ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM INTERIM REPORT COVERING THE PERIOD APRIL 1975 TO NOVEMBER 1978

by

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ALBERTA OIL SANDS

ENVIRONMENTAL RESEARCH PROGRAM

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Table of Contents

	Page
DECLARATION	ii
LETTER OF TRANSMITTAL	iii
SUMMARY STATEMENT	iv
AIR SYSTEM	iv
LAND SYSTEM	vi
WATER SYSTEM	vi
HUMAN SYSTEM	vii
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
ACKNOWLEDGEMENTS	xvi
INTRODUCTION	1
OIL SANDS DEVELOPMENT	1
HISTORY OF AOSERP	1
RESEARCH DIRECTION AND POLICY	2
Program Objectives	3
Year 3 Objectives	3
THE AOSERP STUDY AREA	4
THE CLIMATE	4
THE LAND	7
Geology	7
Topography	8
Vegetation	9
WATER	11
Surface Waters	11
Groundwater	12
THE HUMAN POPULATION	15
Fort McMurray	15
Fort Chipewyan	15
Anzac	15
Fort MacKay	15
AIR SYSTEM	16
METEOROLOGICAL ASPECTS OF AIR QUALITY	16
Temperature	16
Wind	16
Precipitation	19
AIR QUALITY	19
Natural and Man-made Atmospheric Constituents	19
Dispersion and Chemical Transformation	19
Air Quality in the AOSERP Study Area	20
Dispersion	22
Plume Chemistry	23
Deposition of Sulphur	23
AIR SYSTEM STATUS	30
LAND SYSTEM	31
SURFICIAL CHARACTERISTICS	31
Soils	31
Vegetation	32
FAUNA	34
Ungulates	34
Wolves and Other Canids	34
Furbearers	35
Black Bear	36
Other Mammals	36
Birds	36
Waterfowl	36
Upland Game Birds	37
Non-game Birds	37
Raptors	38
Other Fauna	38
RENEWABLE RESOURCE USE	38
Forestry	38
Trapping	38
Outdoor Recreation	39
WATER SYSTEM	40
HYDROLOGY	40
WATER QUALITY	43
Major Ions	43
Suspended Materials and Sediments	46
Nutrients	49
Trace Metals	50
LAKES	51
Buffering Capacity	52
GROUNDWATER	53
Shallow Groundwater	53
Deep Groundwater	53
MICROBIOTA	54
INVERTEBRATES	56
FISH	58
Walleye	59
Northern Pike	60
Goldeye	61
Grayling	61
Lake Whitefish	62
Mountain Whitefish	62
Yellow Perch	63
Longnose Sucker	63
White Sucker	63
Trout	64
Minnows	64
Other Species	64
WATER SYSTEM STATUS	65
HUMAN SYSTEM	66
TARGET GROUPS AND COMMUNITIES	66
RESEARCH TO DATE	66

Table of Contents (Concluded)

	Page
HISTORICAL BACKGROUND	66
SOCIO-ECONOMIC CHANGES	68
DEMOGRAPHIC STRUCTURE	68
ECONOMIC STRUCTURE	70
Agriculture	70
Forestry	70
Fishing	70
Trapping	70
Tourism	71
Oil Sands Extraction	71
Manufacturing Industries	71
Construction Industry	71
Service Industries	71
EMPLOYMENT AND THE LABOUR FORCE	72
Distribution of Employment	72
Composition of Labour Force	73
INCOME	73
HOUSING	74
RESIDENT OPINIONS	74
HUMAN SYSTEM STATUS	76
APPENDIX I	79
Canada-Alberta Agreement for the Alberta Oil Sands Environmental Research Program, Amended-September 1977	79
APPENDIX II	87
Vegetation Species Identified in the AOSERP Study Area	87
APPENDIX III	88
Wildlife Identified in the AOSERP Study Area and Mentioned in the Text of this Report	88
APPENDIX IV	89
Macrobenthos Collected from the AOSERP Study Area, 1976-77	89
APPENDIX V	93
Fish Found in the AOSERP Study Area	93
APPENDIX VI	94
Financial Statement	94
REFERENCES CITED	96
LIST OF AOSERP RESEARCH REPORTS	101

List of Tables

Page

1. Description of Physiographic Regions in the AOSERP Study Area . . . 9
2. Frequency of Inversions at Fort McMurray and Stony Mountain . . . 17
3. Source and Annual Total (Tonnes) of Emissions in the AOSERP Study Area for 1976 . . . 19
4. Monthly Averages and SO_2 Frequency Distributions of ½-Hour Readings at Great Canadian Oil Sands-Fina Airstrip Station . . . 21
5. Monthly Averages and SO_2 Frequency Distributions of ½-Hour Readings at Great Canadian Oil Sands-Supertest Hill Station . . . 21
6. Comparison of Amount of Sulphur in Snowpack within 25 km of GCOS with Sulphur Released by GCOS During the Snow Accumulation Period March 1976 . . . 25
7. Comparison of Deposition Rates of Particulate Sulphur in Alberta . . . 27
8. Deposition Velocities of Elements in Suspended Particulate to the Harwell Collector in June 1977 . . . 28
9. Constituents in Rainwater in the AOSERP Study Area and in Northern Saskatchewan Compared to Those in Eastern Canada . . . 28
10. Stations Recording Precipitation of pH less than 5 as a Function of Distance from the Oil Sands Extraction Plant (1977) . . . 28
11. Legend for Surficial Geology Mapping . . . 32
12. Legend for the Vegetation Mapping . . . 32
13. Mean Annual Number of Animals Reported Harvested for each Furbearing Species in the AOSERP Study Area, 1970-75 . . . 39
14. Hydrological Zones within the AOSERP Study Area 42
15. Organic Carbon Content in ppm of Sediments from the Athabasca River Upstream of Fort McMurray Collected in Winter 1977-78 . . . 49
16. Typical Distribution of Types of Organic Compounds in Athabasca River Water . . . 50
17. Complexing Capacity and Dissolved Organic Carbon of Surface Water from Various Points in Alberta . . . 50

Page

18. Calcite Saturation Index of Selected Lakes in Autumn of 1976 . . . 52
19. Regional Population in the AOSERP Study Area . . . 69
20. Families by Number of Unmarried Children 0-24 Years of Age, Fort McMurray, 1961 and 1971 . . . 69
21. Population by Marital Status for Males and Females, Fort McMurray, 1961 and 1971 . . . 70
22. Registered Traplines in the AOSERP Study Area, 1975 . . . 71
23. Retail Trade Statistics for, Fort McMurray Relative to the Provincial Average . . . 72
24. Service Trade Statistics for Fort McMurray Relative to the Provincial Average . . . 72
25. Experienced Labour Force by Industry, 1961 and 1971 . . . 72
26. Labour Force Participation in 1971 and 1976 . . . 73
27. Labour Force by Marital Status for Males and Females, Fort McMurray, 1961 and 1971 . . . 73
28. Distribution of Family Income, 1973 . . . 74
29. Dwellings by Tenure and Type, Fort McMurray, 1961 and 1971 . . . 74
30. Housing Types in Fort McMurray, 1961-1977 . . . 74
31. Vegetation Species Identified in the AOSERP Study Area and Mentioned in the Text of this Report . . . 87
32. Wildlife Identified in the AOSERP Study Area and Mentioned in the Text of this Report . . . 88
33. Macrobenthos Collected from Streams in the AOSERP Study Area, 1976-1977 . . . 89
34. Fish Found in the AOSERP Study Area . . . 93
35. Distribution of AOSERP Research Project Funds During the Years 1975-76, 1976-77, 1977-78, and 1978-79 . . . 94
36. AOSERP Financial Reports, 1975-76, 1976-77, and 1977-78 . . . 95

List of Figures

	Page
1. Extent of the Athabasca Oil Sands Deposit in Relation to the Alberta Oil Sands Environmental Research Program Study Area	1
2. The Alberta Oil Sands Environmental Research Program Study Area	5
3a. Mean July temperatures	6
3b. Mean January temperatures	6
4. Mean Precipitation (mm), May to September	6
5. A Simplified Geological Cross-Section	7
6. Depth of Overburden of the Athabasca Oil Sands Deposit	8
7. Physiography of the AOSERP Study Area	9
8. Upland Mixed Forest Stand of Aspen and White Spruce	10
9. Upland Black Spruce-Jack Pine Forest with an Understory of Lichen	10
10. Jack Pine on Aeolian Sand near the Richardson Tower Airstrip	10
11. Tall Willow Scrub and Bottomland Balsam Poplar Forest along the Athabasca River, Characteristic of Bottomland and Upland Communities	11
12. The Ground in this Broad-Leaved Sedge Fen is Much too Soft for the Helicopter to Land	11
13. Open Muskeg Emerging Gradually into Black Spruce-Bog Forest	11
14. Athabasca River Looking North over Bitumount	12
15. Lake Athabasca Looking East over Bustard Island	13
16. Steepbank River on its Descent to the Athabasca River	13
17. MacKay River, 6 km by Air from its Confluence with the Athabasca River	14
18. Upper Reaches of Hartley Creek, Showing Muskeg and Beaver Dams	14
19. Annual Wind Direction Frequency at 850 mb	17
20. Wind Roses in the AOSERP Study Area	17
21. Total Sulphation Isopleths for 1976	18
22. Dispersion and Removal Processes	20

	Page
23. Concentration Distributions from a Continuous Point Source as Predicted by the Gaussian Plume Equation	23
24. Cross Plume Measurements of Sulphur Dioxide and Ozone at Distances of 2.3 km and 24 km from the Source 19 June 1977	24
25. Total Sulphur Deposition in Snow Measured March 1976	25
26. The pH in the Top Layer of Snow Measured March 1976	25
27. Relationship Between Concentrations (C_r), Deposition Velocity (V_d), and Downward Flux (F) of Atmospheric Constituents	26
28. Sulphur Deposition Patterns in the Top Snow Layer, 5 March 1976	26
29. Sulphur Dioxide Concentrations Calculated for 8 March 1976 Using Gaussian Model	27
30. Deposition Patterns of Vanadium in June 1977	27
31. Deposition Patterns of Calcium in June 1977	28
32. Calculated Annual Average Sulphur Dioxide Concentrations at Ground Level (Four Sources) and Average Annual Dry Deposition of Sulphur (Five Sources)	29
33. Portion of the 1:50,000 Surficial Geology Map on Mapsheet 74D/14	31
34. Sample of 1:50,000 Vegetation Mapping Illustrates a Mosaic of Vegetation Types on Mapsheet 74D/14	33
35. Preliminary Estimates of Territory Boundaries of Wolf Packs and Maximum Numbers of Wolves per Pack on the AOSERP Study Area During Winter, 1976-77	35
36. Geographical Significance of the Athabasca Oil Sands to Waterfowl Flyways	37
37. Traplines in the AOSERP Study Area	39
38. Hydrological Zones within the AOSERP Study Area	42
39. Representation of Annual Streamflow Balance Based on Average Annual Flow Volumes	42
40. Measured Minimum and Maximum Equivalent Concentrations of Major Ionic Species in 1977 for some Selected Tributaries	43

List of Figures (Concluded)

Page

41. Relationship of Specific Conductance with Discharge for the MacKay and Firebag Rivers for 1977 44
42. Fluctuations in Total Hardness in Zone 1 During Open Water Months During 1977. 45
43. Seasonal Progressions of the Potassium-Discharge Relationship for the Muskeg River in 1977 45
44. Suspended Sediments in Hartley Creek in 1977 . . . 46
45. Longitudinal Profile of the Athacasca River 47
46. Suspended Sediment Rating Curves at the WSC Gauges Below Fort McMurray and at Embarras using 1969-73 data 47
47. Mouth of the Firebag River as it Enters a Channel of the Athabasca River 48
48. Mean Heavy Metal Concentrations in Sediments Collected in 1976 49
49. Correlation Between Total Vanadium and Organic Carbon Concentrations in Bottom Sediments Collected in 1976 49
50. Mean Heavy Metal Concentrations in Fish and Invertebrates from the AOSERP Study Area and Plankton from the Delta Area Collected in 1976 . 51
51. Temporal Variation in Total Alkalinity of Surface Water from Three Lakes in 1977 52
52. Calcium and Bicarbonate Concentrations at Various Depths in Shallow Wells in a Muskeg Region of Hartley Creek, Summer of 1977 53
53. La Saline Spring Near the Athabasca River 54
54. Scanning Electron Micrograph of Material from the Muskeg River, October 1977, Showing Numerous Filamentous Cyanophycean Algae and Bacillariophycean Algae, *Gomphonema* sp. 55

Page

55. Blue-Green Algae, *Nostoc,* and Green Algae, *Cladophora,* in the Ells River, August 1978 55
56. Scanning Electron Micrograph of Material from the Athabasca River Showing Uncolonized Silt Particle and Free Floating Bacteria. 56
57. Scanning Electron Micrograph of Material from the Athabasca River Showing Detritus Particle with Complete Colonization of Surface by Bacteria 56
58. Concentrations of Bacteria and Nutrients in the Interstitial Water of the Muskeg River 56
59. Trophic Classification and Energy Flow in the Aquatic Food Chain 57
60. Scanning Electron Micrograph of Material from the Muskeg River, October 1977, Showing a Thick Mat of Bacillariophycean Algae Stalks Perforated with Holes Possibly Produced by Grazing Chironomid Larvae 57
61. Scanning Electron Micrograph of Material from the Steepbank River, October 1977, Showing a Food Catching Net, Possibly of a Trichopteran Larva . . 58
62. Commercial Yearly Catches of Walleye in the Peace-Athabasca Delta Fishery, 1963-1975 59
63. Location of Tribes (Map of Land Ceded in Treaty 8) 67
64. York Boat 68
65. Percent of Families by Age of the Head of the Family, Fort McMurray, 1961 and 1967 69
66. Old and New Housing Developments in Fort McMurray, 1978. 75
67. New Hospital Under Construction in Fort McMurray, 1978. 77

Acknowledgements

This Interim Report summarizes AOSERP research over the period April 1975 to November 1978. The investigations referred to herein involved over 100 researchers from government agencies, universities, and private consultants. In addition, the first draft of this report was sent to a number of reviewers outside AOSERP for comment. In large measure therefore, this report abstracts the work of the nearly 150 research projects directly connected with or related to oil sands development.

The staff of AOSERP was responsible for assembling this report and accepts responsiblity for interpretation of the results of the investigations. To the very large number of people who assisted us in so many ways, we express our sincere thanks.

Introduction

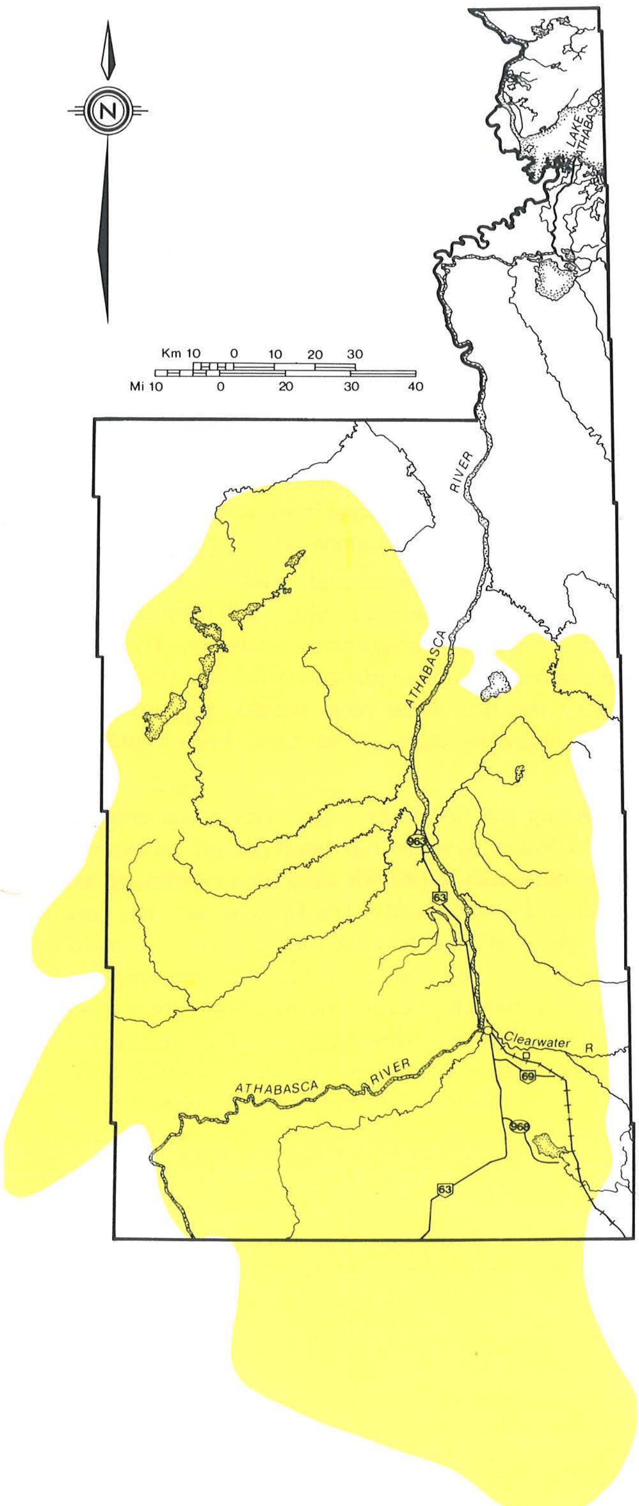


Figure 1. Extent of the Athabasca Oil Sands deposit in relation to the Alberta Oil Sands Environmental Research Program study area.

Oil Sands Development

The development of the Athabasca Deposit (Figure 1), one of several oil sands deposits in Alberta, has been the subject of intense interest for several decades. The Athabasca Deposit contains more than 600 x 10^9 barrels of bitumen reserves, and constitutes about 88 percent of the known oil sands in Alberta. Consequently, its potential to augment the oil supply of Canada has been a driving force in present development, and will continue to generate pressure for further development.

Nearly 200 years ago Alexander Mackenzie reported his observations of the Athabasca oil sands. Almost all of the well-known subsequent explorers, cartographers, and fur traders mention, in their reports, the bituminous outcrops. As early as 1882, it had been suggested that hot water might be used to extract bitumen, and by 1923 a hot water extraction pilot plant was built at the University of Alberta. Numerous events in the development of a commercially feasible extraction process resulted by 1967 in the construction of the Great Canadian Oil Sands (GCOS) plant about 35 km north of Fort McMurray and by 1978 the Syncrude Canada Ltd. (Syncrude) plant at Mildred Lake, a few kilometres northwest of the GCOS operation, went into production. The GCOS operation was initially designed to produce 45,000 barrels per day of synthetic crude oil, and the Syncrude operation 125,000 barrels per day. (A detailed account of commercial oil sand development has been published elsewhere [1]).

Deep deposits not exploitable by surface mining constitute very large reserves, and have become the subject of strong interest. Several major corporations have invested in or are developing *in situ* thermal recovery technology for extraction of deep bitumen deposits (e.g., Amoco Canada Ltd.) and one (Shell Canada Resources Ltd.) has made a public disclosure of its intent to develop another surface mine. Continued development will be controlled, in large part, by favourable economics and demand for synthetic crude oil as conventional supplies of oil decline. For the foreseeable future it can be expected that both open pit mining and *in situ* developments will proceed steadily.

History of AOSERP

The Government of Alberta has an established policy of environmental legislation which allows for the orderly development of resources with a minimum of environmental damage. This policy resulted in particular attention being paid by regulatory agencies to the need for development of an environmental research program for the Athabasca Oil Sands region. Consequently, late in 1973, officials of Alberta Environment (Research Secretariat) and Environment Canada (Environmental Management Service) separately produced internal reports recommending a comprehensive environmental research program. Projections in each of the reports favoured an environmental research program lasting 10 years, with total costs estimated in the range of $30 million to $40 million.

Early in 1974 the Minister of Environment for Alberta requested the concurrence of the Minister of Environment for Canada that senior officials of the two governments be directed to prepare recommendations for a joint research program, to commence in 1975. Following agreement in principle between the Ministers, eight committees composed of federal and provincial government and industry personnel commenced planning. Program co-ordination at that time was the responsibility of the Research Secretariat of Alberta Environment.

In February 1975, the governments of Canada and Alberta became signatory to the Canada-Alberta Agreement for the Alberta Oil Sands Environmental Research Program. For convenience, the acronym "AOSERP" was adopted to describe the Program.

The original recommendations for AOSERP indicated a 10-year life for the Program, with the Canada-Alberta Agreement covering the first five-year period, commencing on 1 April 1975. Alberta accepted administrative responsibility for the Program, which was to be centred in Edmonton. The two governments agreed to provide funding of $4.0 million annually, to be shared equally between the two jurisdictions.

Under the terms of the Agreement, the eight committees were given legal status with full authority to plan and initiate their own research projects. Policy direction was provided by a Steering Committee, consisting of one senior representative from Alberta Environment and one from Environment Canada. Research direction was developed through the eight technical committees, essentially independent of any central program management. As a result, direction for AOSERP was not precise.

During the second year of the Program (1976-77) it became apparent that fiscal and operational control of AOSERP, as well as control of its research policy and scientific direction, was becoming more difficult under the committee system. Each of the Technical Research Committees had provided valuable service to the Program through identification of research needs and available expertise, but implementation of Program objectives outlined in the Canada-Alberta Agreement required centralization in the Program Management office. The Canada-Alberta Agreement was amended to delete the committee structure from the program (Appendix I). To replace the committee structure, the program was centrally reorganized to function under Air, Land, Water, and Human systems.

During final preparation of this report, the Government of Canada decided to withdraw financial support from the Alberta Oil Sands Environmental Research Program, effective 31 March 1979. The Government of Alberta will continue to provide adequate financial support to bring the Program to the conclusion of the five year period ending 31 March 1980. A report will be published in the autumn of 1980 which will summarize all research results obtained during the period 1975-1980.

Program activities during the fiscal year 1979-80 will become an integral part of the Alberta Department of Environment. Reports financed by the Province of Alberta after 31 March 1979 will be published as Alberta Environment documents.

Research Direction and Policy

The Canada-Alberta Agreement identifies general objectives for the Program. Following reorganization of the Program in 1977, specific scientific objectives were developed to provide research direction within each system. In addition, more specific objectives were established for years 3, 5, and 10 of the Program (2).

The present operational goal of AOSERP is to develop an integrated program which will form the base for future environmental management strategies. To meet this objective, priority has been placed on the fact that investigations during the first three years should result in establishment of the baseline states of Air, Land, Water, and Human systems.

During the first three years, substantial emphasis in the Air and Water systems has been placed on developing monitoring networks to provide data for a continuing assessment of air and water quality. The Land System has concentrated on physical inventory of the land surface, including surficial geology, soils, vegetation habitats, and wildlife. The Human System has emphasized human population research, both on past historical development and on the greatly expanded population which resulted from oil sands development. In each of the systems, the objective which has been kept clearly in the forefront is that data obtained by the Program must be useful in interpreting effects of oil sands development on the natural and human environments.

