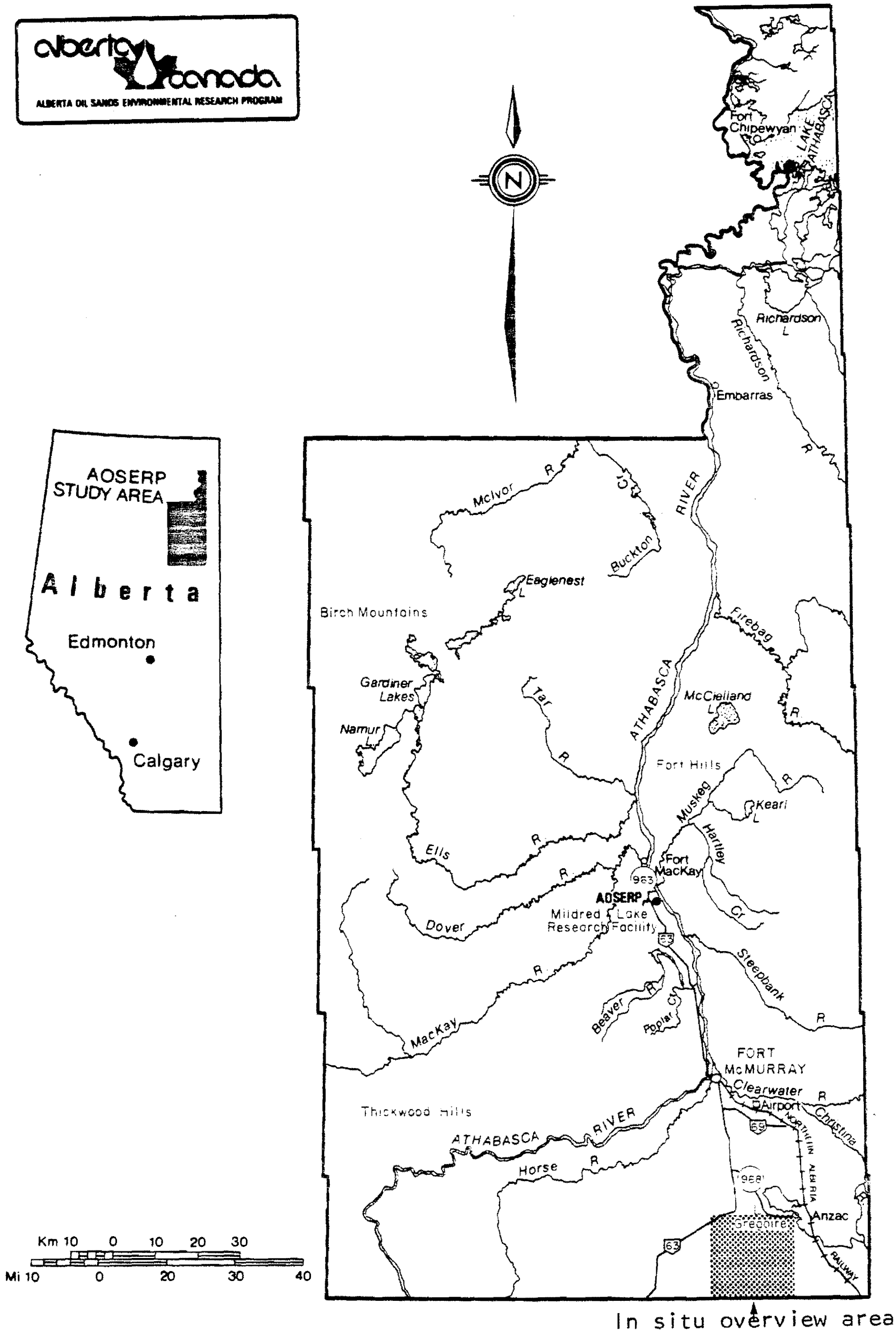

Figure 1. AOSERP study area and in situ overview area.

The study area has been selected to coincide roughly with three of the most advanced in situ production research projects in the AOSERP study area--AMOCO, Gulf/Numac, and Petro-Canada. (The Texaco Fort McMurray pilot project has somewhat similar geology, but is outside the proposed study area. As a steam stimulation project it may have lesser concerns than the AMOCO combustion project.) A specific small area has been selected to permit a fuller analysis than is possible on a larger area or than if an unsited approach is used. The University of Calgary in situ "fire tube" facility will provide directional data on chemicals produced. It may not fully reproduce the long "soaking" time possible underground and some sample retention at high temperatures for later analysis is recommended. Other University of Calgary departments are fully capable of performing all analyses required.

University of Calgary work on the reactions of steam with hot bitumen is also of value here.

The Alberta Research Council staff has the most relevant expertise in both groundwater and geology in the study area and hence is best suited to make projects and recommendations in an area where fully detailed geological and hydrology data are not available.

Upgrading of the produced heavy oils will be excluded from this particular program as emissions from such processing will be essentially the same as those of other upgrading operations.

AOSTRA participation in this in situ overview would be of appreciable value and its provision of samples and/or data from University of Calgary test runs sponsored by it could cut the cost of the program appreciably.

4.4 TRACE COMPOUNDS PROGRAM RECOMMENDATIONS

4.4.1 General

This program is a group of related sub-programs covering a variety of the other concerns noted previously. It integrates slightly with the sulphur overview in the areas such as heavy metals solubilizing in low pH soils and will eventually integrate very closely with in situ programs. But more particularly it integrates almost completely with the biomonitoring and sampling study discussed in Section 5.