While the revised Agreement places program management in the hands of the Director and his staff, research direction is sought from outside the program office. Researchers and research managers from universities, federal and provincial government agencies, research institutions, private consulting firms, and industry have been invited to sit on Scientific Advisory Committees for the Air, Land, Water, and Human systems. These bodies are not intended to represent the interests of their employers, but rather are comprised of persons competent in various disciplines. The Scientific Advisory Committees have been particularly effective in providing recommendations concerning scientific direction for the Program.

Although the Canada-Alberta Agreement for AOSERP provides a legal description of the study area, decisions have had to be made concerning projects on operational corporate leases. Generally speaking, the policy has been followed that projects specific to company leases in the AOSERP study area will not be financed by the Program, but are considered a direct corporate responsibility. Some projects, however, may be of a nature that, although they may be on company leases, their importance and wide scope justify funding by AOSERP. Discussions between Program Management staff and corporate environmental managers revealed substantial common interests in environmental research. As a result of these discussions a model for AOSERP-industry co-operative research was produced by Program Management staff. Comments were solicited from industry and government, and, with some modification, the model has been accepted by industry and approved by Canada and Alberta as part of the operating policy for AOSERP.

PROGRAM OBJECTIVES

Program objectives for AOSERP were defined and published in 1977 (2). Specific objectives for the Air, Land, Water, and Human systems are contained in later sections of this report. Objectives to be met by year 3 of the Program are as follows:

Year 3 Objectives

1. To review existing data with respect to the total area likely to be affected by oil sands development;
2. To identify gaps in the data base and establish projects that will eliminate these deficiencies;
3. To establish monitoring networks in order to obtain baseline data on variables in the environmental systems and review the monitoring requirements annually;
4. To identify environmental and social problems that can be expected to result from presented and proposed oil sands development;
5. To promote the establishment of an integrated data storage and retrieval system encompassing all information pertinent to the Program and ensure that all data generated through the Program is placed in the data system;
6. To establish a conceptual framework by which current knowledge will aid in the design, conduct, or redirection of research projects; and
7. To present a Program report during year three (1978) that describes current understanding of the baseline states and processes of the environmental systems in the AOSERP study area.

The scope of any investigative program is determined by policy direction and by fiscal support. In these respects, AOSERP differs little from a number of others, except perhaps in size (total cost). As mentioned earlier, general policy was set by the Canada-Alberta Agreement for AOSERP and operational policy by a planning document produced internal to the Program. However, within the general and operational policy limits, choices have had to be made as to what activities were most timely and consequently, most likely to satisfy the objectives of the Program. As pointed out by Lewis et al. (3) realistic assessment of environmental impacts of resource development depend to a considerable extent on availability of forecasting tools. This is a particularly important consideration in the capacity of AOSERP to generate useful information.

The Program may be considered broadly to be concerned with developmental impact research as a result of industry activities in the region centred on Fort McMurray, Alberta. The results of AOSERP investigations will be used both by industry and government in monitoring and regulation of oil sand operations. As well the published results will provide the public with information on which can be based reasonable assessment of the likely effects of oil sands development. Lewis and his colleagues, cited above, suggest that "Four basic types of predictive tools can be identified. These are qualitative techniques, retrospective analyses of data and trend extrapolation, process models, and empirical methods coupled with predictive models." As well, the use of scenarios, while speculative may ". . . provide some insights . . ." (3).

Qualitative techniques generally have been used in Canada in the absence of long term quantitative data as initial approximations of impact assessment. They are generally recognized to be deficient as definitive statements describing environmental impacts of resource development. Scenarios are often the first discernable statements to surface, often from organizations and individuals with significant environmental concerns. Application of retrospective data and trend analysis is highly useful, but in most projected or actual developments in Canada these methods cannot be applied because data are lacking. The use of process models is gaining favour, but the costs associated with their development, plus lack of successful examples, has for the most part prevented their effective use in Canada as adequate tools to predict resource development impacts with much accuracy.

In the present AOSERP example, the choice was made early for the Program to pursue a course which would document the baseline conditions in the region likely to be affected by oil sands development. Consequently, the initiation of applied research projects has been infrequent. This Interim Report, therefore, deals primarily with baseline states investigated and reported on to date. Some baseline studies are as yet incomplete; these will be concluded early in 1980. Because the Program has dealt mainly with documenting baseline environmental conditions this report cannot be predictive. Rather, it describes what the Program has accomplished to date, provides direction for future monitoring programs, identifies some knowledge gaps, and the need for applied research in the near future.

The AOSERP Study Area

Boundaries of the AOSERP study area were chosen to enclose the Athabasca River valley in a relatively symmetrical fashion, to encompass present and likely future oil sands surface mining and *in situ* operations, and to include the population centres most likely to be affected, either directly or indirectly, by oil sands development.

The AOSERP study area covers about 2.86×10^4 km^2 in northeastern Alberta (Figure 2). The Canada-Alberta Agreement for AOSERP defines the extent of the study area as the lands within "Townships 84 to 104 in Ranges 6 to 18 West of the Fourth Meridian, and Townships 105 to 115 in Ranges 6 to 9 excluding Wood Buffalo National Park in the Province of Alberta." This area encompasses the larger part of the Athabasca Oil Sands deposit, including most of the mineable area and the leases currently under production or experimental development, or in an advanced planning stage.

The Climate

The climate of a region is directly related to all physical and natural processes and controls the type and amount of vegetation, survivability of species, and capacity of plant life to regenerate. The changing of seasons initiates animal migrations and severity of conditions has a direct effect on maintaining population levels. On the physical side the hydrologic cycle responds not to precipitation events but to the build-up of the winter snow pack, wind, temperature, evaporation, and solar radiation which determines the consumptive use of water by vegetation. Many aspects of human life are also directly affected including types of homes, outdoor activities, and the energy required to maintain community and industrial development. General climatic conditions resulting from latitudinal effects and proximity to Arctic air masses strongly influence meteorological conditions in the Athabasca Oil Sands region. Thus, particular attention has been paid to defining meteorological conditions which will be useful in determining the baseline state of air in the AOSERP study area. From the outset, AOSERP Air System investigations were designed to concentrate on the synoptic meteorology of the study area, and to document air quality in relation to the likely effects resulting from oil sands operations.

Although there are two sites, Fort Chipewyan and Fort McMurray, at which climatological records have been kept for over 30 years most of the information available for the AOSERP study area covers a much shorter time span. Approximately 15 Alberta Forest Service fire lookout sites have kept summer records of temperature and precipitation for over 10 years, climatological stations at Anzac, Tar Island (GCOS), and Mildred Lake Syncrude for less than 10 years, and the AOSERP telemetry network of 8 stations for 2 years. Since the start of AOSERP, snow courses, evaporation, solar radiation, meteorological tower, and minisonde temperature and wind profiles have been regularly observed (16).

Northeastern Alberta lies in that part of the northern hemisphere in which the general atmospheric circulation is from west to east (16). However, this is not a highly persistent pattern and is often disrupted by migrant low pressure systems moving in the westerly stream. These cyclonic systems may entrain cold air from Arctic regions, moving it to southern latitudes, and force warm air northward ahead of the system's path. Thus, cold and warm periods frequently alternate in all seasons in the AOSERP study area; the changes are often accompanied by precipitation.

In the winter season, cold high pressure areas may move south from the Arctic along the Mackenzie-Athabasca valley, dominating the weather pattern in the AOSERP study area for several days. Clear and cold weather is characteristic of this anti-cyclonic winter feature. Visibility may be reduced as a result of ice crystal fog, but precipitation is negligible. Atmospheric subsidence associated with stationary or slow-moving high pressure ridges in the summer is characterized by extended periods of clear dry weather. Effects of the Rocky Mountains that are felt strongly in southern and western Alberta are negligible in the northeast. The moderating effect of the chinook is unknown in the AOSERP study area. However, because air masses moving from the Pacific Ocean have been forced over the coast and interior mountain ranges of British Columbia, they are generally drier upon arriving in Alberta.

Significant seasonal differences in in-coming solar radiation in the AOSERP study area, which lies between 56° and 59° north latitude, account, in large part, for the marked variation in climate throughout the year. If the effects of the earth's atmosphere are neglected, the long hours of daylight near the summer solstice result in these latitudes receiving more energy than areas at the equator. In late December, on the other hand, the daily inflow is less than 15 percent that of the equator.

In winter, solar radiation is low for three reasons: the low angle of the sun results in an oblique angle of interception of energy; the longer path through the atmosphere results in higher absorption; and, added to these effects, the snow surface reflects as much as 80 percent of incident radiation. For the year as a whole, radiation at the top of the

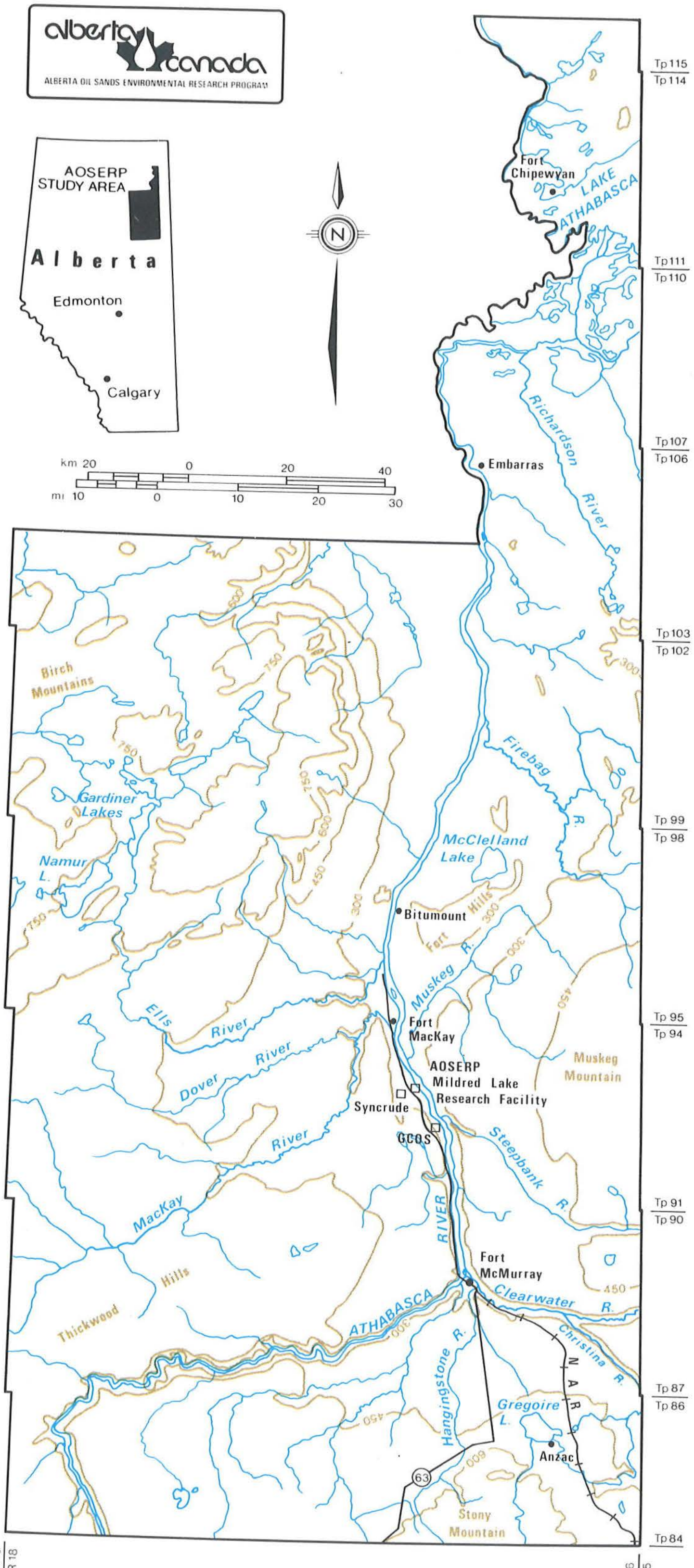
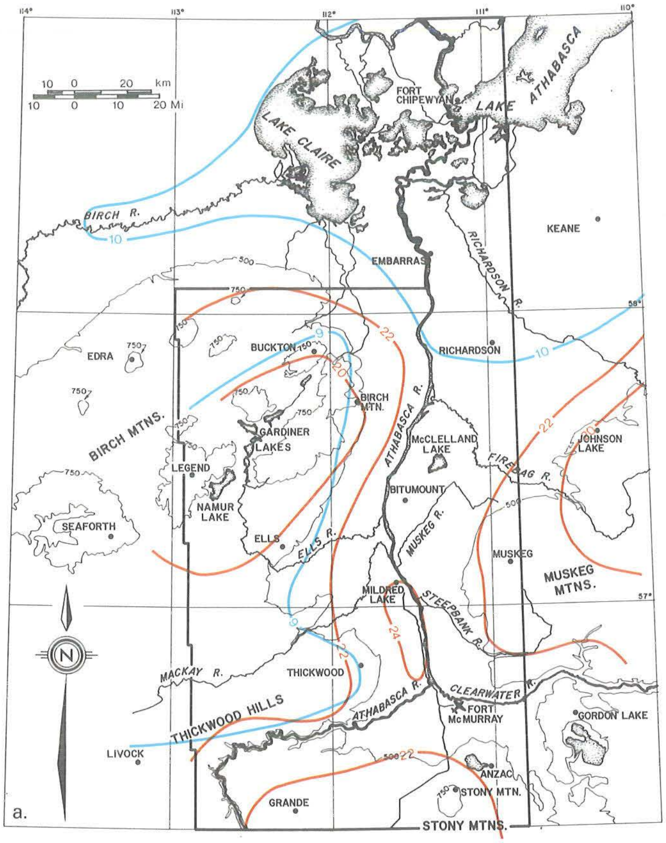


Figure 2. The Alberta Oil Sands Environmental Research Program study area (contours in metres).



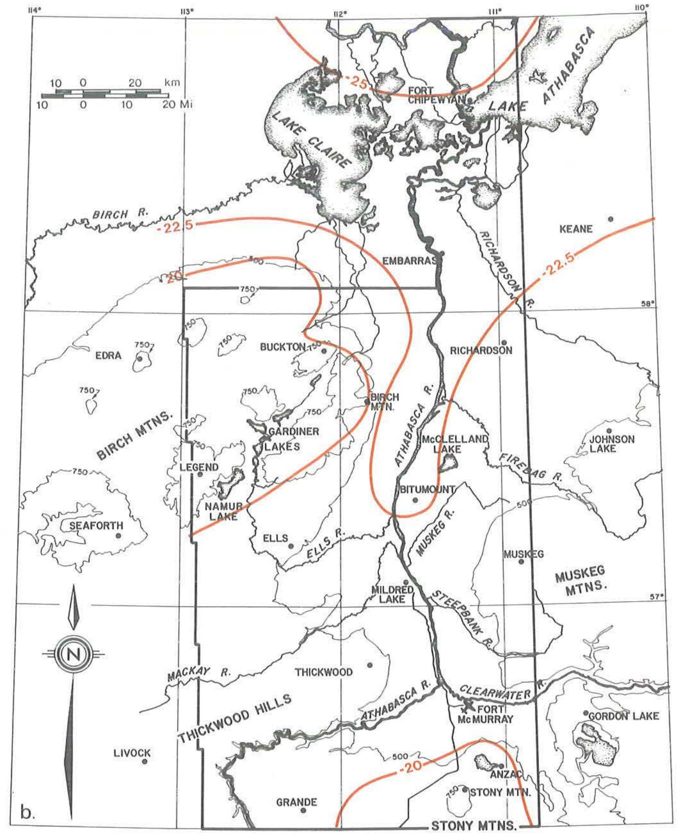


Figure 3a. **Mean July temperatures (°C): maximum (red) and minimum (blue) based on 1941-70 normals and adjusted normals.**

Figure 3b. **Mean January temperatures (°C) based on 1941-70 normals and adjusted normals.**

atmosphere at the latitude of the study area is about 60 percent that at the equator.

The climatic zone of the AOSERP study area is defined in the Köppen classification system as "cold temperate". This indicates a mean temperature for the warmest month of above 10°C and for the coldest month below 3°C. A further sub-classification of "cool short summers" is added in this case to indicate less than four months with a mean temperature of at least 10°C. This contrasts with Edmonton, which has a sub-classification of "cool long summers" by virtue of having four months with a mean temperature of 10°C or higher (Figure 3).

In general, this classification indicates a continental type of climate with significant daily and seasonal variation in temperature and precipitation. Most of the annual precipitation, 285 mm of a total 435 mm, falls in the five summer months. Summer precipitation is derived from a combination of convective storms and large scale weather systems, whereas winter precipitation comes mainly from synoptic scale weather systems (Figure 4).

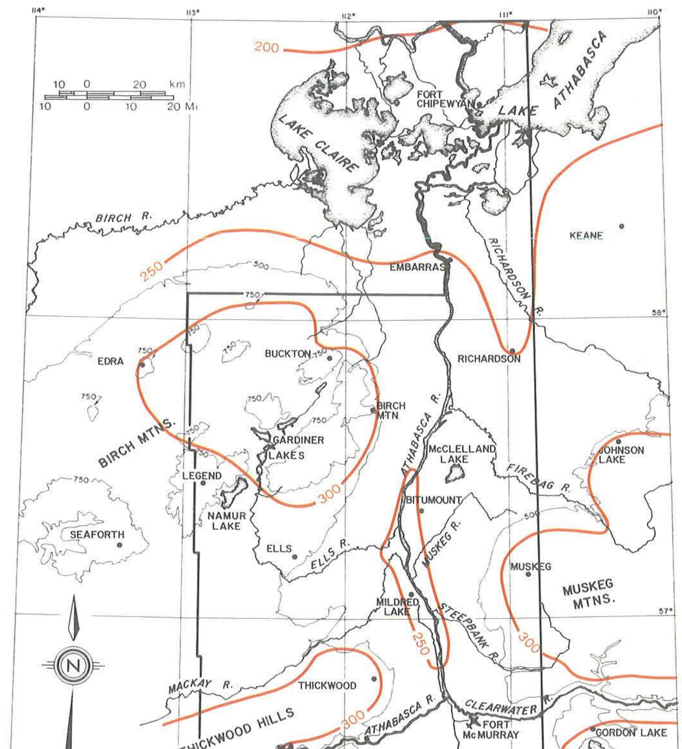


Figure 4. Mean precipitation (mm), May to September based on 1941-70 normals (14).

The Land

Physiography and surficial geology (as well as climate) influence the physical, chemical, and biological characteristics of terrestrial ecosystems. Thus, the physiographic setting of the AOSERP study area requires particular attention in defining baseline states of the region. A considerable portion of Land System research, therefore, has been directed towards characterizing the surficial geology and topography of the study area.

GEOLOGY

The study area is underlain mainly by Cretaceous sandstones and shales; Devonian dolomites and gypsum are found south of Lake Athabasca. Precambrian granites are found north of Lake Athabasca in the extreme northeast (4).

Profiles of the Athabasca and Clearwater rivers are controlled by the pre-Cretaceous erosion surface developed on the Devonian rocks. There are several formations of Cretaceous sediments which form the cliffs of these rivers and their major tributaries. The oldest Cretaceous formation, the McMurray formation, consists of quartzose sands impregnated with a heavy oil technically known as "bitumen". The bitumen content is variable averaging 12 percent by weight of the deposit, but ranging from zero to 18 percent by weight (5). It is this formation which is commonly referred to as the "oil sands". A simplified geological cross-section is illustrated in Figure 5. The depth at which the bituminous sands deposit is buried varies from 7.5 percent (2,117 km^2) of which the bituminous sands covered by less than 60 m (200 ft.) of overburden, 34.2 percent (9,667 km^2) covered by 60 to 150 m (200 to 500 ft.), and 11.8 percent (3,310 km^2) covered by more than 150 m (500 ft.) of overburden (Figure 6). There are estimated to be over 600 billion barrels of bitumen reserves within the Athabasca deposit. Areas with no bituminous sand or very low grade bituminous sand comprise 45.5 percent (12,861 km^2) of the region. Detailed information on the geology and mineral resources is available in "Guide to the Athabasca Oil Sands Area" (1).

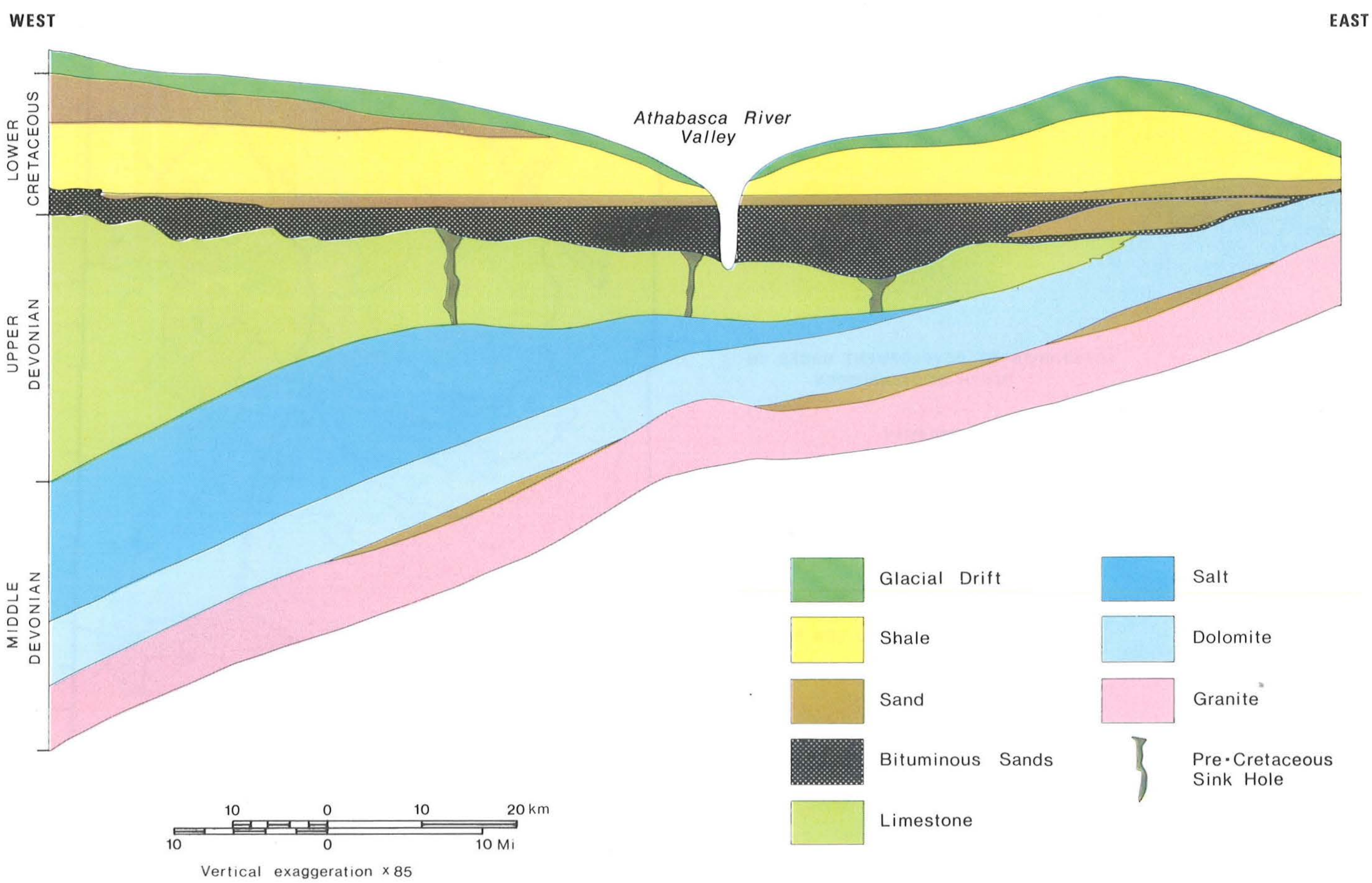


Figure 5. A simplified geological cross-section (1).

Surficial deposits consist primarily of debris left behind by the glacial ice sheet which covered northern Canada during the Pleistocene epoch. Surficial deposits are related to the melting of ice (moraine), erosion (meltwater channels such as the Athabasca and Clearwater river valleys), and deposition from meltwater (deposits of silt, sands, and clay) (1).

There are three main types of surficial deposits in the AOSERP study area: (i) ground and hummocky moraine (till) in the Birch Mountains and Methy Portage Plain, southeast of Fort McMurray; (ii) silt and clay lake deposits around the Birch Mountains; and (iii) sand and gravel deposits from river, lake, and wind sources found in the lower valleys, the eastern part of the area, and in the delta to the north.

Approximately 50 to 60 percent of the study area is covered by organic soils and about 30 percent by sandy soils of aeolian origin (11). Detailed descriptions and maps of soil types are provided later in the text.

TOPOGRAPHY

Ten physiographic regions have been identified (6) in the study area: three in the Alberta High Plains; four in the Saskatchewan Plain; one in the Great Slave Plain; and two in the Canadian Shield (Figure 7). Table 1 gives some of the geologic characteristics of surficial deposits in the 10 regions.

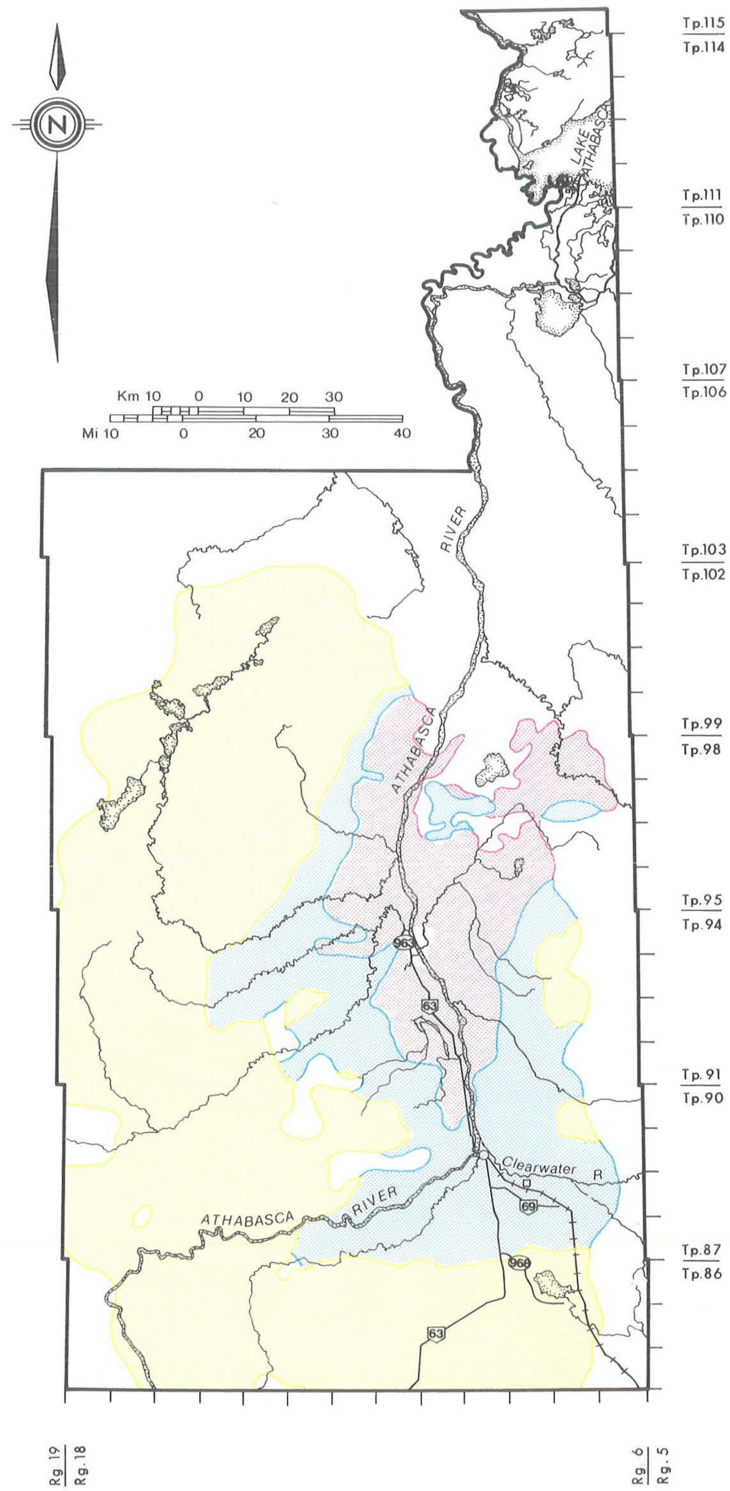


Figure 6. Depth of overburden of the Athabasca Oil Sands deposit (7).

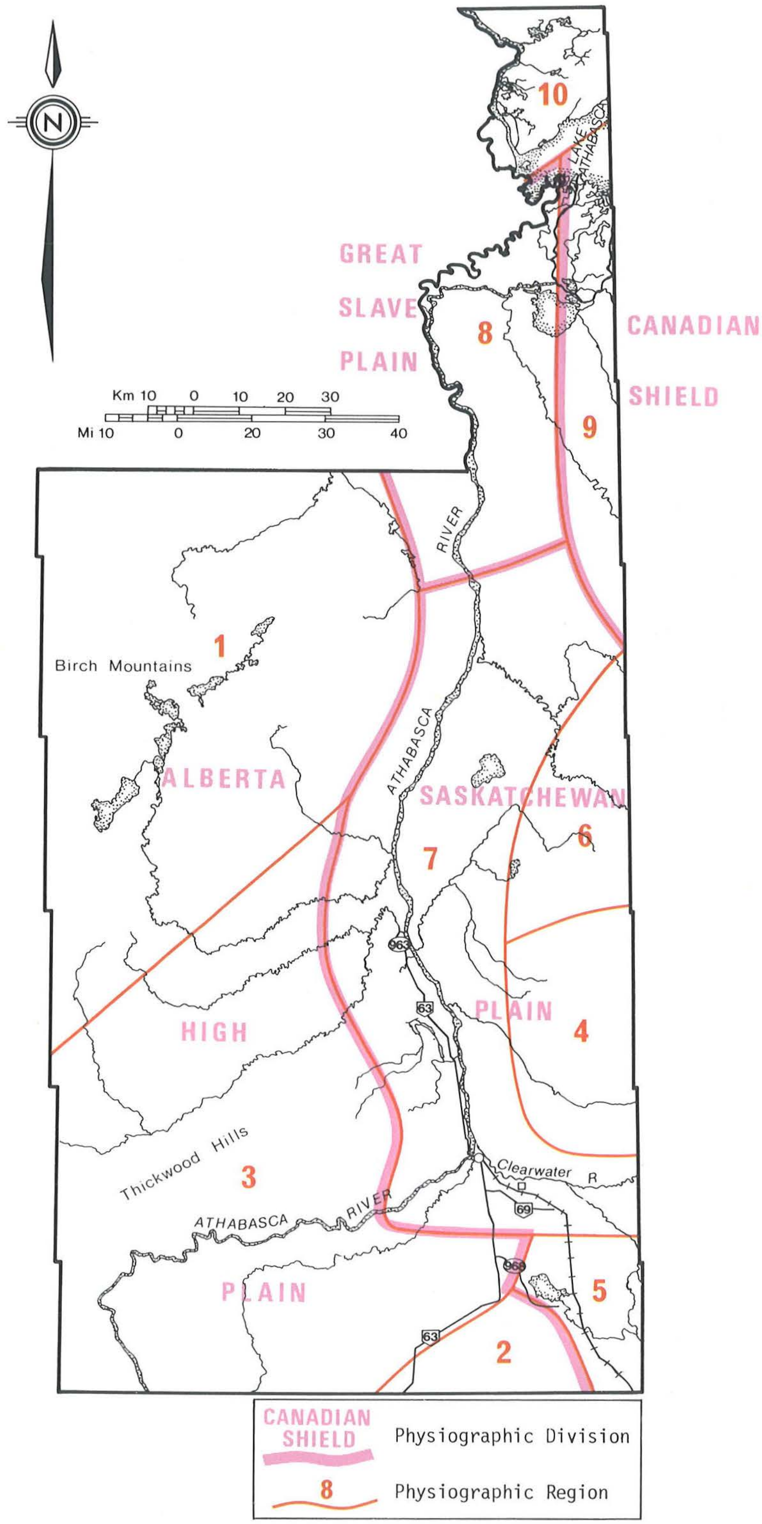


Figure 7. Physiography of the AOSERP study area (6).

The main drainage of the region is provided by the Athabasca-Clearwater system, the valleys of which are incised into a broad, muskeg-covered interior plain to depths of 60 to 90 m. The tributary streams originate in three highland areas (Figure 2): the Birch Mountains, which rise to 135 m, the Stony Mountains, which reach an elevation of 120 m, and Muskeg Mountain, which rises gradually to 90 m. To the southwest of the area is a subdued highland with gentle slopes, the Thickwood Hills, which give rise to northward flowing tributaries of the MacKay River and a few short streams flowing southward to the Athabasca River (1). The Water System section of this report gives detailed information on drainage, basin characteristics, and hydrology.

Table 1. Description of physiographic regions in the AOSERP study area (4).

Physiographic Division	Surficial Geology
Alberta High Plain	
1. Birch Mountain Uplands	— ground and hummock morraine over Upper Cretaceous shales and sandstones.
2. Stony Mountain Uplands	— ground and hummock morraine and sand and gravel over Upper Cretaceous shales and sandstones.
3. Algar Plain	— lower Cretaceous shale and sandstone, overburden of sand and gravel, some lake deposits.
Saskatchewan Plain	
4. Muskeg Mountain Upland	—upper Cretaceous shales and sandstones with sand and gravel overburden.
5. Methy Portage Plain	— lower Cretaceous shales and sandstones with overburden of sand and gravel.
6. Firebag Plain	— as above.
7. Clearwater Lowland	— shales and sandstones in preglacial valley with varied overburden.
Great Slave Plain	
8. Athabasca Delta Plain	— Devonian limestones, dolomites, and gypsum covered by lake deposits.
Canadian Shield	
9. Athabasca Plain	— Precambrian granites with a sand and gravel overburden.
10. Kazan Upland	— Precambrian granites, rocky, ice-scoured surface, red granite outcrops.

VEGETATION

The AOSERP study area lies within the Boreal Forest Region (9). This region comprises the greater part of the forested area of Canada, from Newfoundland west to the Rocky Mountains, and northwest to Alaska. Characteristic tree species found in the study area are white spruce, black spruce, tamarack, jack pine, trembling aspen, balsam poplar, and white birch. A check list of Latin and common names for species identified in the study area is provided in Appendix II.

A preliminary survey of the vegetation types in the study area was carried out (10) to aid in the design of a full-scale vegetation inventory/mapping program. Representative stands were classed by means of a cluster analysis method which grouped closely related stands on the basis of overall species similarity. Four vegetation communities have been defined for relatively well drained sites and four for relatively wet sites. Mapping of the vegetation types at a scale of 1:50,000 has been completed (4).

For the drier sites four vegetation communities are differentiated as follows: white spruce-aspen forest, with the overstory of trembling aspen and white spruce, with occasional white birch and jack pine and less often, black spruce, balsam poplar, and balsam fir (Figure 8); mixed coniferous forest, comprised mainly of jack pine, black spruce, and white spruce, with a diverse understory with few or no tall shrubs and ground cover of bryophytes and lichen (Figure 9); jack pine forest, with the only common tree species as jack pine, limited to a very well-drained sandy site where lichen usually forms a prominent and distinctive ground cover (Figure 10); bottomland and riparian communities, found on the flood plains of major stream courses, and with the dominant species comprised of balsam poplar, with occasional trembling aspen and white spruce, and an understory of willow and alder with low shrub and herbs (Figure 11).

For relatively wet sites, the four communities differentiated are as follows: fens, dominated by broad-leafed and pine-leafed sedges and swamp birch (Figure 12); black spruce-bog forest, dominated by black spruce and containing only the occasional tamarack (larch) (Figure 13); black

Figure 8. Upland mixed forest stand of aspen and white spruce (photo: P. Stringer).

Figure 9. Upland black spruce-jack pine forest with an understory of lichen (photo: P. Stringer).

Figure 10. Jack pine on aeolian sand near the Richardson Tower airstrip (photo: P. Stringer).

Figure 11. Tall willow scrub and bottomland balsam poplar forest (centre and left) along the Athabasca River, characteristic of bottomland and upland communities (photo: P. Stringer).

Figure 12. The ground in this broad-leafed sedge fen is much too soft for the helicopter to land (photo: P. Stringer).

spruce-tamarack-bog forest with co-dominance of black spruce and tamarack, generally less than 10 m in height; lightly forested tamarack and open muskeg, with sparse tamarack less than 5 m in height and black spruce 1-2 m high.

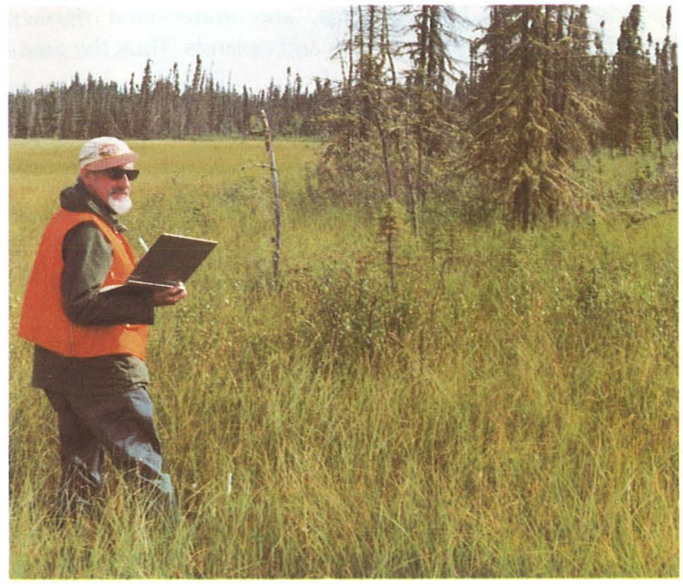


Figure 13. Open muskeg emerging gradually into black spruce-bog forest (photo: P. Stringer).

Water

SURFACE WATERS

Central to the drainage system of the AOSERP study area is the Athabasca River (Figure 14), which originates in the Columbia Icefields of the Rocky Mountains and drains northeasterly for 1,300 km before emptying into Lake Athabasca (Figure 15). The Athabasca River drains a very large area (155,000 km^2) of mostly boreal forest. Its meandering course is incised to more than 150 m in the southern portion of the study area. At Fort McMurray its banks gradually subside and the river follows a broad, straight course, terminating in the Peace-Athabasca Delta 300 km to the north.

At least 35 named tributaries join the Athabasca in the AOSERP study area, chief of which are the Clearwater River, with a drainage basin covering 13,200 km^2, and the MacKay River, with a drainage basin of 5,280 km^2 (12). Most of the streams tributary to the Athabasca River originate in the highlands of Birch Mountains, Stony Mountain, Thickwood Hills, and Muskeg Mountain. Most of these contain slow, meandering sections on the lowlands near their junction with the Athabasca River and in the highlands, with a relatively steep, fast flowing section in between (Figure 16). A wide variety of habitat types such as pool riffle sequences (Figure 17) exist in these streams. The lower Athabasca River divides into numerous channels with associated perched basins to form the southern, active portion of the Peace-Athabasca Delta and is the chief contributor of floodwater, silt, and nutrients which recharge the delta marshes annually. Several important large lakes (Gregoire, Gordon, McClelland, Namur, Gardiner, and Richardson) are contained in the study area as are a sizeable number of smaller lakes occurring to the southeast of Richardson Lake and on the Precambrian Shield northeast of Fort Chipewyan. Several thousand small, shallow ponds, sloughs, beaver dams, and water-filled muskegs (Figure 18) occur on the plains and uplands. Thus the area is diverse in types of surface waters.

GROUNDWATER

The movement of groundwater to and from surface water bodies plays an important role in the hydrological processes in the AOSERP study area. For example, in deep winter essentially the only water available to sustain base flow of the tributary streams is provided by groundwater discharge. Also, since groundwater usually is comprised of substantially different chemical constituents than surface runoff water, not only are the flow characteristics of the surface water affected by the groundwater discharge, the chemical characteristics are also markedly affected. Groundwater can be discharged from a variety of aquifer types and these can be broadly classed into two categories: shallow and deep groundwater regimes.

A most significant shallow groundwater regime is provided by the muskeg-covered glacial drift above the oil sands deposit. The extensive network of muskeg found on gently sloping areas of both the highland and valley plain areas comprise about half the study area. The regime here can be thought of as consisting of standing waters in the muskeg bogs adjacent to shallow groundwater systems in the glacial drift. Flow from such systems helps sustain the flow in many tributaries without upstream surface water storage.

While the effects of groundwater from shallow sources originating in adjacent muskeg appear to prevail in the tributaries of basins in the area, effects of groundwater from deeper sources also play a significant role in the water system. Deep groundwater sources are less affected by winter freezing and so are of particular importance in winter. Also, deep groundwater effects are of prime consideration in mining operations.

Figure 14. Athabasca River looking north over Bitumount (photo: H. Johnston, AOSERP).

Figure 15. Lake Athabasca looking east over Bustard Island (photo: R. Seidner, AOSERP).

Figure 16. Steepbank River on its descent to the Athabasca River (photo: H. Johnston, AOSERP).

Figure 17. MacKay River, 6 km by air from its confluence with the Athabasca River (photo: R. Seidner, AOSERP).

Figure 18. Upper reaches of Hartley Creek, showing muskeg and beaver dams (photo: R. Seidner, AOSERP).

The Human Population

About 27,000 people reside within the AOSERP study area. They are principally located in four established communities: Fort McMurray, Fort Chipewyan, Anzac, and Fort MacKay (Figure 2).

FORT McMURRAY

Fort McMurray is located at the confluence of the Athabasca and Clearwater rivers, 445 km northeast of Edmonton and 35 km south of the GCOS and Syncrude plants and was established initially in 1790 as the "Fort of the Forks" on the present townsite as a trading post for the Northwest Company. The system of rivers and tributaries made the trading post a natural trans-shipment point for the river barges which at that time serviced what later became the Northwest Territories. In addition to transportation, the fort dealt in fur, timber, fishing, and salt.

Fort McMurray as it is named today was established in 1870 by H. Moberly and was named after William McMurray, the Hudson's Bay Company Chief Factor in Fort Chipewyan.

In 1961, prior to the construction of the GCOS plant, the population of Fort McMurray was 1,186. It grew to 6,845 by 1971, and after the construction of Syncrude began, it climbed to 17,500 by 1976, and to 25,000 by September 1978. An analysis of Fort McMurray's population indicates that in 1975 it was a growing community comprised mainly of young people (13).

FORT CHIPEWYAN

Fort Chipewyan, the oldest European settlement in Alberta, is located on the northwest shore of Lake Athabasca, approximately 220 km north of Fort McMurray. It is the most northern, as indicated above, and is the second largest community in the region, with a population of about 1,500 people. There is no all-weather road access to Fort Chipewyan, but surface travel is possible over a winter road from Fort Smith, N.W.T.

Fur trading, missionary activities, and government involvement have historically determined the physical, social, and economic evolution of Fort Chipewyan. The fort was established over 200 years ago; in 1821 it became the centre for all fur trading operations in the Peace-Athabasca Delta area. The major increase in permanent settlement of the population in the community occurred after 1961, partly as a result of a requirement for children to attend school, partly because of a revitalized housing program administered by the Department of Indian Affairs and Northern Development and an expanded welfare system, and partly because of the introduction of various services such as electricity, telephone, and an airstrip. Because of its geographic location, Fort Chipewyan has not been greatly affected by development of the Athabasca Oil Sands (14).

ANZAC

The settlement of Anzac is located on the southeast shore of Gregoire Lake, approximately 50 km southeast of Fort McMurray. Anzac was named after the Australian-New Zealand Army Corps in 1917, when the construction of the Alberta Great Waterways Railway was undertaken.

Local activity is focused on Gregoire Lake and the Indian Reserve, which is located on the south shore of the lake. Gregoire Lake Provincial Park and a resort development with approximately 60 cabins is located on the west side of the lake. The settlement has a population of about 200 people (15).

FORT MACKAY

Fort MacKay is located in the valley of the Athabasca River, just north of the confluence of the MacKay River, about 65 km north of Fort McMurray and 17 km downstream of the Syncrude and GCOS plants. A Hudson's Bay post was established at this point in 1872. In 1956, Fort MacKay had a population of 59 which by 1975 had risen to 258. The introduction of an all-weather road, high dollar wage labour, and easier access to Fort McMurray have changed local life styles and have compounded local social problems. Planned development of the Shell mining operations and of the proposed New Town will be of great significance to the future of Fort MacKay (15).

Air System

There is a strong relationship between meteorological conditions and effective dispersion of emissions from oil sands plants and the subsequent chemical transformation and deposition of airborne pollutants. Thus, AOSERP Air System research is designed to respond to potential problems in the Athabasca Oil Sands region which may be related to meteorology and air quality. In addition, Air System research provides scientific support for the other research systems, by "describing the nature, quantities, and distribution of airborne pollutants which may affect land, water, or human environmental systems" (2).

Air System objectives are defined as follows:

1. To establish data acquisition systems to effectively describe existing physical conditions and processes including: climatology, air quality, precipitation chemistry, lower atmosphere soundings, and inventory of emissions from all sources;
2. To describe major meteorological and air quality characteristics of the oil sands region based on historical and current data;
3. To apply physical models to processes of air pollutant dispersion, transport, and deposition;
4. To develop systems for predicting levels of air pollution resulting from oil sands processing and the extent of dispersion and impingement on land and water; and
5. To provide advice and scientific support to other research sectors in areas relating to meteorology and air quality.

Meteorological Aspects of Air Quality

TEMPERATURE

The temperature structure of the air mass over an area may markedly affect air quality. Temperature inversions (temperature increases with height) may trap airborne emissions and raise their concentrations to levels which cause air pollution. Widespread air pollution similar to that experienced in other parts of the world has not been recorded as a consequence of temperature inversions trapping emissions from oil sands plants. However, frequency of inversions in the Athabasca River valley is such that detailed examination of the possible interaction of fog and industrial emissions is warranted.