The trace compound program will concern itself with:

1. Identification of emissions;
2. Defining those that are potentially toxic (including mutagens);
3. Defining natural chemical and biodegradation of those defined as potentially toxic;
4. Providing background studies relative to sampling, analytical techniques, reporting techniques, and other aspects as needed; and
5. Providing data to other AOSERP programs and to outside agencies.

While the bulk of the efforts will be directed toward water-borne toxicants, some effort will be given to low level air-borne compounds. There will be coverage of materials potentially carcinogenic in humans, but the bulk of work will concentrate on the aquatic environment.

It will be impossible to identify all the individual compounds or even all the groups of compounds likely to cause toxic effects and synergy between compounds may appreciably alter toxic effects. Hence, a sound biomonitoring program is essential and of greater importance than the trace compound program. But as chemical structure is gradually being related to toxicity (especially in mutagenicity and carcinogenicity), a good knowledge of what chemicals are present is needed to take full advantage of toxicity work in other areas in the development of predictive models (Hall 1977).

The trace compounds program has been broken into five main sectors for discussion purposes:

1. Minerals - covering trace minerals complexes and forms in water.
2. Process - covering emission data collection and process samples.

3. Specialists' Panel - multi disciplinary overview and advice.
4. Water - aqueous effluents and river sampling.
5. Air - particle and aerosol collection (low level).

Figure 2 provides a breakdown of the overall trace compound program with the various elements discussed below.

4.4.2 Minerals Sub-Program

The objective of this sub-program is to define if any of the possible heavy metal (e.g., vanadium and nickel) compounds that are or may be present have toxic implications. Work will be undertaken to identify and isolate metal compounds present in natural streams, extraction and fly ash, and coke storage leachmates. Laboratory production of metal compounds and complexes will be carried out duplicating anticipated water and/or soil conditions insofar as possible. Chemical stability of metal compounds and complexes in river systems will be studied in laboratory experiments.

AOSTRA projects and work funded by others on extraction, clay minerals, and heavy metals related subjects will be considered in this program. (Possible integration of the minerals sub-program with AOSTRA university research programs should be explored before this sub-program is commenced.) Industry input will be solicited, particularly as much current work on oils and extraction processes is confidential, but may have relevancy to this sub-program.

Isolated and/or produced compounds will be tested for toxicity in the central toxicity analysis program discussed under "water" below. The "minerals" and "process" sectors will interface closely relative to in-plant chemical balances and with the "water sector" relative to river chemistry. As with other sectors, the specialist panel will provide overview and specialist advice on a regular basis.

This "sector" is not capable of being as explicably defined as other sectors. Possible compounds and their toxicity are largely unknown at this time and there may not be long-term toxicity problems