A comparison of daily maximum and minimum temperatures at Fort McMurray Airport with Stony Mountain, approximately 25 km south and 409 m higher, shows the highest frequency of inversions in December and January. Table 2 illustrates the percent frequency of occurrence of inversions by comparing maximum and minimum daily temperatures at the two locations. The seasonal variation is very evident for maximum temperatures with relatively few occurrences in the summer months. Night-time inversions would appear to be common throughout the year.

An analysis of temperature data from the 10 m and top levels of the 152 m meteorological tower located in the Athabasca River valley near Mildred Lake shows similar results. Between midnight and 0800 inversions were measured more than 60 percent of the time. Between noon and 1800 they occurred 16 percent of the time. On a seasonal basis both night and day inversions increase in frequency in fall and winter (16).

WIND

Air flow through the area provides the most significant mechanisms for dispersion of emissions from oil sands plants. Although the climate of the region is easily described from general information, detailed information on winds in the study area was not available early in the Program; thus, examination of wind trajectories was required in order to make the first estimates of dispersion and deposition of airborne emissions from oil sands development area.

The general upper level circulation in the AOSERP study area is from WNW to ESE as illustrated by an interpretation of 850 mb air trajectories in Figure 19 (17). Because of the effects of topography, however, the pattern of winds at the surface is far more complex (16).

Comparing wind roses at each of the sites in the AOSERP study area shown in Figure 20(a) reveals marked differences, most of which can be attributed to topography. The stations at higher elevations — Birch Mountain and Stony Mountain — most closely approximate the general circulation. Fort McMurray, on the other hand, lies in the broad east-west valley of the Clearwater River and its wind direction frequencies show this orientation. A sheltering effect of Stony Mountain to the south may be inferred. Stations such as Mildred Lake, Bitumount, and Firebag show the north-south directing effect of the Athabasca River valley. Thickwood shows this feature for north winds but not for south, probably due to the river valley to the south. Ells shows the distinct bias of the east-west oriented lowland occupied by the Ells and MacKay rivers. Average wind speeds in the study area appear to be low and the frequency of calm conditions higher than for other areas of Alberta, including Edmonton.

From the data available it is evident that in the oil sands development area winds are oriented north and south along the valley. This feature is more pronounced in winter than in other seasons which would indicate a pattern of ground effects elongated along a north-south axis. Such a

Table 2. Frequency of inversions at Fort McMurray and Stony Mountain (16).

	Percent Frequency of Occurence											
Time of Day	J	F	M	A	M	J	J	A	S	O	N	D
Day/Maximum Temp.	48	32	21	7	14	4	6	6	11	12	37	53
Night/Minimum Temp.	68	65	61	50	53	60	67	61	54	60	58	64

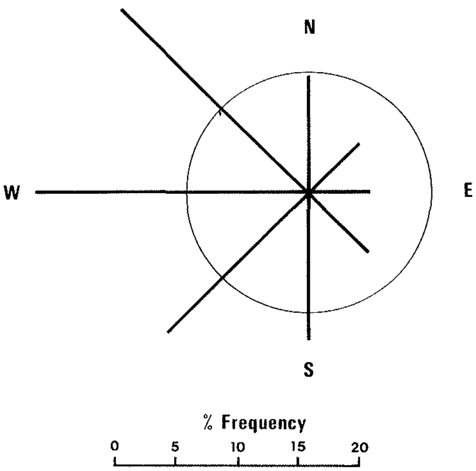
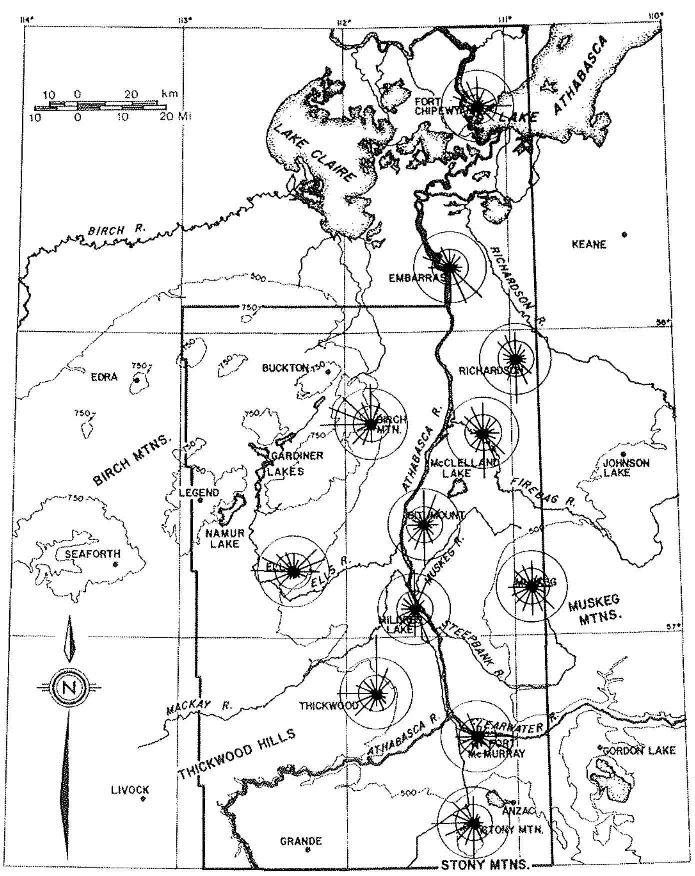


Figure 19. Annual wind direction frequency at 850 mb (1968 and 1973-75)(17).



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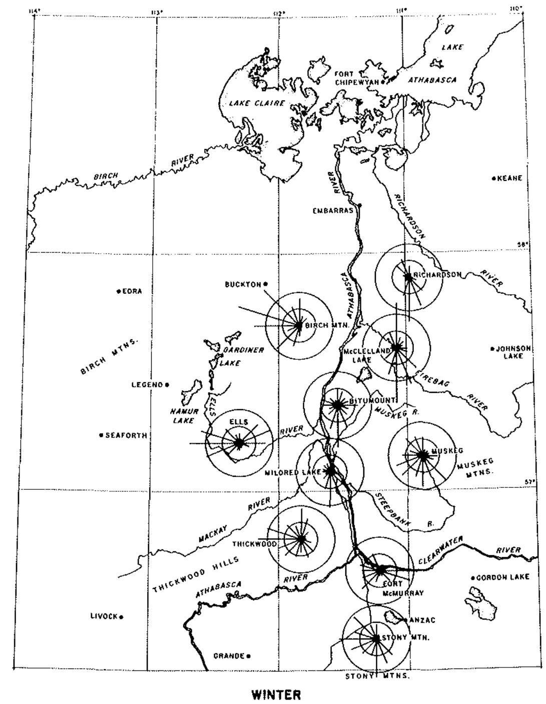

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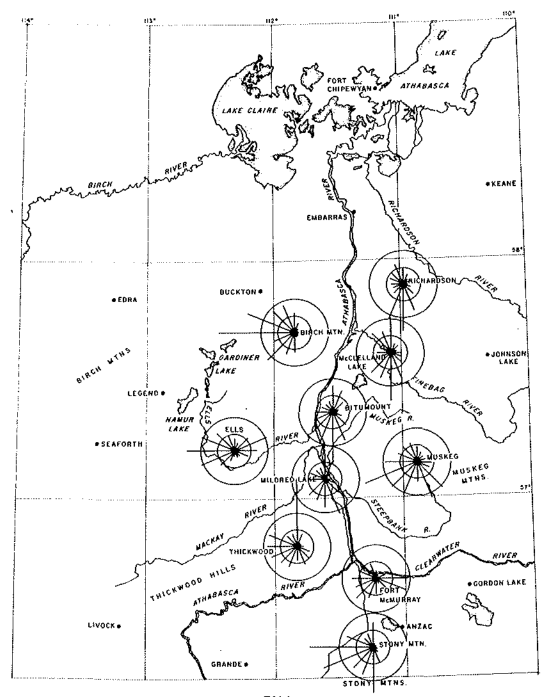


c.

Figure 20. Wind roses in the AOSERP study area (circles represent 5% and 10% frequency).
(a) annual September 1976-August 1978.
(b) winter 1976-78.
(c) fall 1976-78.

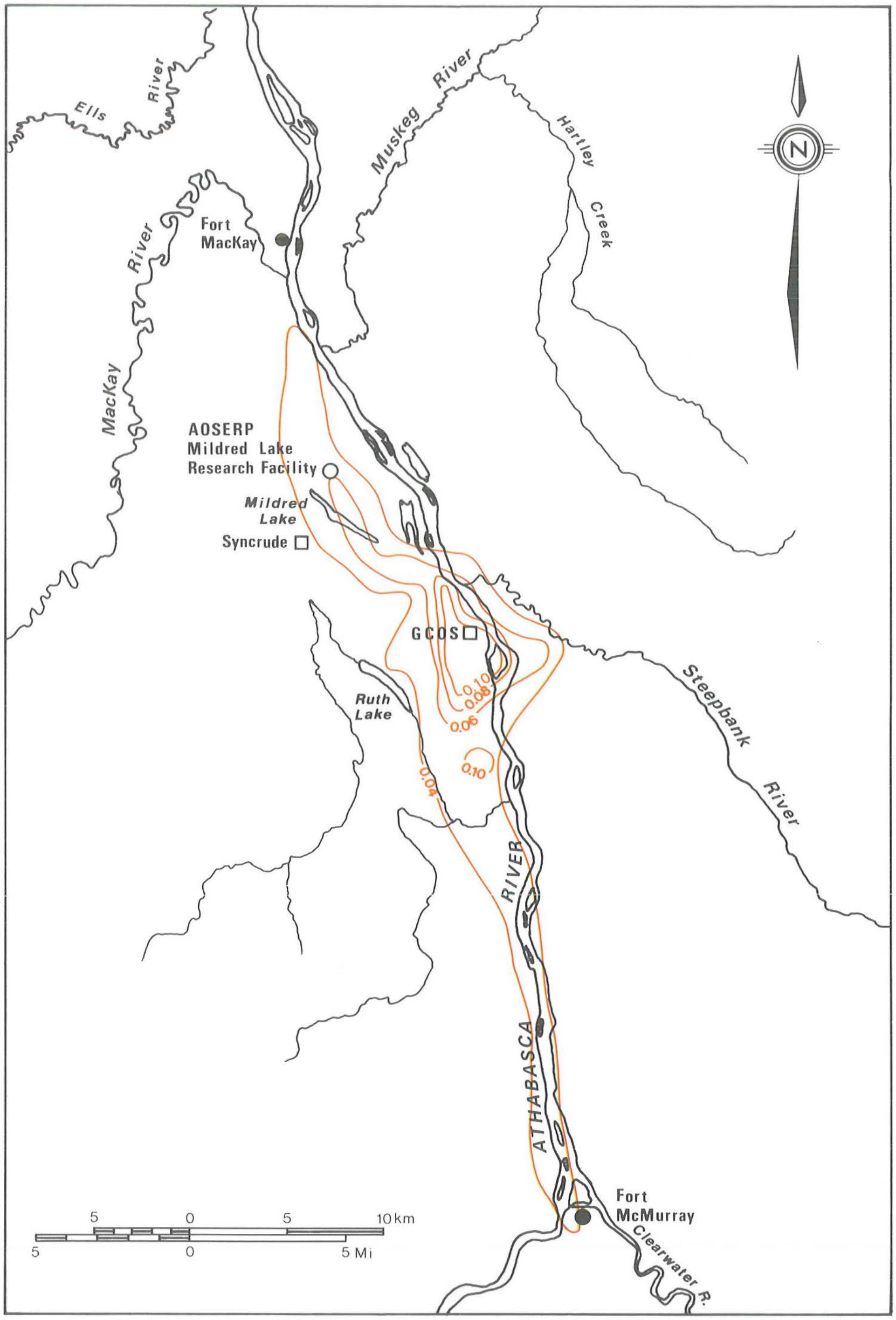


Figure 21. Total sulphation isopleths for 1976 (mg-SO_3/day/100 cm^2) (18).

pattern has been verified by chemical analysis of snow samples and by examination of results of the sulphation plate network (Figure 21) (18).

In summer and fall there is more significant west to east flow which shows up most prominently at Muskeg Mountain, some 40 km east of the oil sands development area. This sector could, therefore, be expected to receive slightly more impact from oil sands area emissions. From a limited number of snow samples and vegetation samples it would appear that the possibility of such an impact warrants further study (19).

In the south part of the area a southerly circulation (south wind) seems to be split by Stony Mountain with the two streams combining near Fort McMurray to be oriented along the river valley. Flow over top of Stony Mountain is not affected. The effects of Stony Mountain on a northerly flow has not been determined, but it would seem likely that it, too, would be split with low level stream flowing around the east and west flanks. The effects of such a flow on emissions in the south part of the area are the subject of ongoing studies.

In the northwest part of the area the wind records for Birch Mountain at an elevation close to 1,000 m above mean sea level indicate that the flow at that level is decoupled from the low level circulation, especially in winter (Figure 20b). Unless emissions are projected to high levels in the oil sands area they would favor following the valley circulation rather than moving over the Birch Mountain plateau.

PRECIPITATION

Long term precipitation records for the AOSERP study area indicate greater amounts of both rain and snow at higher levels. The lower winter snow pack and rainfall amounts are, therefore, characteristic of the river valley and decrease from south to north (16).

In considering precipitation patterns it is worthwhile noting that in the past three years there have been two major storms of over 100 mm in 24 hours. Long term records show that storms of this magnitude have occurred in the past and while not common are significant from the standpoint of integrity of structures such as diversion dams, drainage systems for open pit mines, and the safety of water storage ponds.

Chemical analysis of precipitation samples from many sites in the study area has revealed no pattern of effects of emissions from the oil sands development area. With increasing development, however, such patterns may emerge and the monitoring systems now operating will serve to identify any changes which might occur.

Air Quality

NATURAL AND MAN-MADE ATMOSPHERIC CONSTITUENTS

While natural environmental processes introduce gaseous and particulate constituents into the atmosphere, they are normally considered to be in natural balance, as opposed to man-made constituents which may tend to upset or shift an established equilibrium. For instance, carbon dioxide (CO_2) produced by growing vegetation, and hydrogen sulphide (H_2S) and methane (CH_4) produced by decaying matter, are natural emissions. Water vapour (H_2O) is introduced into the atmosphere naturally through evaporation and transpiration, and dust particles are introduced through wind erosion.

Industrial emissions generally are more concentrated and, until diluted by dispersion, may directly and adversely affect the environment. Sulphur dioxide (SO_2) is the most abundant man-made pollutant in the AOSERP study area and may affect vegetation by direct exposure. When oxidized and combined with other elements in the atmosphere it is transformed to the sulphate ($SO_4^=$) form and may tend to acidify rain, by which it is removed. Oxides of nitrogen (collectively referred to as NO_x) are produced by industrial processes and automobile engines. Substantial amounts of dust and particulate matter are generated by road traffic and in oil sands development activities.

A study carried out in 1977 (22) documented the sources of many man-made and natural emissions to the atmosphere in the study area. A summary of the main constituents is shown in Table 3. Industrial operations accounted for most emissions, but the contribution by urban centres to dust loading and NO_x was significant. Estimates of natural emissions from the study area have been made but not confirmed by actual measurements.

Table 3. Source and annual total (tonnes) of emissions in the AOSERP study area for 1976 (18).

Type of Emissions	Source and Amount (tonnes) Industrial	Urban
Sulphur dioxide	93,036	36
Hydrogen sulphide	97	23
Oxides of nitrogen	1,632	1,129
Dust (particles)	15,536	5,123
Hydrocarbons	744	127

DISPERSION AND CHEMICAL TRANSFORMATION

After emissions leave a source such as an industrial plant they spread out, mix with the ambient air, and generally are diluted. The rate of dispersion is related directly to temperature and velocity of the emissions, and to wind speed,

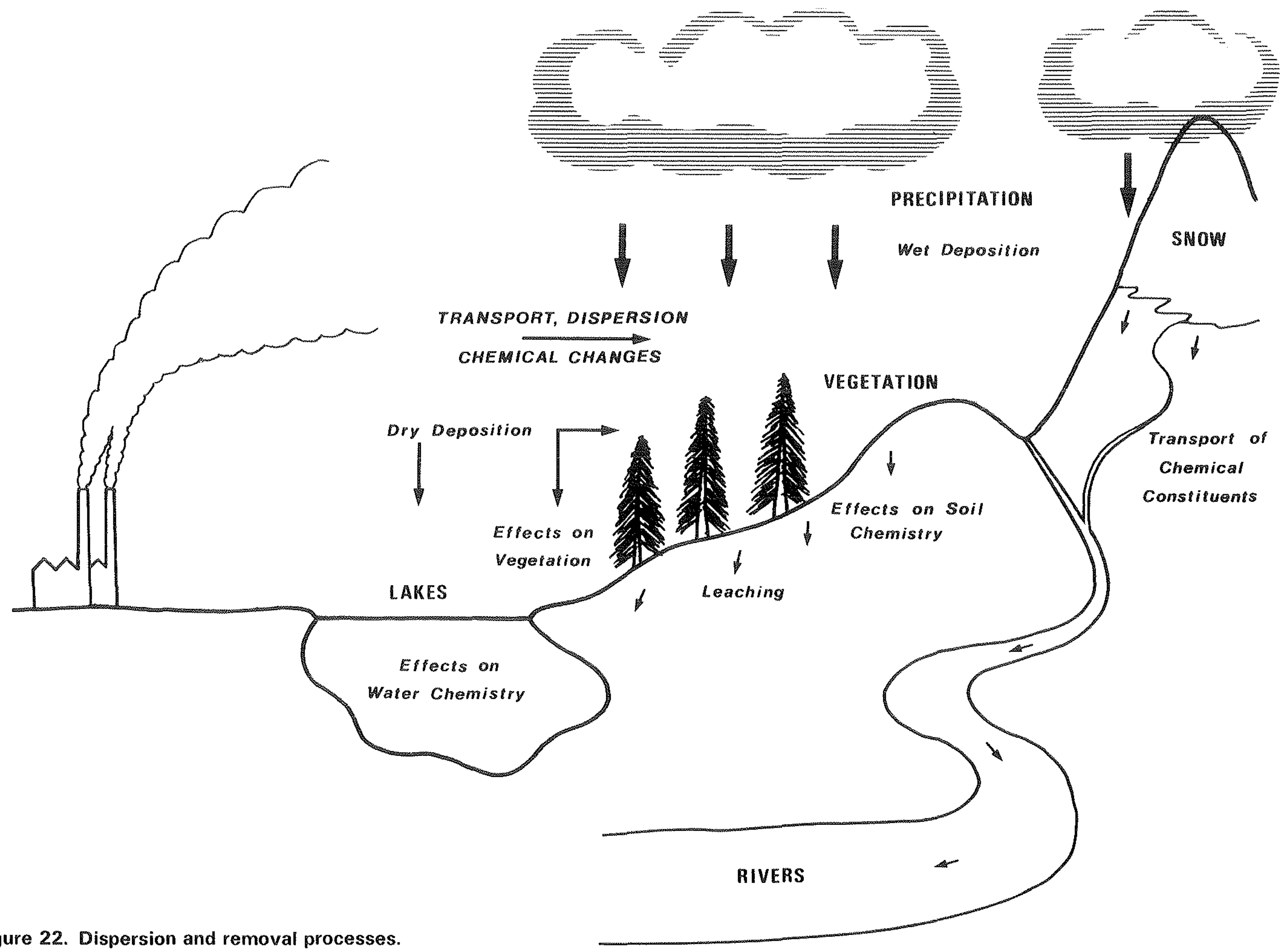


Figure 22. Dispersion and removal processes.

ambient temperature profile, and turbulence (Figure 22). In order to predict the plume effects at ground level, therefore, it is considered important to have a good understanding of meteorological characterstics of the areas.

Chemical processes taking place among the great number of gaseous and particulate components of the plume and between these components and the free atmosphere are complex, but must be evaluated to predict the ultimate fate of each component. The rate of change of gaseous sulphur dioxide (SO_2) to the sulphate ($SO_4^=$) form must be known to predict where and how quickly it may be removed by rain. The role of metallic elements such as iron (Fe) and nickel (Ni) in facilitating or retarding these reactions and the effect of solar radiation have yet to be assessed in the AOSERP study area (19, 21).

Atmospheric constituents may be removed from the atmosphere by several means, depending on their form. As noted above, soluble compounds are most readily removed by precipitation. They may either be incorporated in cloud and deposited with rain or snow or they may be scavenged by rain as it falls through the atmosphere. Particulate matter emitted in the plume may be removed by the scavenging of rain and snow or, under dry conditions, may fall out by downward settling. Heavier particles will fall out closer to the source. Gaseous constituents may be removed by a process of downward diffusion and turbulent downward mixing to the point where contact is made with the surface. An objective of Air System research is to evaluate these processes in the context of existing meteorological and air quality conditions in the AOSERP study area. Investigations have commenced to determine the amounts of various constituents released in the airshed of the study area and the mechanisms and rates of removal (22).

AIR QUALITY IN THE AOSERP STUDY AREA

To establish chemical composition of the atmosphere under predevelopment conditions, a study was carried out in March 1976 at Birch Mountain, 80 km north of the oil sands development area (23). Air was drawn through a filter at a rate of 100-200 m^3 over periods of 4 to 6 days and the atmospheric aerosols collected on the filter were analysed for 16 constituents using a combination of wet chemical and neutron activation techniques.

The sample analyses indicate very low concentrations of all constitutents, as would be expected in such a remote area. Elements in highest concentrations (greater than 10 μg/m³) were chlorine (Cl), sodium (Na), calcium (Ca), potassium (K), magnesium (Mg), and aluminum (Al). All except the last are abundant in sea salt, indicating a maritime origin for the measured airmass.

Other elements such as aluminum (Al) and manganese (Mn) appear to be soil-derived, whereas traces of arsenic (As), antimony (Sb), vanadium (V), and zinc (Zn) are probably of man-made origin. It should be pointed out that even the cleanest air may contain some man-made trace constituents.

There were relatively few air quality measurements made in the AOSERP study area prior to the start of oil sands processing in the late 1960's. Since then, however, through the combined efforts of industry and AOSERP, 13 continuous monitors have been installed and over 100 total sulphate exposure sites established. Ten of the continuous monitoring sites measuring only sulphur dioxide (SO_2) are located in the vicinity of oil sands development activities. Two have been established away from the development area, 30 and 80 km north, respectively. The farthest north, Birch Mountain, measures sulphur dioxide (SO_2), ozone (O_3), and particulates. The nearer site, Bitumount, and a station in the town of Fort McMurray monitor sulphur dioxide (SO_2), hydrogen sulphide (H_2S), carbon monoxide (CO), oxides of nitrogen (NO_x), hydrocarbons (HC), and ozone (O_3). High volume sampling is carried out on a periodic basis for particulates.

The exposure cylinder network provides information on cumulative sulphur compound impingement on a monthly basis.

Table 4. Monthly averages and SO_2 frequency distributions of ½-hour readings at Great Canadian Oil Sands-Fina Airstrip station.