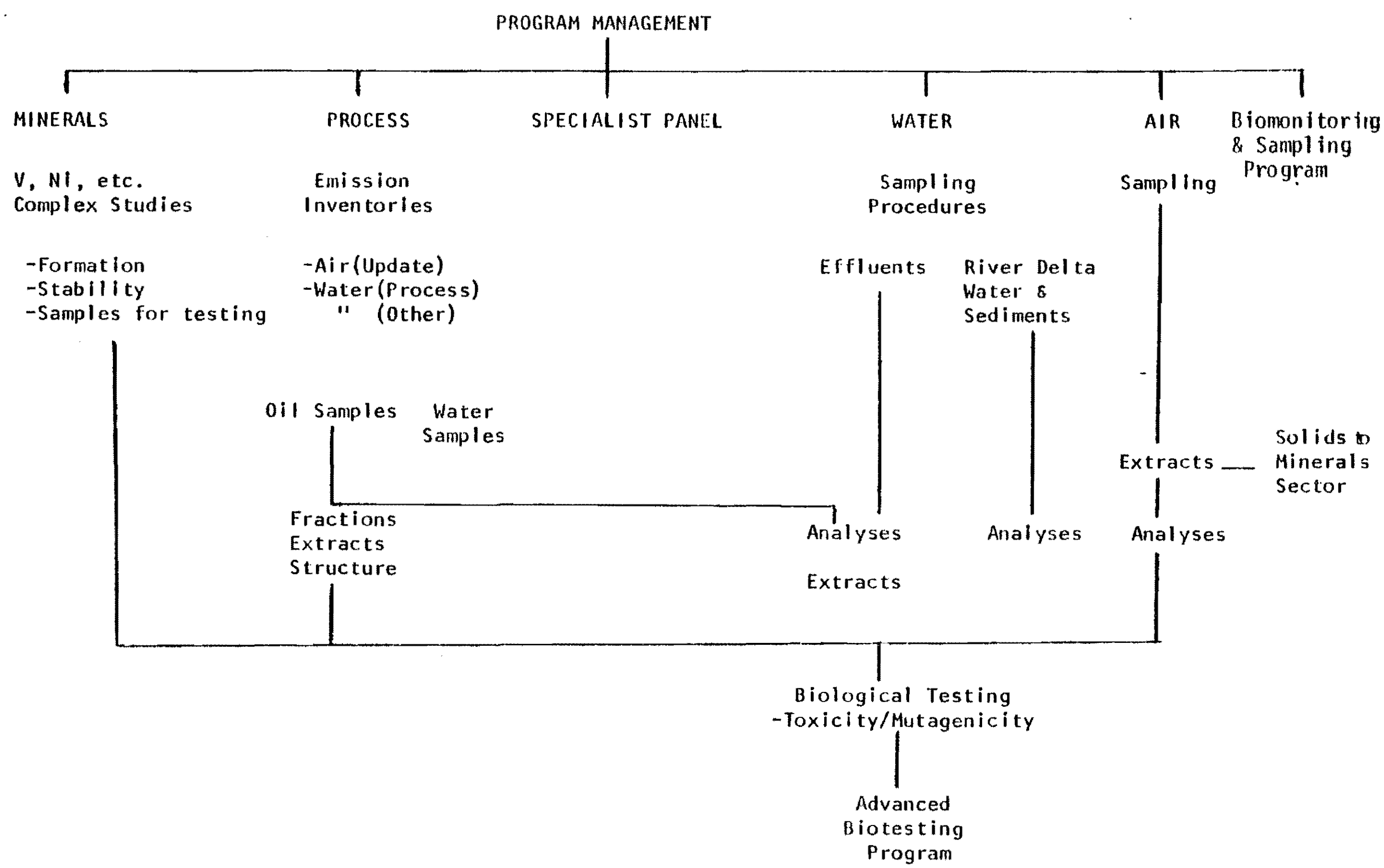

Figure 2. Trace compound program.

in this area. A one-year program is proposed with a second year to be decided upon approximately four months before the first year ends. Funding at a rate of $80 000 in the first year is recommended. (A second year with the same funding should be anticipated.)

Figure 3 provides a brief breakdown of recommended work for year one of the minerals "sector". Progress in the complex sub-program will likely determine the success of this year's efforts.

4.4.3 Process Sub-Program

The contractor for this sector will provide oil sands technology knowledge throughout the trace compounds program and will assist relative to upgrading aspects of in situ production as the in situ overview discussed above excludes upgrading.

Identification of chemical structures of compounds present in various fractions of bitumen, intermediate stream, and synthetic crude oils will be co-ordinated by this contractor although any actual analyses to determine structures will be done by the Hydrocarbon Research Center at the University of Alberta, the University of Calgary, and/or the Alberta Research Council. Input on potentially mutagenic structures and analytical procedures recommendations will be provided by the specialist panel.

The various process water streams and their sampling will also be the responsibility of this sector working with the "water" sector.

As Figure 4 shows, this sector will also upgrade the air emission inventory to reflect chemical composition in more detail than at present. This will entail co-ordination with the air sector portion of the trace compounds program. An aqueous effluent inventory will also be prepared for oil sand projects, current and projected. There are three optional "extras" that may be considered:

1. Revise existing inventory of air emissions computer programs and update entire inventory records with the expanded chemical data. (Otherwise only written data will be available--suitable for this program,

Literature Search to establish priorities
Contacts with other workers on related projects - AOSTRA and its university research groups, industry, federal Departments of Energy, Mines and Resources and other university groups.
(Finalize Scope of Work & Work Plan)

Inorganic Program
- Sample and analyze Fly ash from Syncrude and GCOS
- Analyze nonbenzene soluble particulates from "air sector" sampling
- Identify possible forms
- Detailed Literature search-toxicity bioaccumulation, mutagenicity, etc.
- Test Solubilities and Reactions in river water and soils (modified by SO_2,etc.)
- Prepare samples for toxicity testing

Complex Program
- Sample natural streams
- Collect plant & In Situ test program Samples
- Identify trace metals present
- Identify trace metals forms present
- Extract (if possible)
- Prepare artifical complexes
- Test solubilities, stability and reactions in river environment
- Prepare samples for toxicity testing.

Summarize progress
Recommend further work

Figure 3. Minerals sub-program, year one.