Conc. Range (ppm SO_2)	<0.001		0.001 - 0.060		0.061 - 0.170		0.171 - 0.200		0.201 - 0.340		0.341 +		
Readings	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	SO_2 ppm Monthly Average
Month													
July/76	820	70.8	317	27.3	22	1.9	0	0.0	0	0.0	0	0.0	.007
Aug.	973	68.9	429	30.4	11	0.8	0	0.0	0	0.0	0	0.0	.007
Sept.	636	44.2	646	44.9	144	10.0	6	0.4	8	0.5	0	0.0	.024
Oct.	1132	81.0	258	18.5	8	0.6	0	0.0	0	0.0	0	0.0	.006
Nov.	807	57.0	543	38.4	47	3.3	6	0.4	11	0.8	1	0.1	.013
Dec.	1214	81.8	255	17.2	12	0.8	0	0.0	3	0.2	0	0.0	.004
Jan./77	1287	86.7	186	12.5	8	0.5	1	0.1	2	0.1	0	0.0	.003
Feb.	914	73.6	291	23.4	34	2.7	0	0.0	3	0.2	0	0.0	.008
Mar.	1202	84.6	199	14.0	17	1.2	1	0.1	1	0.1	0	0.0	.004
Apr.	1364	94.7	51	3.5	20	1.4	2	0.1	1	0.1	2	0.1	.003
May	1428	96.4	49	3.3	5	0.3	0	0.0	0	0.0	0	0.0	.001
June	1148	80.2	243	17.0	35	2.4	3	0.2	3	0.2	0	0.0	.007

Table 5. Monthly averages and SO_2 frequency distributions of ½-hour readings at Great Canadian Oil Sands-Supertest Hill station.

Conc. Range (ppm SO_2)	<0.001		0.001 - 0.060		0.061 - 0.170		0.171 - 0.200		0.201 - 0.340		0.341 +		
Readings	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	SO_2 ppm Monthly Average
Month													
Apr./76	1319	91.8	104	7.2	13	1.0	0	0.0	0	0.0	0	0.0	.003
May	1222	84.7	215	14.9	5	0.4	0	0.0	0	0.0	0	0.0	.003
June	1037	76.6	287	21.2	30	2.2	0	0.0	0	0.0	0	0.0	.006
July	1367	91.9	119	8.0	2	0.1	0	0.0	0	0.0	0	0.0	.002
Aug.	1339	90.1	146	9.8	1	0.1	0	0.0	0	0.0	0	0.0	.002
Sept	1180	95.2	56	4.5	3	0.2	1	0.1	0	0.0	0	0.0	.001
Oct.	1459	98.1	29	1.9	0	0.0	0	0.0	0	0.0	0	0.0	.000
Nov.	1328	98.1	26	1.9	0	0.0	0	0.0	0	0.0	0	0.0	.001
Dec.	1406	94.6	75	5.0	5	0.3	0	0.0	0	0.0	0	0.0	.001
Jan./77	1358	97.3	37	2.6	1	0.1	0	0.0	0	0.0	0	0.0	.001
Feb.	1321	98.3	21	1.6	2	0.1	0	0.0	0	0.0	0	0.0	.000
Mar.	1335	89.9	142	9.6	7	0.5	0	0.0	0	0.0	0	0.0	.002
Apr.	1361	94.5	72	5.0	7	0.5	0	0.0	0	0.0	0	0.0	.002
May	1431	98.9	15	1.1	0	0.0	0	0.0	0	0.0	0	0.0	.000
June	1388	96.9	44	3.1	0	0.0	0	0.0	0	0.0	0	0.0	.001

Monthly average ambient air concentrations of SO_2 vary from 0.001 ppm to 0.024 ppm depending on the station and month for which the readings are given. Several months of NO_2 measurements yield average concentrations at the 0.01 ppm level, less than the air quality objective of 0.03 ppm for the annual average, but higher than an estimated global background concentration of 0.0004 to 0.0005 ppm. Ozone concentrations are highest at the remote station (18). Maximum 24 hour concentrations of O_3 are 0.05 to 0.06 ppm, while the monthly average is 0.04 to 0.045 ppm. Federal and provincial air quality objectives set the 24 hour O_3 concentration at 0.015 ppm.

In observation of background and near source ambient SO_2 data, it is significant to not only review the average concentrations but to determine the maxima and minima as well as their frequency of occurrence. Table 4 illustrates these phenomena for a monitoring station close to the source (within 3 km). Table 5, by comparison illustrates results from a station further removed from the source (12 km), where events show a significant decrease in frequency of the high concentration measurements. True background stations reinforce this trend, by concentration measurements which suppress most (99.8 percent) of the readings into the first two standard columns of concentration ranges used in the tables.

Although this trend of decreasing SO_2 concentrations with distance from the source is to be expected, there are several studies underway to define and quantify the processes by which pollutants are dispersed and removed.

The distribution of ambient sulphur compound levels can best be seen in Figure 21, which shows the sulphation isopleths for 1976. The GCOS processing plant is the major contributor to the elevated levels.

DISPERSION

During the period of time covered by this report (April 1975 to November 1978) data have been gathered on the extent to which industrial emissions contribute to atmospheric loading of various constituents. The Great Canadian Oil Sands plant located some 35 km north of Fort McMurray was the only operational facility in the area prior to midsummer 1978 when Syncrude came on stream; this has been the principal source investigated in the studies to date.

A plume is frequently represented as a flattened cone with its long axis horizontal and its point at the emission source (Figure 23). The plume spread and diffusion in this context is described in terms of lateral and vertical dispersion coefficients.

Considerable theoretical and experimental work has gone into the formulation of dispersion coefficients for a variety of emission characteristics, wind speeds, and ambient temperature profiles. The objective of this work is to develop a means of reliably predicting plume behaviour for a wide range of conditions at a particular site.

To evaluate the extent to which available empirical and theoretical formulations represent conditions in the AOSERP study area, an aircraft fitted with a sulphur dioxide monitor and turbulence measuring instruments was flown in the plume to determine its actual configuration under a variety of conditions. Experimental traverses at 3.2 km, 8 km, and 16 km were made in varying atmospheric conditions in March 1976 and June 1977; appropriate meteorological measurements were made from the ground by other researchers engaged in the field studies (16, 23, 24, 25).

Results of these studies indicate that, in winter, lateral spread of the plume in the study area is 2-3 times larger than what would be expected on the basis of experimental work carried out elsewhere (24, 25). Vertical spread close to the stack was found to be similar to predicted values but increased more slowly downwind than expected. This is attributed to a condition of increasing stability with height, which is not accounted for in conventional formulations. The Athabasca River valley did not appear to affect plume behaviour at the heights at which traverses were flown.

In the summer experiment, horizontal dispersion close-in was larger than predicted, but increased more slowly downwind. In two of the cases studied, results close to the stack were approximately equal to those predicted, but in two others were 2-4 times larger. Measured vertical dispersion coefficients agreed with theoretical calculation close to the source (3.2 km), but did not increase substantially downwind. As in the March study, this is attributed to reduced mixing due to increased thermal stability with height. It has been noted that although these results do not fit previously accepted theory they agree with more recent theoretical and experimental work of other researchers.

From comparisons of turbulence statistics measured in flights parallel to the wind direction but along different paths, it was concluded that the Athabasca River valley did not enhance turbulence at plume height. In two cases when markedly enhanced turbulence was encountered within the plume near the river valley, it was close to the source; it is suggested that a combination of complex terrain and initial momentum and buoyancy of the plume was the cause.

The slightly higher turbulence measured on runs 8 km to the east of the river valley suggests that variation in vegetation cover may be a factor in turbulence enhancement rather than the valley itself.

The results of these measurements, when compared to those obtained in October 1971 and February 1973 (26), show similar characteristics. In neutral conditions, measured values of lateral and vertical dispersion were significantly greater than predicted values close to the source and, even at a distance of 10 km, were approximately five times greater than would be expected. Unstable conditions showed the same trend; measured dispersion was generally larger than predicted but a better correspondence was observed at greater distances.

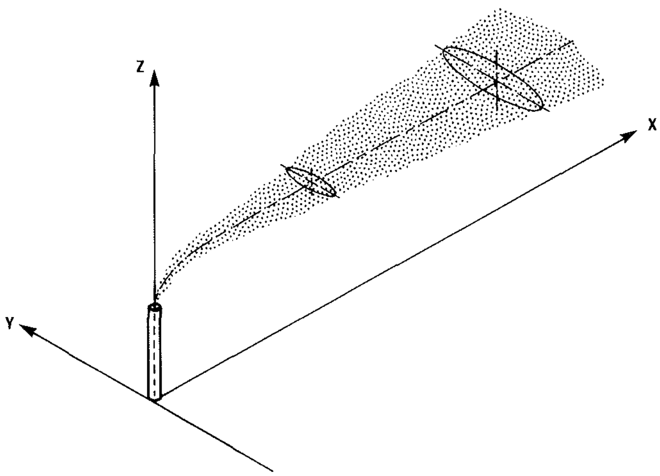


Figure 23. Concentration distributions from a continuous point source as predicted by the Gaussian plume equation.

PLUME CHEMISTRY

The mixture of gases, particulates, and water vapour emitted from an industrial process chimney is a dynamic mixture in which physical processes such as sublimation of volatile elements, condensation of water vapour, and a range of chemical reactions are taking place both among constituents in the plume and between the plume and the surrounding atmosphere far downstream from the emission source. Since the nature of constituents in the plume determines the manner in which they may be removed, it is important to know the results of these chemical reactions.

Two studies carried out in the AOSERP study area in February (27) and June 1977 (18) were designed to measure the rate at which SO_2 is oxidized and ultimately transformed into particulate sulphate ($SO_4^=$). A helicopter was used to fly instruments through the GCOS plume at varying distances, from a few hundred metres to 40 km, from the source to measure the ratio of SO_2 to particulate sulphate material. Water vapour, ozone, and metallic particulates such as nickel, iron, and vanadium were also measured.

Results indicate that, in winter, the fraction of total sulphur in sulphate form remains essentially constant at about 1.3 percent for plume downwind distances of an hour or more. Runs before sunrise in June gave similar results; the sulphate fraction remained constant at about 2 percent for a downwind distance of at least two hours plume travel. In June runs after sunrise, however, a definite increase in the sulphate fraction to 3 percent was noted at a downwind distance equal to one hour's travel.

One of the interesting features of the plume measurement in June was the pronounced O_3 deficiency near the stack due to chemical scavenging by emitted NO. On several flights in late morning and afternoon conditions, however, a slight excess of O_3 was noted in the plume at larger downwind distances. Figure 24 shows plume cross-section measurements of SO_2 and O_3 at a distance of 2.3 km and 24 km from the source.

The mechanisms for conversion of SO_2 to $SO_4^=$ is suggested to proceed via photochemical reaction. Ozone production is known to be consistent with a photochemcial mechanism. Excess ozone was observed on several occasions of high conversion rates of SO_2 to $SO_4^=$ and would seem to support the photochemical mechanisms, as would the low winter versus high summer conversion rates with higher solar angles.

Although potential catalysts such as vanadium, manganese, and iron were present in the plume in both winter and summer experiments, there is no evidence that oxidation rates were enhanced by their presence.

DEPOSITION OF SULPHUR

The fate of sulphur compounds emitted by the oil sands industry is of particular concern in the AOSERP study area because sulphur compounds are characteristically associated with acidity. During winter months, sulphur compounds are deposited in the snowpack, both as a result of scavenging during precipitation events and by particulate deposition and direct downward gaseous transfer. The principal objective of a study undertaken in March 1976 was to determine the pattern of deposition and to estimate how much of the sulphur emitted by oil sands processing (anthropogenic) activities is deposited in snow in the area (23).

The snowpack was about 75 cm deep over the area and sample cores were taken from 56 sites within a 25 km radius of the oil sands production facility. Several samples were collected at each site and these were separated into bottom "old snow" and top "new snow" portions. A number of control samples were also taken from remote forestry sites to establish background levels. Each sample was melted and immediately analyzed for pH and conductivity, then bottled for subsequent laboratory analysis for total sulphur content. The results show that a north-south strip parallel to the Athabasca River valley received most of the anthropogenic sulphur deposited in the area. Outside of this narrow strip of deposition, the quality of snow was almost indistinguishable

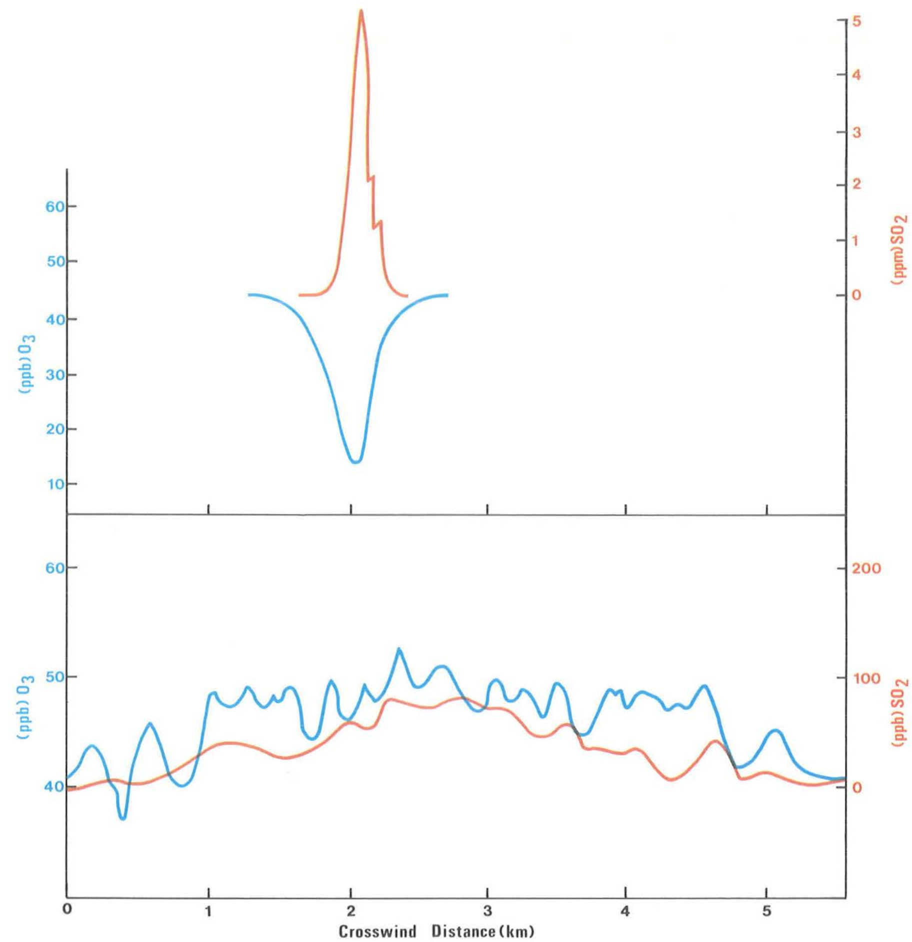


Figure 24. Cross plume measurements of sulphur dioxide and ozone at distances of 2.3 km (above) and 24 km (below) from the source 19 June 1977 (19).

from that collected at remote foresty sites approximately 75 km from the source. Figure 25 illustrates the pattern of deposition revealed by sample analyses.

Regions of maximum sulphur deposition are located southwest of the extraction plant (GCOS) and along the river between the plant and Fort McMurray. Strong deposition along the river as well as adjacent areas suggests that the circulation pattern during the period of deposition was predominantly oriented along the river valley. Surface wind records at Mildred Lake for the period February to March 1976 confirm that the prevailing wind was from the south.

Areas of high sulphur deposition are generally associated with regions having low snowpack pH (acid) and high conductivity and if the sulphur in the snowpack were deposited as sulphuric acid, the pH of the resultant meltwaters would be lower than 5.0. This is not the case in the study area, however, as is evident in Figure 26, which shows snowpack pH in the Mildred Lake area. Much of the snow has a pH above 6.0 and one point sampled had a pH of 8.0, indicative of pronounced alkaline buffering.

It is postulated that the alkaline buffering constituents are from wind-blown dust, products of slash burning, or emissions of alkaline metal oxides by the plant. They must be of anthropogenic origin, however, since the pH in snow in remote areas is 4.9 to 5.5. Because of leaching of sulphur during warm periods, which occurred in January 1976, it was found that lower layers contained less total sulphur than the top, fresher snow. After adjusting the total sulphur deposition in the snowpack for natural background, it is estimated that less than 0.2 percent of the sulphur emitted comes to the ground within a 25 km radius of the source (Table 6). These low levels of deposited sulphur are consistent with the measurements made in 1973, when it was found that less than 2 percent of the sulphur released from a sour gas plant in central Alberta was deposited within 40 km of the source during the winter (28).

It is important that rates of deposition of airborne constituents emanating from oil sands plants be quantified, in order to evaluate environmental effects and so that reliable mathematical models can be developed to aid in air quality control. Deposition processes are complex, and include the combined effects of gravitational settling of particulates, downward diffusion of gases, and turbulent downward mixing of gases and particulates. The relationship of these processes is shown in Figure 27.

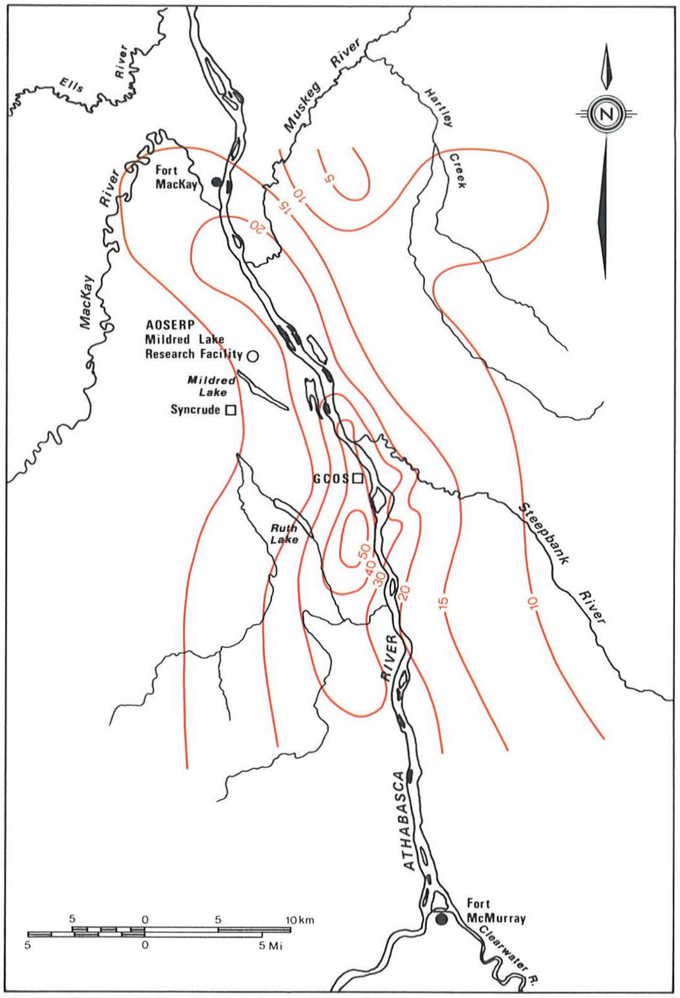


Figure 25. Total sulphur deposition in snow measured March 1976 (mg-S/m^2) (23).

A great deal of effort has been directed toward measuring deposition velocities of atmospheric gases and particulates and relating the values determined to atmospheric stability, wind speed, and surface type. Very little work has been done, however, on the transfer of these constituents to snow surfaces and none has been done in conditions similar to those in the AOSERP study area. To fill this knowledge gap two approaches were followed to evaluate the deposition velocity of gaseous sulphur dioxide in a winter situation: the first relates to deposition at a single site and the second to a large area (19).

In the first case, snow was sampled daily at a site near Mildred Lake in parallel with ambient sulphur dioxide measurements. During one period of about 8 hours on 8 March 1976, high sulphur dioxide concentrations (17 µg-S/m^3) were recorded at ground level and the total sulphur deposited on top of a fresh layer of snow was measured as 1.8 mg-S/m^2. From this information a deposition velocity of 0.25 cm/s was calculated.

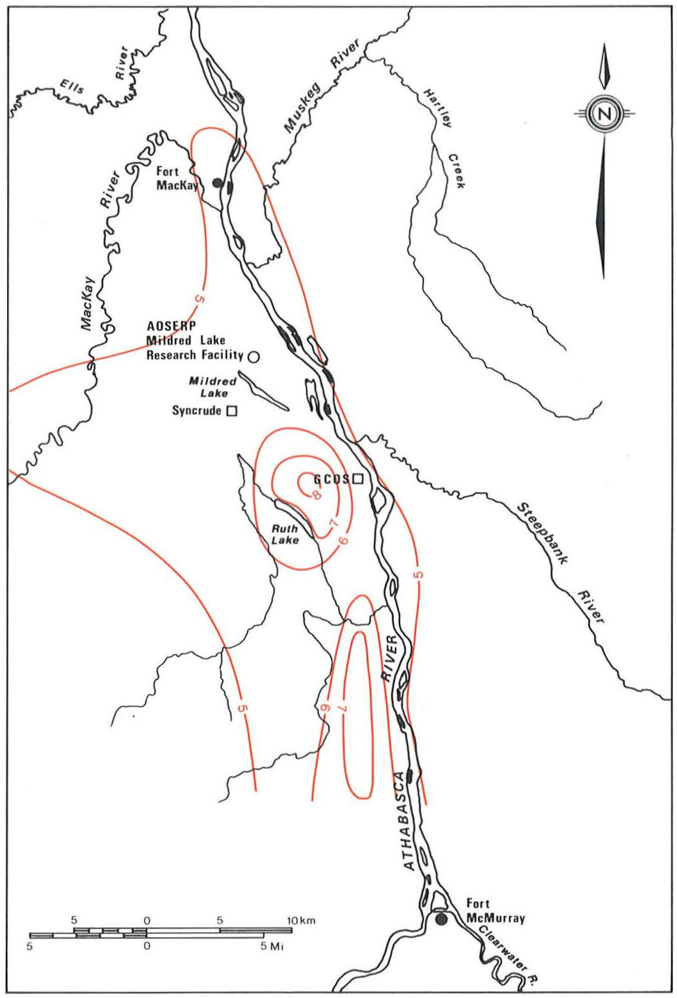


Figure 26. The pH in the top layer of snow measured March 1976 (23).

Table 6. Comparison of amount of sulphur in snowpack within 25 km of GCOS with sulphur released by GCOS during the snow accumulation period March 1976.

Layer of Snow	Sulphur Released from GCOS (tonnes)	Anthropogenic Sulphur Retained by Snow (tonnes)	Fraction Retained in Snow
Top (unleached)	2,690	3.8	0.14%
Bottom (leached)	16,617	10.2	0.062%

In the second case, samples from the top layer of the snowpack (Figure 28) from 40 sites were used to determine total sulphur depositions over the area for about a month.

A Gaussian-type climatological dispersion model was used to calculate ambient ground level concentrations for the same 40 sites for the period of deposition based on known emission rates and wind and stability characteristics (Figure 29). By averaging these values and dividing the deposition flux as measured by the predicted concentrations, an average of deposition velocity, V_d, was obtained. Results indicate a deposition velocity (V_d) of 0.3 to 0.4 cm/s.

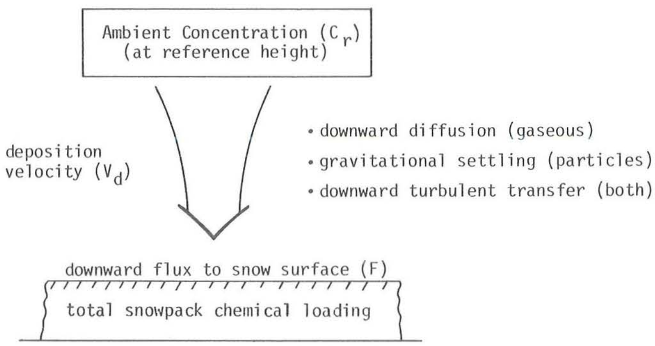


Figure 27. Relationship between concentration (C_r), deposition velocity (V_d), and downward flux (F) of atmospheric constituents.

These results compared with V_d values of 0.52 and 1.6 cm/s made in eastern Canada under neutral and unstable conditions (29) and a value of 0.1 cm/s made under very stable conditions (30). Deposition rates are usually higher in unstable conditions because the associated increased low level turbulence mixes more of the constituent to the surface where it may be removed by physical or chemical processes. Rates of deposition are lower under neutral conditions, and lowest under stable conditions.

To evaluate rates of deposition of atmospheric constituents in summer, a two-part study was undertaken in June 1977 (19). The first part of the study was carried out in the field to collect samples of particulate and gaseous sulphur and other particulates, and to determine particle size distribution. The second part involved determining particulate deposition rates and the chemical composition of particulates.

A network of 15 Harwell collectors was used to sample dry deposition of particulates within 20 km of the oil sands development area (19). Previous studies indicate that this collector represents deposition to a grass surface fairly well for an element whose mean mass lies in the particle size range 2-10 µm. This is the case for particulates originating from wind-blown dust sources and for Al, Mn, and V originating from the power plant plume whose mass medium diameter is in the range of one micrometre. Particulate sulphur is in the submicron range and, therefore, its deposition is underestimated by the Harwell collector.

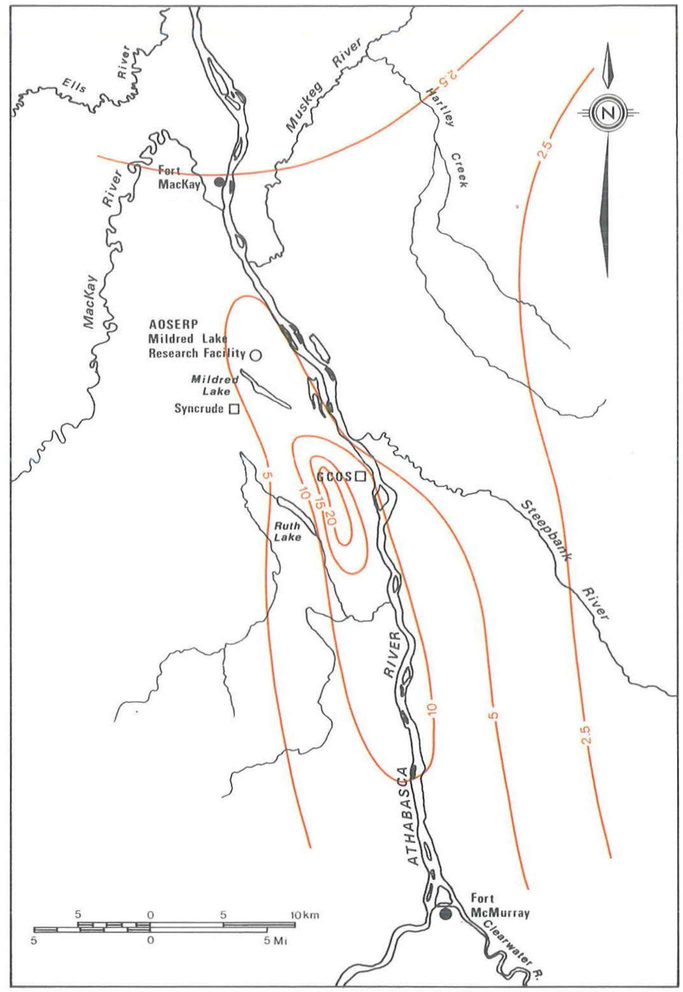


Figure 28. Sulphur deposition patterns in the top snow layer, 5 March 1976 (mg-S/m²).

A comparison of particulate sulphur deposition rates with total deposition rates measured in winter as well as with annual estimates for central Alberta is given in Table 7. Bearing in mind that particulate sulphur deposition is underestimated by the Harwell collector, it can be seen that near the source it is quite comparable to annual averages for central Alberta and maximum deposition in winter in the AOSERP study area.

Away from the influence of oil sands activity, particulate sulphur deposition is very low compared to total deposition rates in central Alberta. When the areal deposition patterns of particulates are plotted it is apparent that material of anthropogenic origin (particulate sulphur and vanadium) are deposited mainly to the east of the source (Figure 30) or downstream in the prevailing wind for a period of the study. Deposition of particulate sulphur was detected as far away as Muskeg Tower, 40 km to the east. Deposition patterns for materials of predominantly wind-blown origin, such as Al, Ca, Mg, Mn, and Ti, are difficult to correlate with wind directions because of their wide source area. The absence of high deposition to the northeast or east of the oil sands development area, which would be expected from a south-southwesterly prevailing wind, suggests that the wind-blown dust carrying these elements to the collector'is of relatively local origin (Figure 31). The average deposition velocities of elements in Table 8 were calculated using the average ambient concentration of each element at one site (Mildred Lake) and deposition flux taken from the deposition pattern plots (Figure 30 and 31). In spite of a degree of uncertainty in their derivation, they represent useful values in estimating deposition velocities if an ambient concentration is available from model calculations or measurements.

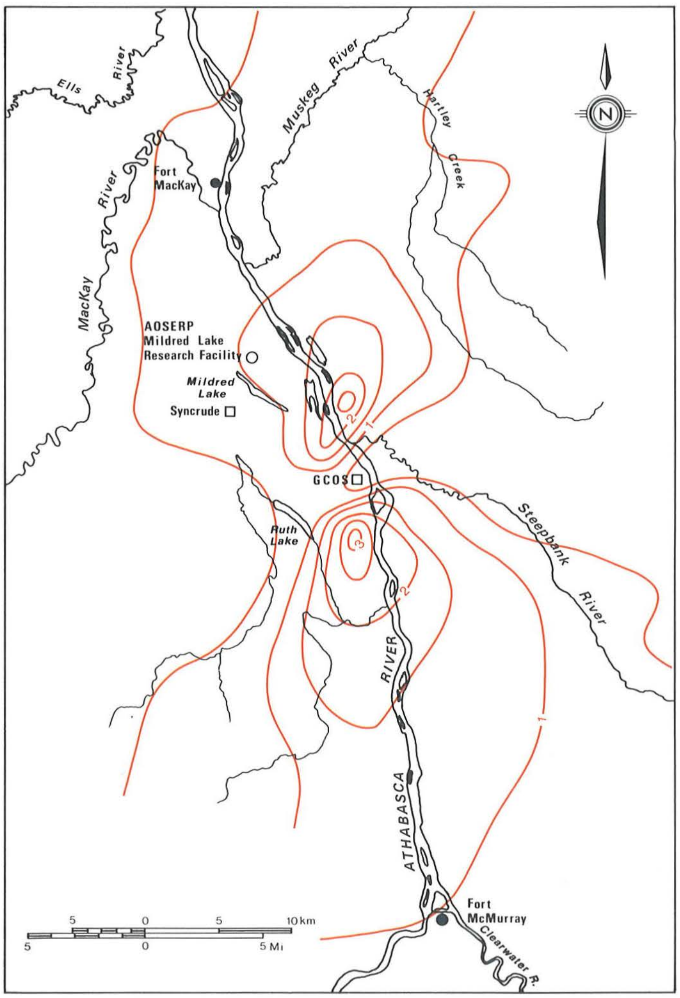


Figure 29. Sulphur dioxide concentrations calculated for 8 March 1976 using Gaussian model (μg/m^3).

Pollutants may also be removed from the atmosphere by wet deposition. Two processes may be involved: inclusion of the pollutant material in cloud droplets to be subsequently deposited in precipitation, termed rainout, and pollutant scavenging by precipitation, referred to as washout. Rain event samples collected over two seasons (1976-77) in the AOSERP study area show generally similar chemical characteristics (33). Over 100 samples were collected each season at 10 sites in the area, most of them remote from the oil sands development area. To avoid contamination, samples were collected by uncovering a special collector only during rain events of 10 mm or more. Each collected sample of rainwater was decanted into a separate bottle and refrigerated until it could be sent to a laboratory for chemical analysis. Results of analyses are summarized in Table 9 and compared with similar measurements in Saskatchewan and southern Ontario.

Table 7. Comparison of deposition rates of particulate sulphur in Alberta.

Location	Period	Deposition Rate (kg-S/ha/y)	Reference
Athabasca Oil Sands			
maximum	June 77	0.99	(27)
background		0.04	(part-S deposition)
maximum	Feb. 76	3.6	(23)
background		<0.44	(total deposition)
Central Alberta			
average	annual	0.5-1.1	(31) (total deposition)
average	annual	2.1	(32) (total deposition)

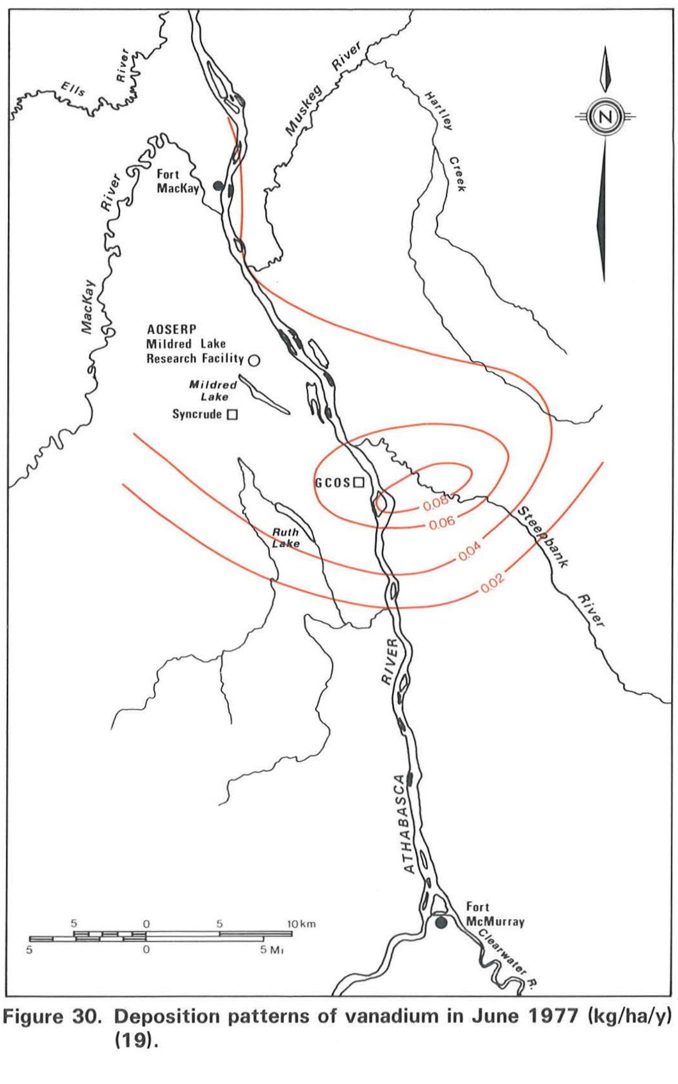


Figure 30. Deposition patterns of vanadium in June 1977 (kg/ha/y) (19).

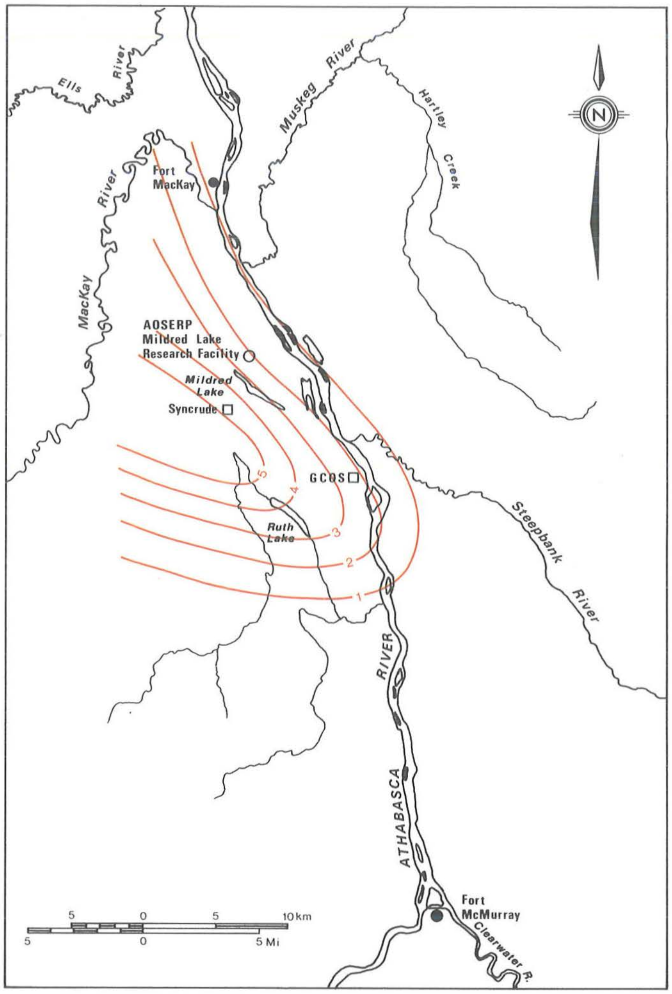


Figure 31. Deposition patterns of calcium in June 1977 (kg/ha/y) (19).

Table 8. Deposition velocities of elements in suspended particulate to the Harwell collector in June 1977 (19).

Deposition Parameter	Elements						
	Al	Ca	Mg	Mn	Part-S	Ti	V
Deposition Rates (kg/h/yr)	2.8	1.8	0.5	0.045	0.70	0.24	0.045
Average Concentration (ng/m^3)	1,800	2,500	640	38	320	130	66
Deposition Velocity (cm/s)	0.49	0.23	0.25	0.38	0.69	0.59	0.22

The pH of rain in the AOSERP study area averages 5.3, which is slightly lower than that of distilled water in equilibrium with ambient carbon dioxide (CO_2), pH 5.4 to 5.6. The range of pH was from 4.3 to 6.9 with all except two sites having at least one occurrence of pH less than 5.0 in 1976 (41 out of 118 samples) and seven out of 15 sites in 1977 (33 out of 77 samples). Stony Mountain, Birch Mountain, and Thickwood Hills appear to have the highest frequency of low pH events (Table 10). The causes of these differences are not evident at this time. Distance from the oil sands development area does not seem to be a factor, however, since one of the sites is closest (30 km) and two are

Table 10. Stations recording precipitation of pH less than 5 as a function of distance from the oil sands extraction plant (1977).

Site	Distance From Source (km)	Number of Samples pH < 5	Total Number of Samples
Thickwood	30	2	5
Fort Hills	40	1	9
Ells	55	2	7
Stony Mt.	70	8	12
Birch Mt.	80	1	15
Legend Lookout	100	1	5

Table 9. Constituents in rainwater in the AOSERP study area and in northern Saskatchewan compared to those in eastern Canada (33).

Rainwater Constituent	May - Sept. 77 AOSERP Network All Sites Arith Mean	May - Sept. 77 AOSERP Network All Sites Precip. Weighted Mean	July - Aug. 77 Cansap Network Cree Lake, Sask. Precip. Weighted Mean	June - Aug. 77 Mount Forest Southern Ontario Precip. Weighted Mean
pH	5.2 (77)	5.3 (64)	5.4	4.2
$SO_4^=$ - S	0.18 (129)	0.14-0.18 (113)	0.3	2.9
Cl^-	0.54 (130)	0.48 (114)	0.05	0.19
NO_3^- - N	0.06 (109)	0.05 (97)	0.06	0.74
NH_4^+ - N	0.12 (89)	0.12-0.13 (79)	0.24	0.51
K^+	0.32 (101)	0.28 (87)	0.10	0.092
Na^+	0.10 (101)	0.06-0.08 (87)	0.06	0.18
Mg^{++}	0.10 (101)	0.08-0.09 (87)	$<$0.01	0.27
Ca^{++}	0.11 (101)	0.09 (87)	$<$0.05	0.82
Cond. (μmho/cm)	9.6 (74)	8.9 (61)	6.6	53.1

Numbers in brackets are the number of data used to calculate the mean.
Concentrations in mg/l.

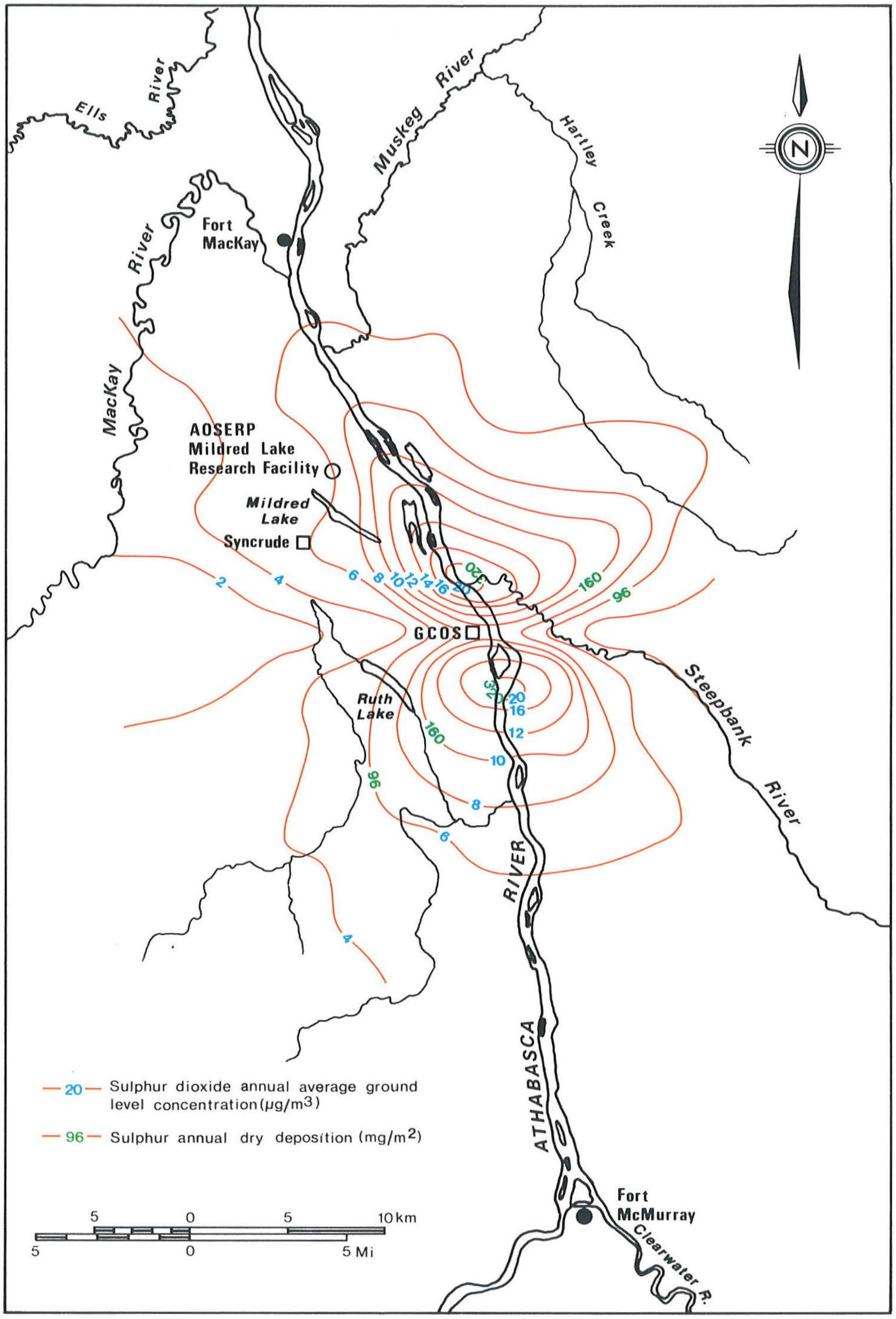


Figure 32. Calculated annual average sulphur dioxide concentrations at ground level (four sources) and average annual dry deposition of sulphur (five sources) (35).

at a considerable distance from the obvious source (70 and 80 km, respectively).

It is noted in Table 9 that pH measurements in the AOSERP study area are comparable to those in Saskatchewan; however, the low pH for the Ontario samples is attributed to substantial industrial emissions in eastern Canada and the U.S.A. The higher concentrations of magnesium (Mg) and calcium (Ca) are due to exposed sources of soil-dust in the oil sands development area as opposed to the completely forested area surrounding Cree Lake. The higher concentrations of chlorine (Cl) are as yet unexplained since sodium (Na) levels are normal.

To evaluate the average annual ground level concentration of sulphur dioxide related to oil sands extraction and upgrading activities, a numerical model, the Climatological Dispersion Model (34), was applied using the best available emission data for existing and projected plants and long term meteorological data adapted to the area. Figure 32 shows the predicted pattern of sulphur dioxide concentration on an annual average resulting from oil sands activity.

The maximum desirable level, according to Canada Ambient Air Quality Objectives and Alberta regulations, is 30 $\mu g/m^3$, which is considerably higher than the 20 $\mu g/m^3$ predicted for the areas closest to the source.

On the basis of the single operating plant in the area and using an assumed deposition velocity of 0.1 cm/s, an estimate of annual dry deposition of sulphur of 350 $mg/m^2/y$ was obtained. This agrees quite well with the estimate of 430 $mg/m^2/y$ made by projecting March 1976 snow deposition measurements to annual averages.

A map was also prepared of annual dry deposition of sulphur considering two major oil sands plants in operation. The results are also shown in Figure 32.

On the basis of these predictive deposition rates, it would appear that sulphur loading on the surface in the vicinity of oil sands operations will be similar to the 300-600 $mg/m^2/y$ estimate (31, 32) resulting from sulphur gas plant operations in Alberta.

Air System Status

From the foregoing it is evident that Air System research has concentrated on defining the synoptic meteorological conditions in the oil sands study area by means of a telemetry network which provides basic data to aid the interpretation of air quality information. In general, information is adequate to indicate the boundaries of distribution of atmospheric constituents originating from the plume of the GCOS plant, and will be able to define the extent and distribution of constituents from the Syncrude operation. Meteorological studies have revealed no significant anomalies from what might be expected in an airshed at the latitude and having the physical characteristics of the AOSERP study area.