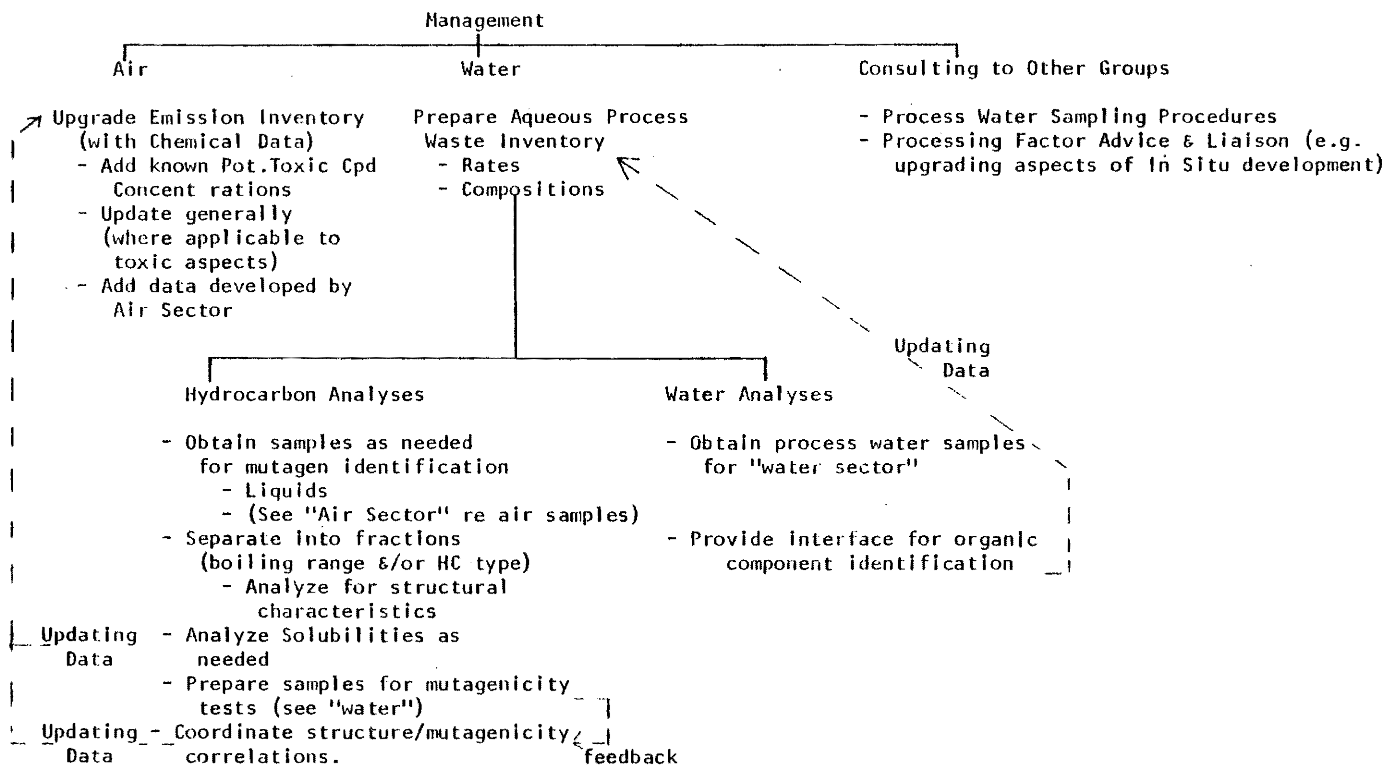

Figure 4. Process sub-program, year one.

but of little value for other work);

2. Prepare a computer data base for water effluents similar to the expanded air emission system. Such an approach does not appear essential for emission toxicity per se, but is strongly recommended if an overall water material balance program is developed; and
3. Add natural, municipal, and other water inputs (not directly related to oil sand projects) to the water inventory.

These options would increase first year costs, but may be worthwhile for other portions of AOSERP work. The lack of use to date of the air inventory is a cause for concern and potential users must be requested to define their needs relative to format and content before any revisions are made to the air inventory or a computer-based water inventory is attempted.

Relating mutagenicity and carcinogenicity to molecular structure is an end objective of this sub-program. As knowledge is accumulating for lower forms of life, at least, some correlations may be possible during AOSERP's term. For example, the University of Alberta's Genetics Department, in conjunction with a number of other North American institutions, will complete in the first half of 1979 a comprehensive study of techniques for, and correlations of, mutagenisis and chemical structures (Von Borstel personal communication November 1978). But work in this area is at an early stage, especially for comprehensive use in programs such as AOSERP.

Confirmation that raw bitumens and synthetic crudes are not toxic in any short or long context sense is a necessary activity of the process and water sub-programs. This has been assumed in this report and by others but needs full scientific verification.

Much of the process sector work can be completed in one year but ongoing advice and overview will be needed in other sectors. Also there will be a continuing need to update the inventories, relative to potentially toxic substances as new projects are defined, existing plants change and revise processes, structure/mutagenic relations are established, and as the toxicity of various effluents is evaluated. We estimate expenditure of $80 000 for the sub-programs (without options but including same hydrocarbon characterization analyses) presented on Figure 3 for the first year (with an allowance of $40,000 per year in subsequent years for support and updating activities).

The tentative AOSERP Project WS 1.2.2 "Regional Inventory of Water Use Requirements and Effluent Discharges" is more extensive than the basic water effluent inventory proposed here, but may be a more realistic overall approach in the AOSERP program and will not be much more in dollar terms (roughly $30 000 in the first year). Possible use of developed data in river simulation model development should be considered in any case (Hodgson 1978).

4.4.4 Specialists' Panel

This panel will act as the quality overviewers throughout this program, as well as provide expert advice as needed and may directly supervise special short high technology studies and/or laboratory work. They will not be involved in program management.

We envisage a core to the panel of four recognized specialists in various fields, with specific experience in the AOSERP study region, such as:

G.W. Hodgson	Environmental Services Centre, University of Calgary
D.S. Montgomery	Hydrocarbon Sciences Centre, University of Alberta
P. Von Borstel	Genetics Department, University of Alberta
J.W. Costerton	Biology Department, University of Calgary

The specific roles of the specialists' panel will be:

1. Overview and critique this plan;
2. Overview and critique proposal requests for the various sectors and their sub-programs where applicable;

3. Overview and critique formal plans for each sub-program as it is initiated;
4. Overview each sub-program on a regular basis (at least every 3 months);
5. Provide expert advice to the various sub-programs--updating on related current work, suggesting approaches to be taken, recommending analytical procedures, etc.;
6. Provide overview and critique of the overall trace compounds program and recommend changes and/or ongoing work; and
7. Where very specialized short term studies and/or laboratory programs are to be undertaken, members of the panel may personally direct these.

The panel will not participate in AOSERP management or in the management of the sub-programs, other than through the above-noted activities.

The core panel members will be retained for a minimum of 25 days per year with approximately 12 days spent in meetings and discussions and the rest in preparatory work. Other specialists will be retained on an as-needed basis. A budget of $70 000 per year is required for the panel allowing for studies or laboratory work proposed by the panel.