Air quality measurements to date compare favourably with those in other parts of Alberta. Concentrations of sulphur and nitrogen oxides and ozone have been found to be generally lower than air quality objectives set by Alberta Environment. No evidence has been obtained for formation of smog as a result of entrapment of air pollutants near inversion layers, although the frequency of temperature inversions is relatively high in winter months. Air quality measurements to a large degree reflect the generally favourable meteorological conditions in the region, as well as the adequacy of pollution control regulations.

The assessment of dispersion and deposition of constituents originating from stack emissions to date indicate that dispersion patterns and deposition rates can be defined with some confidence. These data will be important in the establishment of long term air quality monitoring networks in the oil sands region. In addition, more precise quantification of dispersion patterns, and chemical transformation and deposition rates for various airborne constituents will be of critical importance in the construction of predictive models which may be used in air pollution control in the region.

Land System

The physiographic setting of the AOSERP study area has largely determined direction for Land System investigations. Research in the Land System is directed toward physical, chemical, and biological characteristics of the terrestrial ecosystem, the major components of which are soils and terrestrial flora and fauna. General objectives of Land System research are involved with identifying the responses of these components to possible stresses imposed on them as a result of oil sands development. Land System objectives are defined as follows:

1. To review and assess the available information pertaining to terrestrial ecosystems of the AOSERP study area;
2. To undertake studies which may be used to establish the baseline states for physical, chemical, and biological constituents of the terrestrial ecosystems of the study area which could be altered by oil sands development;
3. To identify substances which may be introduced into the metabolic pathways of the terrestrial ecosystems of the study area and their effects on these metabolic pathways;
4. To assess and report on all physical, chemical, and biological disruptions of the terrestrial ecosystems in the study area resulting from oil sands development;
5. To undertake studies directed toward restoration of biological productivity to terrestrial ecosystems disrupted, damaged, or destroyed in the course of oil sands development; and
6. To derive a conceptual and/or mathematical model which can be used to predict the effects on the terrestrial ecosystem and its capacity to assimilate those effects without permanent or long-lasting debilitation.

The decision was made by AOSERP management to concentrate first on the likely impacts of development on the soils and vegetation, outside the areas of disturbance on plant sites; to investigate the probability of successful reclamation by testing candidate floral species and documenting the acute biochemical effects of SO_2 on soils and vegetation; and by mapping the distribution and extent of habitats and the faunal groups living in those habitats.

Surficial Characteristics

Establishment of soils and vegetation is dependent to a large degree on physiographic relief. As noted earlier, 10 major physiographic divisions have been identified in the study area, within which soils and vegetation may be further classified in recognizable units. Figure 33 shows typical surficial characteristics for a portion of the study area, plotted at a scale of 1:50,000 on standard map sheets (the legend for these map sheets is given in Table 11).

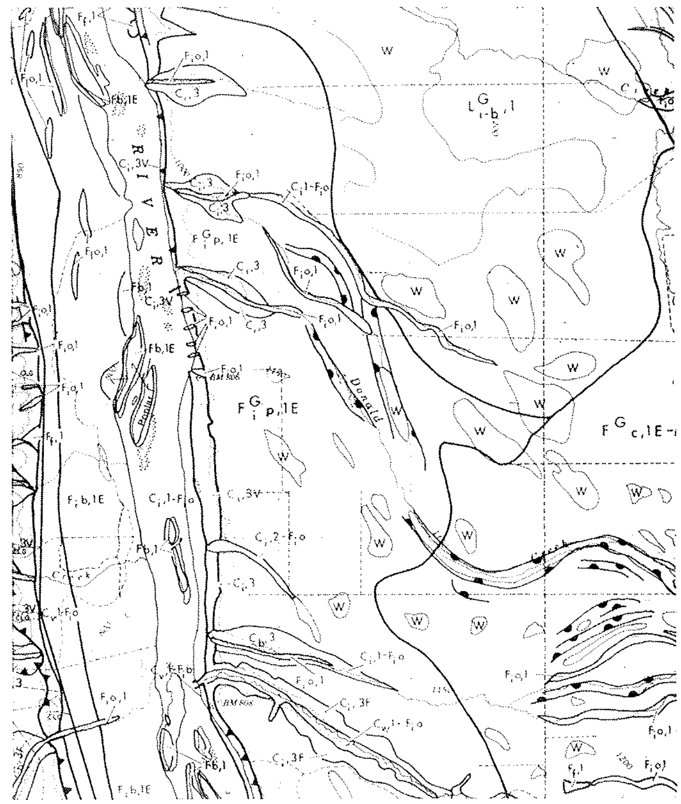


Figure 33. Portion of the 1:50,000 surficial geology map on mapsheet 74D/14 (4).

SOILS

Dominant upland soils are Gray Luvisols formed on glacial tills and glaciolacustrine deposits, and Eutric Brunisols formed on coarse glaciofluvial deposits. Luvisolic soils develop characteristically in well to imperfectly drained sites in medium to fine textured, base saturated materials under forest vegetation. Brunisolic soils are distinguished from Luvisols by lacking the Luvisolic Bt horizon (soil layer) which is enriched with silicate clays (8). White spruce, trembling aspen, and jack pine are the dominant tree species on these soils (11).

Regosols and Gleysols are soils developed on materials of recent deposition. Regosols are young, poorly developed soils which reflect the characteristics of the parent material from which they are derived. Regosolic soils in the study area occur on recent alluvial and fluvial fan materials. Gleysolic soils are poorly drained, and reflect the influence of waterlogging for significant periods. Most of these soils have organic (i.e., peat) surface layers (11).

Organic soils in low-lying, poorly drained areas occupy a large portion of the study area. These soils are developed on two types of organic deposits, moss peat and sedge peat. Moss peat is derived from *Sphagnum* spp. and other types of mosses under black spruce and tamarack, which form areas referred to as bogs or muskeg. Sedge peat is derived from dominantly sedge vegetation occurring with some shrubs and tree vegetation in open peatlands called fens (11).

In addition to mapping, baseline data are also being collected on the physiochemical properties of both natural and mined soils (i.e., tailings sand) (36). Tailings sand is a byproduct remaining after the bitumen is removed from the oil sand and is of primary concern regarding subsequent reclamation. Investigations include studies on nutrient cycling, biological activity, and soil-vegetation-moisture relationships. This information will be used to aid in reclamation of areas disturbed by oil sands development and to assess impacts in physically undisturbed areas through long-term monitoring of soil-vegetation characteristics.

Additional research includes the characterization and utilization of peat and the effect of SO_2 deposition on soils (37). When overburden is stripped during open pit mining of oil sands, surface peat deposits are removed and stockpiled for later use as a reclamation material, because mixtures of tailings sand with till, or with organic matter such as peat, provide a much better plant growth medium than sand alone. In view of the potential importance of peat as a reclamation material, the study is designed to determine if prolonged storage of peat may affect its physiochemical properties (38).

VEGETATION

AOSERP vegetation research was concentrated in two main areas: biochemical response of vegetation to acute exposure to SO_2 and ecological habitat mapping. Biochemical research is intended to provide basic knowledge of cellular physiology of tree species following exposure of plants to concentrations of SO_2 sufficiently large to cause cellular damage (39, 40). These exposure levels are several orders of magnitude higher than any recorded in the area to date, but are required to provide information which can be used in comparative assays if vegetation damage is detected in future. Vegetation research also included establishment of biomonitoring and benchmarking plots for use in detection of possible future impact of SO_2 on vegetation (37). Locations for biomonitoring plots were determined on the basis of vegetation community associations, as well as on location in relation to the likely impingement of SO_2.

In order to provide base maps for all terrestrial research, the AOSERP study area was mapped at a scale of 1:50,000 from Landsat imagery and from photographs obtained in 1977 and 1978 at scales of 1:60,000, 1:30,000, and 1:15,000. The larger scale photographs were taken as an aid to ground truthing selected transects where considerable knowledge of habitats already existed (4). Table 12 is the legend for the vegetation mapping and may be used to interpret the area provided as an example in Figure 34. This example illustrates that the AOSERP study area is a mosaic of vegetation types, as opposed to large areas with little or no differentiation.

Table 11. Legend for surficial geology mapping (4).

SURFICIAL GEOLOGY AND LANDFORMS

Standard: $A\,{}^{b}_{c}\,d, e, f$ Where:
- A genetic material
- b qualifying descriptor (not always used)
- c surficial expression
- d specific landform information (not always used)
- e local relief
- f modifying process (not always used)

Composite Area:
- = both components present in approximate proportions
- – first component more abundant

SURFACE EXPRESSION
- a apron
- b blanket
- f fan
- h hummocky
- i inclined
- l level
- m rolling
- r ridged
- t terraced
- u undulating
- v veneer
- x extensively eroded

LOCAL RELIEF
- 1 less than 10 m
- 2 10-50 m
- 3 51-150 m
- 4 over 150 m

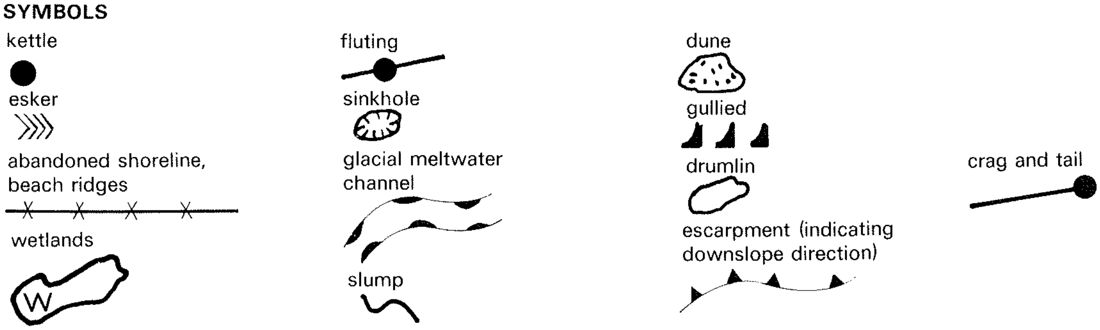
MODIFYING PROCESS
- D deflated
- E eroded (channelled)
- F failing
- H kettled
- K karst modified
- V gullied

GENETIC MATERIAL
- C Colluvial
- E Eolian
- F Fluvial
- L Lacustrine
- M Morainal
- R Bedrock
- U Undifferentiated parent material, undistinguishable due to organic cover.

QUALIFYING DESCRIPTOR
- G Glacial

LANDFORM
- b fluvial bars, terraces
- k kame
- t kame terrace
- p outwash plain
- r outwash bench, terrace or bar remnants
- c meltwater channel sediments
- o active floodplain, oxbows, meander scars
- u undifferentiated

SYMBOLS



Example: $F\,{}^{G}_{i}\,p, 1, E$

- F Fluvial genetic material.
- G Glacial origin
- i Inclined surface
- p Landform-outwash plain.
- 1 Relief less than 10 m.
- E Modifying process-eroded (channelled).

Table 12. Legend for the vegetation mapping (4).

1 BOTTOMLAND & RIPARIAN COMMUNITIES
- a Bottomland and Riparian Forest
- b Deciduous Shrub

2 UPLAND COMMUNITIES

Undifferentiated (usually complex)
- a White Spruce-Aspen Forest
  - 2aA aspen
  - 2aM mixed
  - 2aC coniferous
- b Mixed Coniferous
- c Jack Pine
- d Upland Open

3 WETLAND COMMUNITIES

Undifferentiated (complex)
- a Fen Communities
- b Black Spruce Bog Forest
- c Semi-open Black Spruce — Tamarack Bog Forest
- d Lightly Forested Tamarack and Open Muskeg

4 BURN

5 NON-VEGETATED

Symbols
- (Pj) jack pine
- (Sw) white spruce
- (P) poplar
- (A) aspen
- (Sb) black spruce
- (T) tamarack
- (W) willow
- (Q) aquatic vegetation, undifferentiated
- (C) conifer
- (D) deciduous shrub
- (O) open

Height Class (m)
- 1 1 - 10
- 2 11 - 20
- 3 21 - 30
- 4 31 +

Crown Cover
- A open
- B medium
- C dense

Continued . . .

Table 12. Concluded

Example 1:

complex → 2aM; height class → 3; community type → 2aM (Sw)3b ← crown cover; species information → (Sw)

2	Upland community.
aM	Mixed White Spruce-Aspen forest.
(SW)	Spruce dominant.
3	21 to 30 m in height.
B	Medium crown cover.

Example 2: 3(D)

3	Wetland community - undifferentiated (complex)
(D)	Deciduous shrub dominant.

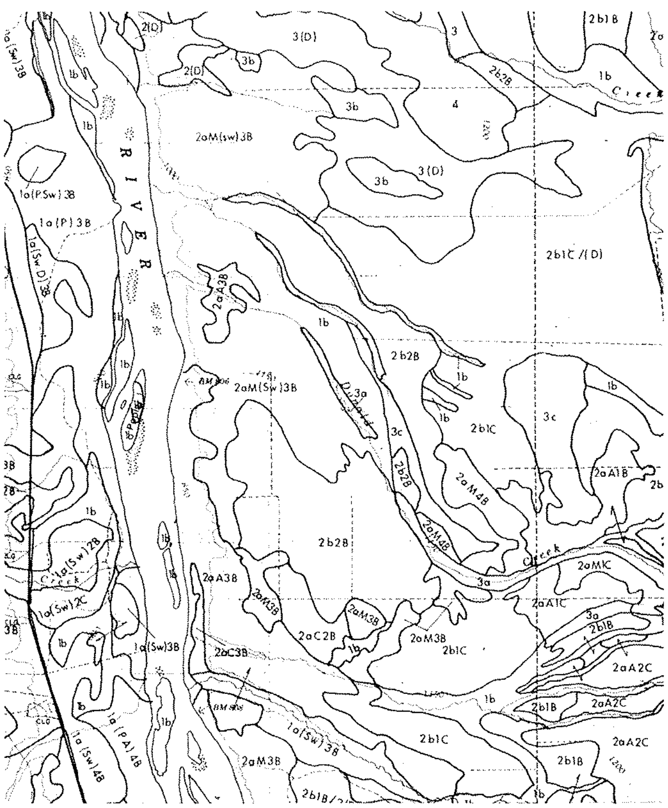


Figure 34. Sample of 1:50,000 vegetation mapping illustrates a mosaic of vegetation types on mapsheet 74D/14 (4).

Surficial geology, soils, and vegetation maps were prepared as a part of the ecological habitat mapping effort by AOSERP (4, 11). Because no co-ordinated set of habitat maps existed for the study area, a set of working maps was created, containing information on the distribution of terrestrial and aquatic vegetation associations, major landforms, surficial geologic features, soils, water bodies, stream courses, topography, and cultural features. Using the photographs mentioned earlier, existing National Topographic Series (NTS) topographic sheets and several other sources of mapping data, ecological habitat maps were prepared. These maps will be used as base maps for ecological research and as base maps for more detailed habitat mapping of areas where more detail is required. Copies of all maps will be available through the Map and Airphoto Distribution Centre of the Alberta Department of Energy and Natural Resources. These maps and photographs will form the baseline reference material needed to carry out long-term monitoring of environmental change, particularly as the area undergoes natural successional change.

Succession is the sequence of changes in vegetational structure and species composition with time. Fire is an integral feature of the forests in the study area (41). A study prepared by the Land Use Assignment Branch, Department of Energy and Natural Resources (42) indicated that recurrent fires in the Fort McMurray-Gregoire Lake area were responsible for the considerable amount of even age forest stands present. AOSERP studies have indicated that the occurrence of fire at different times and places results in apparently similar sites often supporting very different plant communities, depending on the time and rate of succession since the last fire (10, 11). The climax community for much of the upland areas, for example, would likely be white spruce forest, but pure white spruce stands are much less common today than are the trembling aspen and mixedwood communities, which are earlier stages of fire succession. Further research on successional trends is planned to clarify possible changes over long periods, because of possible environmental stresses resulting from regional development. The distribution and nature of plant communities plays an important role in their suitability as habitat for wildlife which utilize vegetation for both food and shelter. Effects of long-term succession in plant communities on caribou, black bear, and carnivores are not easily classified, although considerable information is available on the response of moose and deer, as well as small mammals and furbearers to early successional changes following fire.

Reclamation research being undertaken by AOSERP has been designed to take advantage of natural successional trends by utilizing native species and naturalized introduced species to accelerate natural revegetation (43). For example, the conditions necessary to lead to a potential end point of a jack pine stand established on sand are being studied by mathematical modelling (44).

Because grasses are some of the earliest species to establish on an area following disturbance and are valuable for controlling erosion, grasses are currently being seeded on the tailings sand dike prior to the planting of tree species (45). Native species of grasses and legumes are being tested in plots at the Alberta Environmental Centre at Vegreville and the AOSERP Mildred Lake Research Facility to determine those potentially best suited for reclamation in the area.

FAUNA

Historically, wildlife in the AOSERP study area has played an important role in the cultural and economic development of the region. Most of the area is relatively isolated and is inhabited by some species whose range in Alberta has been limited by settlement. Factors limiting increased faunal density or diversity in the study area may be associated with nutrient levels, poorly drained soils, climate, limited habitat types, and possible interspecific competition. The species of animals most closely associated with human subsistence (e.g., ungulates, furbearers) generally have received greater attention than all others combined. However, to gain an understanding of possible effects of oil sands development on faunal components of the terrestrial ecosystem requires investigation of all groups. Thus, it is emphasized that although animals such as moose, caribou, and wolves capture public attention, small mammals and birds, as well as insects, constitute biomass orders of magnitude greater than the obviously more visible faunal components, and require extensive examination and analyses. A checklist of fauna identified in the AOSERP study area is given in Appendix III.

UNGULATES

The moose ranges throughout the AOSERP study area. General distribution is closely related to the quantity and quality of available forage; highest densities of moose are observed in open or disturbed habitats (e.g., burns, logged areas) with an abundance of forage, and lowest densities in areas with little forage, such as the pine forests northeast of the Firebag River (7). Intensive studies of this large herbivore were initiated in 1976 in the Muskeg River basin. Based on extensive population surveys and data extrapolation, the population in the AOSERP study area is estimated at approximately 5,100 animals (7).

Seasonal movements occurred in apparent response to environmental factors such as food and snow depth (46). Pronounced seasonal differences in use of cover types existed: lowland use increased dramatically from March to May; upland use was greatest from July to November; and upland use decreased in favour of other habitat types during winter and spring. Moose were largely absent in winter from the Birch Mountains and the jack pine-dominated area north of the Firebag River. Seasonal movements were also related to rut activities in the fall and calving in the spring. Cows exhibited less seasonal movements than bulls. The observed fecundity and survival rates indicate a stable or declining population, with wolves and hunters being the main cause of adult mortality.

Unlike moose, populations of woodland caribou have been found only in the Birch Mountains and in the extreme southern portion of the AOSERP study area. Baseline studies of the Birch Mountain caribou herd were initiated in 1976. This group of somewhere between 130 and 340 animals appeared to be relatively undisturbed by development. A total of 400 to 450 caribou were calculated to be present in the study area (47).

Woodland caribou utilize forest habitat year-round, feeding mainly on terrestrial and arboreal lichens in winter and on a variety of vascular plants in summer (48). Seasonal changes in relative use of habitat types in the AOSERP study area seemed related to availability of food resources, snow depths, and social behaviour. Lowland habitats were the primary habitat type used by woodland caribou, and were important year-round; however, during summer, increased use appeared to be made of habitats containing a larger component of forbs and grasses. During the summer, bulls and cows with calves were solitary, while cows without calves banded together in small groups. During and after rut, the animals aggregated into larger groups, while in late winter, groups of mature bulls remained separated from groups of cows and young bulls (47).

Native hunting and wolf predation appeared to be relatively minor mortality factors; in years of normal snowfall, the population is apparently stationary (years of low recruitment of calves to the population appears to be related to winters of deep snow).

Other ungulates found in small numbers in the study area include the mule deer and white-tailed deer. The southern portion of the study area represents the northern limit of white-tailed deer range; however, mule deer may be found throughout northeast Alberta into the Northwest Territories (49).

WOLVES AND OTHER CANIDS

The AOSERP study area is inhabited by several species of economically valuable furbearers ranging in size from the red squirrel to the timber wolf. Furbearers have played an important role in the cultural and economic development of the region in the past. In addition, the study area is important as one of the few regions in the province where species sensitive to disturbance, such as the wolverine, are still found (50).

The timber wolf, one of the largest of North American wolves, ranges throughout the mixedwood forests of northern Alberta (49). Baseline studies of this carnivore have concentrated in the Birch Mountains and Muskeg River drainage, in association with ungulate research. Based on this research, the wolf population of the study area has been estimated at approximately 150 animals (1 wolf per 179 km^2). Most wolves travel in packs of two to three animals in size. The packs are territorial; for example, nine wolves in the Muskeg River pack had a territory of 1,500 km^2 in the winter of 1976-77, as shown in Figure 35. Territory size varies seasonally depending on the availability of food. Summer

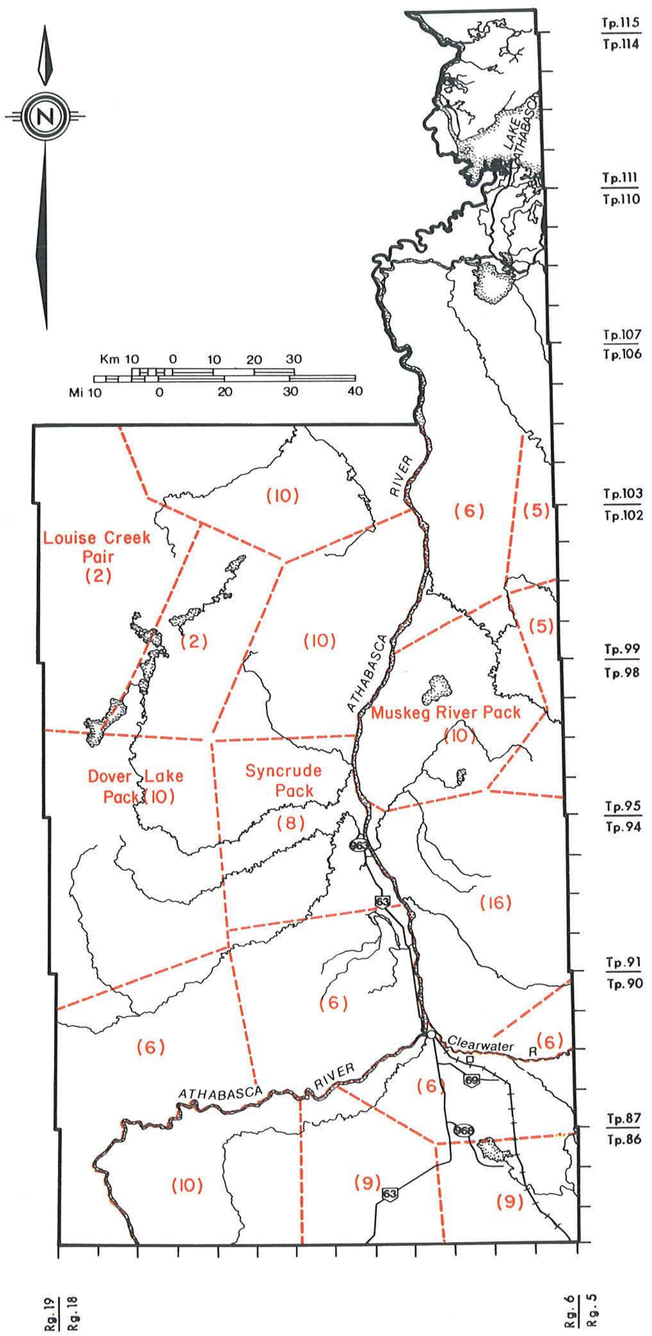


Figure 35. Preliminary estimates of territory boundaries of wolf packs and maximum numbers of wolves per pack on the AOSERP study area during winter, 1976-77. The boundary of the Muskeg River Pack territory is the only one based on sequential radio telemetry locations (50).

food habits vary with the availability of prey; moose, beaver, and snowshoe hare comprise the major prey, while winter observations of the Muskeg River pack indicate a greater reliance on moose as the major prey. The wolves captured disproportionately more young, old, and disabled moose. Wolves accounted for 65 percent of the annual adult moose mortality in the study area. Two years of wolf data indicate that the population appears to have increased in size slightly; major mortality appears to be associated with trapping of adults and early deaths of pups.