4.4.5 Water Sub-Program

The water sub-program contains the bulk of laboratory work in the trace compounds program. The provision of toxicity testing of minerals, process, and air sectors will be complementary to the principal objectives of identifying toxic compounds in aqueous effluents. As short-term toxicity problems have not been identified to date, the emphasis will be on mutagenic and bioaccumulation activities.

The water sub-program must fully integrate with the development of aquatic biomonitoring and sampling studies and field work and these latter activities may take precedence over this sub-program in certain cases and revise the recommendations set out here in others.

The water sub-program may be divided into a squence of 3 steps:

1. Sampling;
2. Physical testing and bioscreening; and
3. Advanced biological testing.

The latter phase will evolve from the results of the preceding phase and the biomonitoring and sampling program discussed in the next section. The planning for an advanced biological testing program must be largely done during Phase 2. We have not attempted to define advanced biological testing except to assume that it must cover bioaccumulation and other life cycle aspects of compounds indicated as long-term toxicants.

A biological specimen bank was previously proposed for long-term effect evaluation (Chemical and Geological Laboratories Ltd. 1977). This will require facilities mainly after AOSERP's term and hence commitments by others. The specialists' panel should consider this and recommend further action, if any, by AOSERP.

The sub-programs of this sector are outlined in Figure 5. Generally the initial work is an expansion of earlier work (Strosher and Peake 1976, 1978) and is aimed at characterizing aqueous wastes and attempting to define persistency factors, if any, of the released potentially toxic substances. Mutagenicity testing will follow the characterizations to attempt to establish critical groups of compounds for persistency testing (including conventional chemical biodegradability). Individual compounds will be identified in the major groups to relate mutagenicity test results to structural relationships developed in this program and elsewhere.

The chart does not show any samples from in situ operations, but these may be available and should be at least considered in the biotesting work.

The advanced biological sub-program has not been adquately defined here to recommend organization and approach. It is recommended that the specialists' panel review this, in parallel with biomonitoring and sample study development.

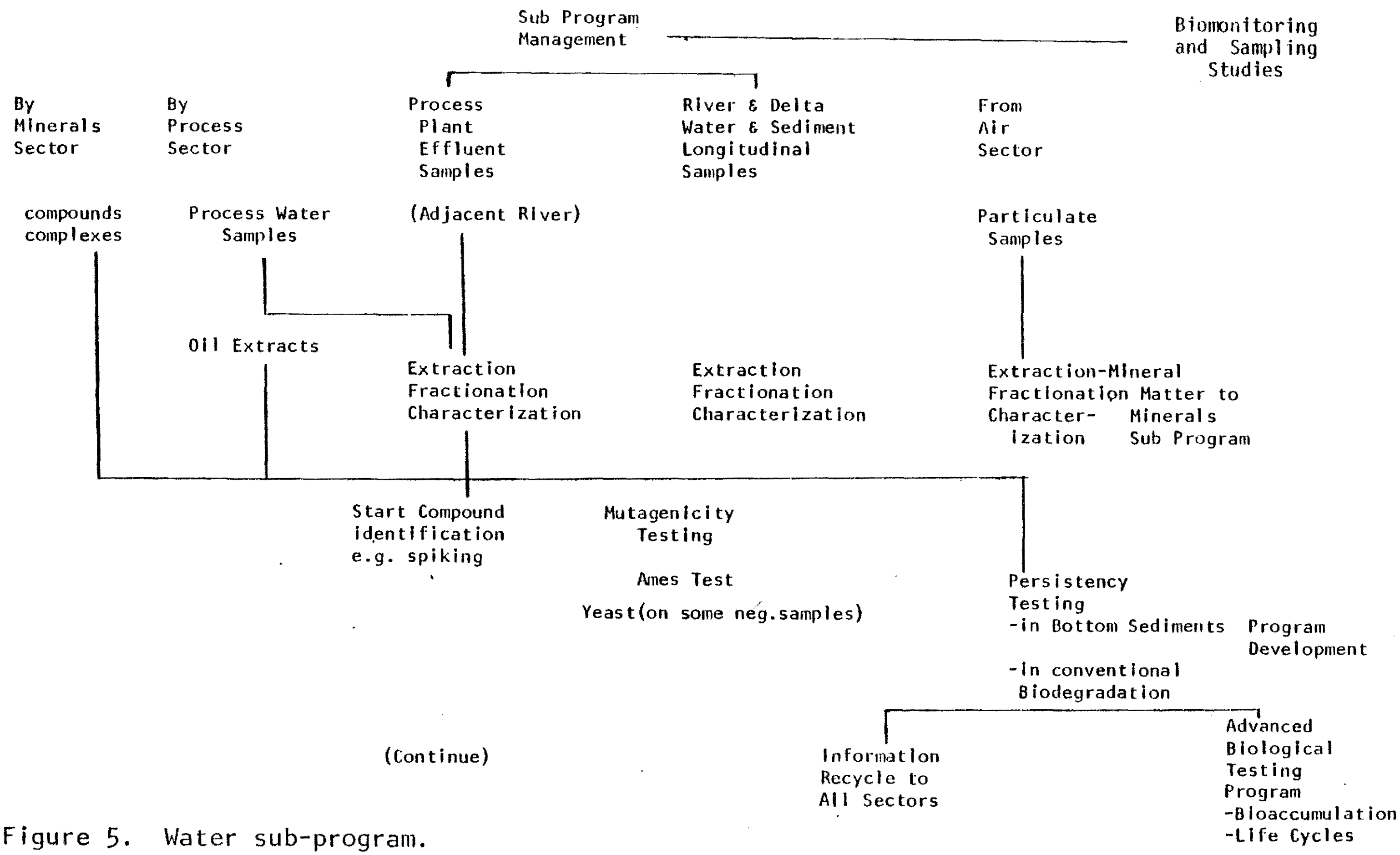

Figure 5. Water sub-program.

At $300 per Ames test, the water sector laboratory programming will of necessity be very selective as to the number and the nature of each sample analyzed. Hence, crash approaches do not appear appropriate. The time of year may be of importance even to plant effluent samples (due to chemical and biological activities in the various effluent channels and ponds), a concern to be considered in the finalization of the sector sub-programs.

At this time, we estimate approximately $100 000 will be required in each of two years to bring the water sector to the advanced biological testing stage, but again we note the need to fully integrate with all aqueous biomonitoring development activities.

4.4.6 Air Sub-Program

This sub-program as defined here is concerned with potentially toxic materials in the air other than SO_2, as covered under the sulphur overview. Its focal point will be presence of mutagenic and carcinogenic compounds in the air (as other toxic compounds do not appear to be present in significant amounts). The very limited work to date indicates that any deposition of mutagenic/carcinogenic compounds will be largely in the immediate area of the plants.

The testing of compounds collected under this sector will be handled by the water and/or minerals sectors, as appropriate. The air sector may be formally integrated into the process or water sectors but, as it is the major linkage to industrial health surveys and analysis from a toxicity viewpoint, its individual identity should not be lost.

Some additional testing is proposed herein relative to inorganic materials and relative to mutagenicity. A number of low level samples will be required near Syncrude and GCOS and at meteorologically selected sites in the surrounding area. Samples from Bitumount, Birch Hills, and Fort McMurray should also be examined for baseline definition.

A check on the percentage recovery of mutagenic compounds in high volume air sampling equipment is necessary. While appreciable variation in hourly and daily low level emission rates is expected, the low acute toxicity and long-term accumulative effects of the compounds covered in this sub-program indicate little need to get more than long-term samples.

We estimate an expenditure of $60 000 per year (for each of two years) for this work (including analyses covered under the "water sector" and sample collecting) with The University of Calgary Environmental Sciences Center, the appropriate agency because of its continuity from previous work (both in the AOSERP region and elsewhere in Alberta).

Integration with activities of the Dr. W.W. Cross Cancer Institute, the Alberta Department of Labour's Occupational Health and Safety Division - Occupational Hygiene Branch and with the panel's genetics specialist will be essential.

4.5 PROGRAM MANAGEMENT

The work to identify potentially toxic materials requires very appreciable integration and co-ordinated effort. While the sulphur overview and the in situ overview both lend themselves to teams working largely on their own under general AOSERP management, the same is not true of the trace compound program. The direction of that program should be from within AOSERP.

Except for the minerals sector and the undefined future advanced biodegradability program, most of the work can be programmed in advance. Planning and then cost and time controls will be the major activities of the manager.

The programs recommended will in some cases not be complete at the end of AOSERP's initial 5-year period. Advanced biotesting will not be complete and time may not be available for the completion of documentation from the more conventional work involving seasonal factors which must span at least 18 (and preferably 24) months.

Table 2 presents a summary of estimated costs of the recommended programs. The relatively high percentage for integrating activities, such as management and the specialist panel, is to be

Table 2. Recommended program cost estimate[a].

Program	Sector/Stage	First Year		Second Year	
Sulphur	Overview	40		-	
	Ongoing	40[b]		100[b]	
	Total		80		100
In Situ	Overview	50		-	
	Ongoing	50[b]		50[b]	
	Total		100		50
Trace Compounds	Minerals	80		80[b]	
	Process	80		40	
	Panel	70		70	
	Water	100		100	
	Air	60		60	
	Management (AOSERP)	50		50	
	Total		440		400
Contingency			60		60
Overall[c]			680		610

[a]Figures are in $1000.

[b]Allowance for work resulting from overview (or first year) but not now in AOSERP plans or in programs recommended herein.

[c]This table does not cover any monitoring program recommendations.

noted but is necessary to achieve the multidisciplinary approach considered essential in these programs.

5. MONITORING RECOMMENDATIONS

5.1 SULPHUR DIOXIDE AND RELATED COMPOUNDS

The monitoring related recommendations of the sulphur overview will probably be largely oriented to biomonitoring if serious concerns are identified. The actual emissions of SO_2 and particulates are reasonably well known and ground level SO_2 levels are very closely observed near the two existing plants.

The emissions of the various nitrogen oxides are not nearly as well defined. It was previously recommended that studies be done to develop a better understanding of the rates and composition of natural emissions of all types in the region (Shelfantoock 1977). The many natural emissions (e.g., NO_x, hydrocarbons, and chemicals formed in the atmosphere) may be very important to the region's air chemistry and the sulphur overview should be specifically asked for recommendations in these areas.

5.2 IN SITU DEVELOPMENTS

The in situ overview should provide recommendations for monitoring emissions of all types from experimental and prototype in situ production operations beyond the existing AOSERP/AMOCO joint air monitoring program.

5.3 AQUEOUS SYSTEMS

5.3.1 General

Toxicants in acute concentrations enter the river system only due to very occasional abnormal operations and not on a regular basis. There is no evidence of short- or medium-term biological stress in the river or related delta areas. Hence, long-term toxicity aspects appear to be of most concern and this requires on-going biomonitoring programs in the lower river and delta regions to detect any adverse stresses. As noted above, the multiplicity of potential long-term toxicants and their possible synergy with each other and with otherwise inert materials necessitates parallel development of knowledge of the toxicity of specific emissions and of a responsive biomonitoring programming. The biomonitoring program will be the most important until suitable predictive models can be developed.

Sampling of the river itself can be done reasonably well by traverses at fixed intervals, samples being taken at repetitive points and depths and averaged at each traverse. Due to river mixing taking an appreciable distance to approach full dilution, the accuracy of such an approach will be lower at the point of effluent discharge. In the delta region, however, even with water sampling it will be difficult to achieve a degree of confidence in the validity of test results.

Both sediment and aquatic organism sampling is further complicated by changing river bottom geography and sediment concentrations. Annual and seasonal variations, and variations due to natural phenomena such as bottom scour, greatly complicate the sampling problem.

5.3.2 Biomonitoring and Sampling Study Recommendations

At this time we recommend a program of attack on the river sampling problem. A study should be commissioned to:

1. Summarize all AOSERP and related work to date relative to river sampling;
2. Review and comment on current river water sampling procedures relative to future biomonitoring programs;
3. Establish delta region water sampling procedures;
4. Establish river bottom sediment sampling procedure programs;
5. Recommend delta region bottom sediment sampling procedures; and
6. Recommend biological specimen sampling procedures for a monitoring program.

There will be several stages in each of these sectors including appreciable field testing to determine mixing and natural changes.

Parallel with a sampling study we recommend a study to identify the bio-organism(s) that should be monitored. While many of the specialists interviewed considered a long-term biomonitoring approach essential, no firm recommendations were received. The bio-monitoring program will consist of both correct sampling and the representative organism(s). As the costs of any biomonitoring program will be very significant (especially when a 3- to 5-year period is probably needed to establish good baseline data), program design is of great importance.

5.3.3 Other Aspects

Upstream industrial and agricultural development is of major importance and upstream quality monitoring is a continuing necessity. Such testing must cover the same tests (physical and biological) as downstream. The presence of agricultural chemical specialties has been noted in the Athabasca River, hence, agricultural operations and their emissions are also of concern in this regard. Activities in the municipal and recreational areas, both in the study region and upstream, will also be of concern in trying to define "natural" ranges.

Pond leakage has been noted to be of major concern but evaluation of the test borehole sampling approach is needed to confirm its adequacy to detect leaks in time to institute remedial measures. Knowledge of groundwater conditions--at least data in the public domain--appears limited to adequately assess the current program.

The development of an adequate river/delta sampling and biomonitoring may take 24 months due to the need to consider seasonal changes. The cost of such development work has not been estimated.

5.4 HUMAN ASPECTS

The Human System of AOSERP has proposed studies on human and mental health in the region. The monitoring of human health is of major concern and herein only some aspects of possible carcinogenisis have been noted. The Human System should work closely with the Dr. W.W. Cross Cancer Institute and Alberta Labour on this aspect and all identifications of potential carcinogens should be co-ordinated with those agencies. Some work in the air sub-program may provide data on emission of such compounds in this regard and samples of various products and intermediates from oil sand upgrading (process sub-program) may show compounds considered carcinogenic (but not necessarily emitted from any plant).

5.5 SUMMARY

Table 3 presents a quick overview of physical and biomonitoring recommendations. The toxic compounds program will itself provide appreciable background data, but will not be part of any monitoring process except by accident. The need for proper river and delta sampling and biomonitoring programs is to be emphasized. Such data are needed as much to define "where we are" as to show "where we are going".

Table 3. Emission monitoring activities.

EMISSION	PRESENT PROGRAMS		FUTURE PROGRAMS					NOTE
			SOURCE DATA		IMPACT DATA			
	PHYSICAL	BIOLOGICAL STRESS	RATE (a)	COMPOSITION (a)	GROUND CONC. (a)	GROUND COMPOS. (a)	BIOLOGICAL STRESS (a)	
TO ATMOSPHERE								
High Level SO_2	Plt Data & Major Network for Grnd. Conc.	In house (GCOS) Syncrude etc. AOSERP (plots)	Plt.Data	Plt.Data	Continue Existing& Expand - Long Range Network Possible	See Ground conc.	Formal test Plots Lichen counts Growth tests(?)	See Air System Data Directory - AOSERP June 1978- for details of Existing Monitoring
NOx	Calc'd (Backgnd Monitors)	(with SO_2)	Occas.Plt Test	Occas.Plt Test	See SO_2	See SO_2	See SO_2	
Particulates	Plt.Data & Network for Grnd.Conc.	(with SO_2)	Plt.Data	Occas.Plt. Test	See SO_2	See SO_2	See SO_2	
Heavy Hydrocarbons	-	-	Est'd.	Est'd & Tests	Occas. Sampling	Sample Analysis	Worker Health record assessment	

Continued . . .

Table 3. Concluded.

EMISSION	PRESENT PROGRAMS		FUTURE PROGRAMS					NOTE
			SOURCE DATA		IMPACT DATA			
	PHYSICAL	BIOLOGICAL STRESS	RATE	COMPOSITION	GROUND CONC.	GROUND COMPOS.	BIOLOGICAL STRESS	
TO ATMOSPHERE (Cont'd.)								
Low Level Hvy.Hydrocarbon	-	-	Est'd.(b)	Est'd &Tests(b)	(combined with High Level Hvy Hydrocarbons)			(b)
TO RIVER/DELTA			(c)	(c)	(c)	(c)	(c)	
Process Effluents	Plt.Data &Special Tests	(fish tests)	Plt.data & Special Tests	Plt. data & Special Tests	Regular River Surveys	Regular River Surveys	Fish Tests (AE req'd.) Biomonitoring System	
Mine Depressuring Water	Plt.Data & Speical Tests	(fish tests)	Plt.data & Special Tests		-	Regular River Surveys	Fish Tests (AE req'd.) Other bio tests	
Extraction Water	Plt.Data & Special Tests (d)	(fish tests)	Plt.data & Special Tests	Plt.data & Special Tests	-	"	Biomonitoring (b)	
Other Exploitation Wastes	Plt.Data & Special Tests (d)	(fish tests)	Plt.Data & Special Tests	Plt.data & Special Tests	-	"	"	

NOTES: (a) Sulfur Overview will provide recommendations - those shown are very preliminary.
(b) Emphasis on mutagenic / carcinogenic compounds.
(c) Biomonitoring studies will provide recommendations - those shown are very preliminary.
(d) Test holes monitor pond leakage to groundwaters.

6. SUMMARY

This plan for the identification of potentially toxic emissions from oil sand developments has been based on a survey of over 40 specialists in various aspects of environmental protection and oil sand development and upon the writer's analyses of oil sand development activities.

The survey solicited comments on toxic emission related problems and concerns and on approaches to defining the concerns. The survey indicated no firm awareness of serious existing biological stress. However, several concerns were expressed relative to possible significant long-term biological stress due to sulphur dioxide emissions, in situ developments, and the presence in air and water emissions of compounds potentially mutagenic and carcinogenic.

The sulphur dioxide emissions are anticipated to increase to 654 tons per day when the Shell plant comes on stream and the GCOS expansion is complete. As Syncrude, Shell, and GCOS further expand, and as full scale in situ developments proceed, the emission may be anticipated to increase at least to a level equivalent to the total emissions from all Alberta natural gas processing plants (440 long tons of sulphur per day in 1977). Concern for the lakes on the Precambrian Shield has been expressed due to these sulphur emissions, the concern reflecting eastern Canadian and northern European problems. An overview of all aspects of sulphur emissions is recommended to define the potential problems and to recommend further AOSERP studies in this regard.

Possible leakage of toxic compounds from in situ developments was noted as a concern by many. The lack of data in this regard and the potential magnitude of any such leakage prompt a recommendation for a review of in situ production technology as applied to one small area of the AOSERP study region relative to possible leakage of toxic compounds to groundwaters. This review will also provide a background for AOSERP planning relative to in situ developments.

Other concerns are largely relative to trace organic and inorganic compounds and complexes of both and their possible long-term damage to aquatic life and man. These concerns are largely chronic in nature as instances of possible acute toxicity appear to be quite localized in occurrence and activity. The proposed trace compounds program will be broad to cover the many chemicals present and the possible environments within which they will react, degrade, and/or be bioaccumulated.

The review shows few introduced chemicals and those that are introduced now do not appear to be of direct concern, but may assist in creating toxic complexes. Data on air emissions have been previously documented, but it is recommended that work be updated and significantly more chemical data be added to the data bank.

No inventory of aqueous waste data including rates has been developed and one is recommended (possibly including all natural flow as well). The great range in flows and compositions greatly complicates such an inventory and it appears necessary to carry the analysis back into the various processes to properly characterize the waste (and to provide for changes).

The trace compound program will also bring together previous work in AOSERP on characterizing organic constituents in aqueous streams and on-going work for the Alberta Environment Research Secretariat on potential carcinogens emitted to the air. Tying into the trace compound program will be biomonitoring and sampling studies to develop the sampling and biomonitoring techniques needed for AOSERP aqueous biomonitoring activities.

The problems and concerns noted in the interviews have been largely in the form of broad general statements of the problem, but we expect some gaps have been left and some work needed in the future which has not been anticipated. This emphasizes the need for comprehensive biomonitoring programs.

A full toxic literature search of the various compounds that might be present was not carried out due to their very large number, but significant literature search is recommended in all proposed programs. Such data as we did find were not relative to long-term aspects in similar receiving systems.

A full toxicological program is not presented as the ongoing land vegetation monitoring and in situ aspects are not considered beyond the overview stage. Also, aspects of short-term affects were assumed to be largely concerns of Alberta Environment and the individual operating companies. However, the major long-term concerns have been covered with those exceptions. The overall plans presented total approximately $650 000 per year for two years, but ongoing commitments may result. Consideration of the continuity beyond the AOSERP initial five-year mandate is necessary in several instances.

Existing monitoring programs are recommended as continuing with recommendations for enhanced monitoring to come out of the above-noted programs including the biomonitoring and sampling study work. Biomonitoring appears to be the major end object, but major confidence in this approach is some years away. Human aspects are touched on only in the area of cancer with a very long-term monitoring process.

Throughout this review, no areas appear to warrant crash work. Many of the concerns expressed were common to other industries and other regions. But the work proposed does not appear to have major synergism with work elsewhere other than for mutual insight and guidance.

This plan is intended to be a working document on which to base the ongoing AOSERP toxic emission activities.

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8. 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
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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
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
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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
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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
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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
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49.	WS 1.3.3	The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
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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	Self-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

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Alberta Oil Sands Environmental Research Program
15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta T5K 2J6