Other Canidae which are present in the study area include the coyote and the red fox. The adaptable coyote, the most abundant carnivorous furbearer in the area, prefers regions of disturbed or reduced cover (51). The red fox, the least abundant canid and of minor economic importance, feeds on berries, green shoots, birds, mice, and other small mammals (49), and prefers semi-open country (52).

FURBEARERS

The numerous lakes, rivers, streams, and wetland areas of the region support populations of semi-aquatic mammals the most abundant of which are beaver and muskrat.

The beaver, the largest of North American rodents, is common in the study area; a 1976 survey of the Syncrude lease estimated population density at 1.9 beaver lodges per km^2 (51). Aquatic habitats with an abundance of poplar, willow, alder, birch, and aquatic vegetation for food and building supplies are required. Beaver are the most economically important furbearers in the region. Trapping and wolf predation are the major mortality factors. An annotated bibliography on aquatic furbearers in the AOSERP study area has been published (53).

Muskrat activity is concentrated on lakes, although these animals may also be found in ponds and other areas of slow moving water where emergent vegetation, their main food, is abundant. They are prolific breeders and a population increase of 80 percent in two years was noted on the Syncrude lease in the absence of trapping. Muskrat are trapped throughout the study area; although trapping may be a significant mortality factor, baseline information on other probable factors is lacking at this time. Research is in progress to provide information on distribution and abundance of aquatic furbearers in the AOSERP study area.

Results to date, on the GCOS tailings sand dike indicate that the shelter provided by the heavy growth of the grass (aided by fertilization) causes a substantial rise in the small mammal populations, in particular that of the meadow vole. This small mammal in high density populations apparently kills or seriously damages trees planted for long-term reclamation by girdling the bark. Research is being conducted to find a more efficient method of establishing vegetation cover with species which naturally invade disturbed sites in the study area, and to control damage to the vegetation by small mammals and other herbivorous organisms during the critical early stages of reclamation (43, 54).

BLACK BEAR

The black bear is common in the study area. The potential population has been estimated at between 5,200 and 7,400 bears, based on habitat potential carrying capacity found at Cold Lake and then applied to the AOSERP study area (53).

The black bear is an omnivore which eats roots, berries, and other vegetable matter, as well as nuts, insects, small mammals, and carrion (49). Black bears have been known to kill small- to medium-sized ungulates and the possibility exists that they are contributing to mortality of calf moose and caribou in the area.

The recent increase in the human population of the Fort McMurray area in response to oil sands development has resulted in increased bear-human interactions. Nuisance bear complaints increased from 19 in 1974 to 178 in 1975, when some 100 bears were either destroyed or transported to more remote areas. At this time, relatively little is known about the baseline states of black bear in the study area; however, a study recently has been initiated to determine what additional research is required (56).

OTHER MAMMALS

Very little baseline information is available at the present time on the two other species of semi-aquatic mammals found in the study area, the river otter and mink. The mink is somewhat more common than the otter; however, populations are small for both animals and they are of minor economic value compared to beaver and muskrat. The otter inhabits a wide variety of aquatic habitats while the mink prefers low-lying, boggy terrain and sluggish streams (49). Baseline research on semi-aquatic mammals is continuing.

Furbearers also present in low-numbers are marten, fisher, and wolverine. Fisher are considered to be more common than marten, which have not been reported on fur harvest records since 1970 (51). The fisher and wolverine are carnivorous, while the marten will eat insects, berries, birds, eggs, squirrels, frogs, and other small mammals(49).

The most common small predator in the region is probably the ermine weasel which feeds on birds, squirrels, mice, and other small mammals and is trapped for its white fur. Another weasel, the least weasel, is present but is relatively uncommon to rare (49).

The most abundant furbearer is the red squirrel which prefers mature coniferous forests where it feeds on white or black spruce seeds (57). Also present, but much less abundant, is the northern flying squirrel. Only the red squirrel is trapped for its fur, as flying squirrel pelts are too soft to be of value (51).

Many animals exhibit cyclic population trends, with large variations in numbers depending on the stage of the cycle. Lynx populations are known to exhibit marked cyclic fluctuations in response to the abundance of the varying hare, their major prey. At present, lynx numbers in the study area are very low; however, numbers are expected to increase in the future as the hare population increases.

Several species of small mammals inhabit the area, including the voles, the most common of which is the red-backed vole, the white-footed mouse, and the cinereous shrew. Ranges of several species of bats extend over the study area; however, no dependable baseline data yet exist for these mammals in the study area.

BIRDS

Baseline investigations on birds of the AOSERP study area were initiated in 1975. In the first three years, research was directed toward answering two major questions: what birds inhabit the area; and how important is the area to the various species. Inventories were initiated to derive a species checklist and, at the same time, give some idea of abundance, distribution, habitat use, and breeding status (i.e., migrant, resident, etc.) of the avifauna in the region (58,59). Considerable emphasis was placed on gamebirds (waterfowl and upland species) and additional studies were initiated to cover concerns for rare and/or sensitive avifauna of the area (60, 61, 62, 63).

Waterfowl

Relative to other waterfowl breeding areas, such as prairie potholes and the Peace-Athabasca Delta region, the Athabasca Oil Sands wetlands are not important for waterfowl production. Low waterfowl production is attributed to low soil and water fertility, sparse vegetation growth, and correspondingly poor availability of food, nesting cover, and brood cover characteristics of most of the area's wetlands (64). However, the strategic position of the area with regard to migratory flyways (Figure 36) results in the extensive utilization of selected wetlands as spring and fall staging areas.

Timing of spring migration varies from year to year; however, ducks are observed from early April with the peak of migration around the first week in May. The implication of spring-staging surveys is that the study area wetlands do not play a major role in the northward migration of ducks. Throughout the spring migration, as well as during most, if not all other periods of the season, the wetlands are utilized more by diving ducks such as scaup, ringneck, bufflehead, and goldeneye, than by dabbling ducks such as mallard, widgeon, green- and blue-winged teal, and shoveler. Gordon Lake is an important wetland during this period. In general, lakes with shallow marsh aquatics supported the highest duck densities of all population segments (spring-staging, breeding pairs, broods, moulting ducks, fall-staging) throughout the year (58, 59).

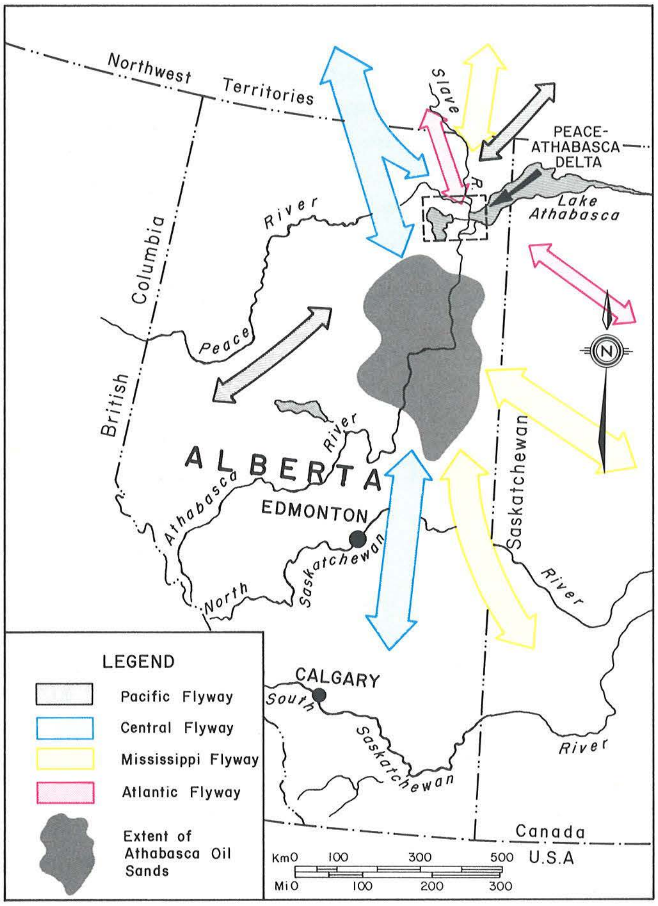


Figure 36. Geographical significance of the Athabasca Oil Sands to waterfowl flyways (64).

The six most common species utilizing AOSERP study area wetlands for breeding and production are mallard, lesser scaup, ringneck, bufflehead, widgeon, and goldeneye. Wood Slough, West Muskeg Lake, Saline Lake, and Little McClelland Lake were highest in terms of densities of breeding pairs and broods.

Results of research to date indicate that parts of the study area are of major importance during fall migration. The fall-staging population of the Peace-Athabasca Delta, in the northern part of the AOSERP study area, has been estimated to number as high as 1.2 million ducks under favourable conditions. Although the major movement out of the Delta is in a southeasterly direction, substantial numbers from the Mississippi and Central flyways pass through the Fort McMurray region. The degree of fall waterfowl use of this area will depend upon annual fluctuations in Delta populations (64). Significant numbers of geese (Canada geese, white-fronted geese, snow geese) and swans (whistling swan) are seen in the area only during migration stops. Two species relatively sensitive to disturbance include the sandhill crane, which is rare in the area, and the common loon, which is widespread and abundant.

During surveys of the Namur-Gardiner Lakes region an inventory was made of several species of colonial birds. Two of the more commonly observed species were Bonaparte's gull and Franklin's gull. Two colonies of California gulls were located in the Birch Mountains, while sightings of the common tern were infrequent. Arctic tern, Caspian tern, and ringbilled gull have been identified in the region, but are very rare.

A colonial bird worthy of special mention is the white pelican. The white pelican rookery at Birch Lake is inhabited by approximately 70 breeding pairs of birds. Intensive research on the breeding and foraging behavior of these birds has been undertaken (60, 61). In recognition of the sensitivity of these colonial nesters to human disturbance during the breeding season, areas critical for nesting have now been given protected status by the Government of Alberta.

Upland Game Birds

The most abundant upland game bird in the region is the spruce grouse, which breeds in coniferous-dominated habitats ranging from dry young jack pine to wet mature black spruce. The next most abundant species is the ruffed grouse, while the least abundant is the sharp-tailed grouse. The ruffed grouse breeds throughout the area in deciduous and mixed forest habitats with substantial shrub understories. Observations of sharp-tailed grouse have been sporadic and in a variety of habitats (58, 59).

Unlike the grouse, which are resident birds, the willow ptarmigan is a winter migrant to the study area. The abundance of this species is variable and is probably dependent on the severity of the winter in its northern summer range. The ptarmigan is found in a variety of habitats but prefers areas with an abundance of willow and other shrubs upon which it feeds.

Non-Game Birds

Terrestrial non-game birds comprise the greatest number of bird species inhabiting the study area and range in size from the ruby-throated hummingbird to the great horned owl. The larger number of species precludes a detailed discussion. However, the factors affecting distribution and abundance of these birds as determined from the surveys are presented.

The densities of individual species exhibit extreme variance, resulting from both habitat quality and species behaviour. An annotated checklist of the status of each species of avifauna which have occurred in the AOSERP study area has been prepared from the research. The checklist details seasonal occurrence, relative abundance, and habitat preferences, where known.

While some birds, such as the common yellowthroat, are selective, with strong preference for specific habitats (in this case, wet areas dominated by willows), others, such as the Tennessee warbler, are very adaptable and are found over a range of habitat types. Thus, the number and abundance of species in any particular area varies in any habitat type. One of the most important factors governing the capacity of habitat to support an abundant and diverse breeding avifauna is the form and species composition of the shrub layer. The form and species composition of the treelayer (if present), ground stratum, and water regime are also important. Each habitat type has a characteristic species composition, determined by the habitat preferences of the individual species.

More than any other portion of the study area, the Athabasca River valley contains an abundance of favourable habitats, as evidenced by the more than 100 bird species which breed there. River valley habitats are among the most valuable in the study area because of the diversity of feeding and resting niches provided by the variation in tree and shrub species, vegetation heights and densities, and the abundance of forest/scrub, forest/river, and scrub/river interfaces.

Raptors

Baseline studies of rare and endangered raptors (birds of prey) were also begun in 1975.

The bald eagle was the most abundant of the four raptors studied. Fifty-seven productive breeding territories, most of which are in the Canadian Shield and sandplains areas, have been identified (62).

The osprey ranked with the peregrine falcon as the second most abundant raptors. Eleven productive osprey nest sites were found (63). Both the bald eagle and the osprey feed mainly on fish, while the peregrine falcon feeds on other birds and small mammals.

The last known productive remnant of peregrine falcon populations in Alberta exists in the northeastern corner of the province, partly within the study area (of 14 known nesting sites in the region, five are in the study area).

The golden eagle is the rarest raptorial species in the study area; only four productive nests were identified (63). The study area population is not, however, considered to be a substantial portion of the Alberta population of these birds, which also breed in the Rocky Mountains.

OTHER FAUNA

A study of amphibians and reptiles was carried out in 1976 (65). The wood frog is the most abundant amphibian in the AOSERP study area and the Canadian toad and the boreal chorus frog are also common, with estimated densities of 19.6, 12.0, and 2.3 per 1,000 m^2, respectively. Moist edges along watercourses with sedges, horsetails, and willow are preferred for all three species. No reptiles have been recorded for the study area.

Baseline studies of insect fauna were initiated in 1978 (66). It is anticipated that insects will comprise one of the most important faunal categories in the AOSERP study area, as has been documented for other northern environments (67, 68).

Renewable Resource Use

FORESTRY

The commercial timber species present in the area are white and black spruce, balsam fir, and jack pine. The balsam poplar and trembling aspen in the study area represent some of the highest quality hardwoods in Alberta; however, these have not been used to date (69).

Economic drawbacks to the development of the timber industry in the area are that the commercial tree species (spruce and pine) are small and grow very slowly, access to timber stands is limited, and the oil sands plants draw much of the available labour. Fort McMurray's largest lumber mill (Swanson Lumber Co. Ltd.) was forced to close down due to stagnant sales in 1974. There are no pulp mills.

TRAPPING

Trapping is one of the oldest industries in Canada and has played an important role in the history and development of the oil sands area (70). Between 1970 and 1975 there were up to 130 traplines in the study area (Figure 37). Traplines averaged 165 km^2 in size, the mean annual value of wild fur per trapline was calculated at $1,252.00.

Recent fur harvest records indicate that the muskrat, squirrel, and beaver are the most important furbearers in terms of total numbers of animals harvested. Following in importance are hare, weasel, lynx, and mink (Table 13). Other species, such as the coyote, fisher, fox, marten, otter, and wolf, are also trapped, but in much smaller amounts. The most economically important species are the beaver, lynx, and muskrat which contributed over 80 percent of the annual fur value (70).

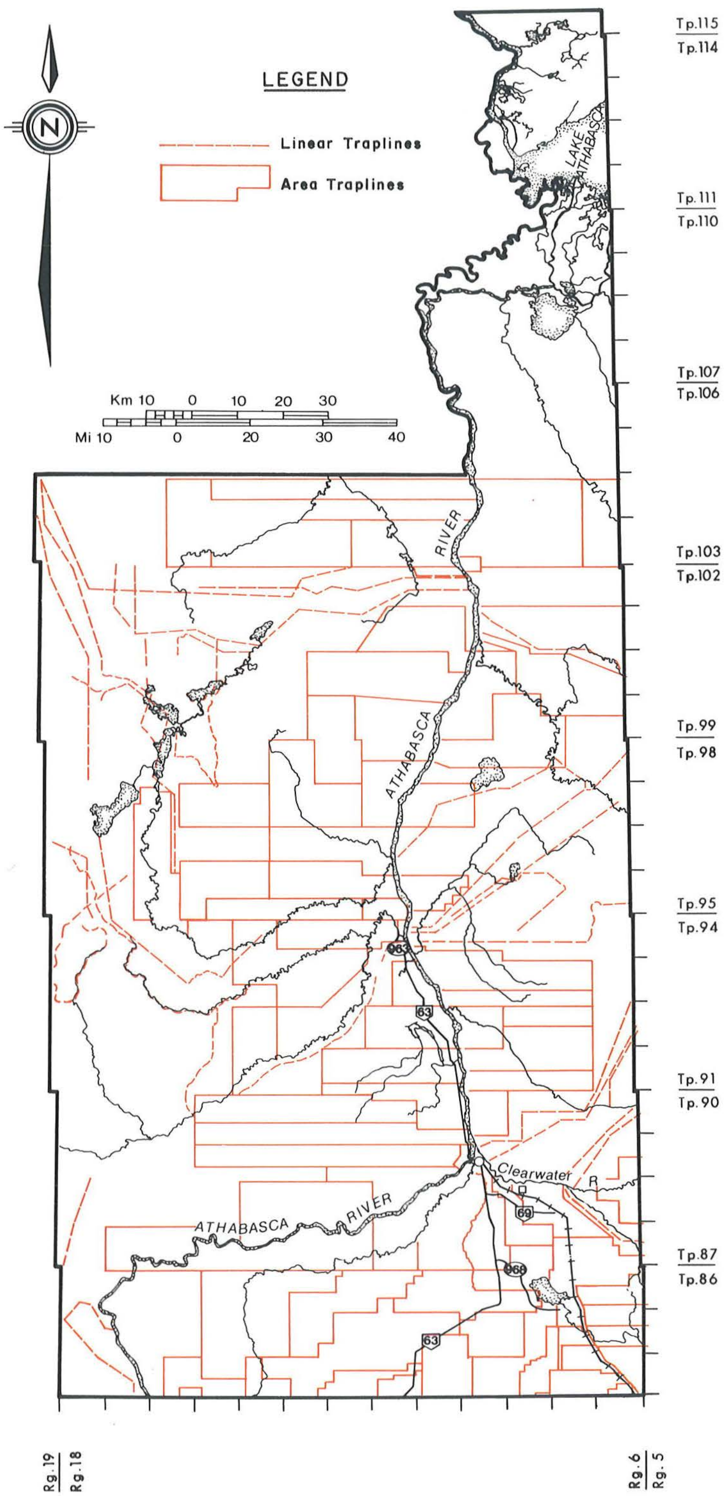


Figure 37. Traplines in the AOSERP study area (70).

OUTDOOR RECREATION

Human population increase, both that which has already occurred and that which is likely to result from further development of the Athabasca Oil Sands, will result in increased demand for recreational opportunities and facilities. Existing recreational facilities are limited at present and overuse of such areas as the Gregoire Lake Provincial Park (71), indicates that the existing development areas are already inadequate.

Table 13. Mean annual number of animals reported harvested for each furbearing species in the AOSERP study area, 1970-75 (nil yearly catches are excluded)[a] (53).

Furbearers	Number of Animals
Beaver	21.9
Coyote	0.8
Fisher	0.6
Fox	0.7
Hare	13.8
Lynx	4.7
Marten	0.1
Mink	4.1
Muskrat	115.8[b]
Otter	0.2
Skunk	0.8
Squirrel	63.6
Weasel	5.6
Wolf	0.2
Wolverine	Tr[c]

[a] Number of traplines reporting catches was 13, 85, 104, 96, and 78 in 1970-71, 1971-72, 1972-73, 1973-74, and 1974-75, respectively. Average size of trapping areas was 164.7 km^2.

[b] It is believed that almost all of these muskrats came from the delta area north of the AOSERP study area.

[c] Tr = trace, <0.05.

Four main categories of scenic and recreational potential have been identified: rivers, lakes, uplands, and historical sites (42).

Recreational use of fish and wildlife resources were examined in a socioeconomic study initiated by AOSERP in 1976. Results of a survey of study area residents and residents throughout Alberta were compared. More than 8,000 Alberta anglers reported a total catch of 164,500 fish in 1975-76 with pike, yellow walleye, and arctic grayling accounting for 91 percent of the catch (72).

Upland game bird hunters reported 5,800 kills, the majority of which were grouse, but partridge and ptarmigan were also included. Ducks accounted for 87 percent and geese for 13 percent of the total waterfowl kill by 220 hunters (72).

Over 1,000 big game hunters reported a total of 139 moose, 33 bear, and 2 caribou killed during the 1975-76 season (72).

In addition to the above, there was significant non-consumptive use of wildlife resources, including such activities as sight-seeing, photography, or hiking, in areas where there are opportunities to observe wildlife (72).

Water System

Baseline Water System research has been directed in several main thrusts, each intended to define conditions which can be related to possible impacts of oil sands development. Such research is viewed as involving the first steps of an overall program involving the following objectives (2):

1. To review and assess the available information pertaining to aqueous systems of the AOSERP study area;
2. To undertake studies which may be used to establish the baseline states for physical, chemical, and biological constituents of aqueous systems of the study area which could be altered by oil sands development;
3. To identify substances which may be introduced into the metabolic pathways of aqueous systems of the study area and their effects on metabolic pathways;
4. To assess and report on all physical, chemical, and biological disruptions of aqueous systems in the study area resulting from oil sands development;
5. To derive a conceptual and/or mathematical model which can be used to predict the effects on aqueous systems and their capacity to assimilate those effects without permanent or long lasting debilitation; and
6. To undertake studies directed toward restoration of biophysical productivity to aqueous systems disrupted, damaged, or destroyed in the course of oil sands development.

Water System research has focused on baseline research and has been arranged in the following categories: hydrology, water quality, groundwater, lakes, microbiota, invertebrates, and fish. Emphasis has been placed on elucidating the conditions most important to the aquatic ecosystem, and which are the most likely to be affected by oil sands development. It should be noted that several other investigations and reviews in applied areas have been carried out but these are not covered in this document (73, 74, 75, 76, 77, 78, 79, 80, 81, and 82).

Hydrologic investigations generally have the central requirement of collecting sufficient data on stream flows and groundwater movements for use in predicting the nature and volume of water involved in the hydrologic cycle of a region. When sufficient data have been collected over an appropriate time span (generally a decade or more) predictions acquire greater reliability. During the early stages of the establishment of AOSERP, the decision was made to establish a surface hydrologic network of sufficient density that a large amount of information could be gathered in the shortest possible time span (83). The location of hydrometric stations is shown in Figure 38. These stations were located throughout the region to make possible the eventual measurement of discharge for surface streams over the whole area, in addition to the calculation of chemical budgets for streams when sufficient chemical data became available.

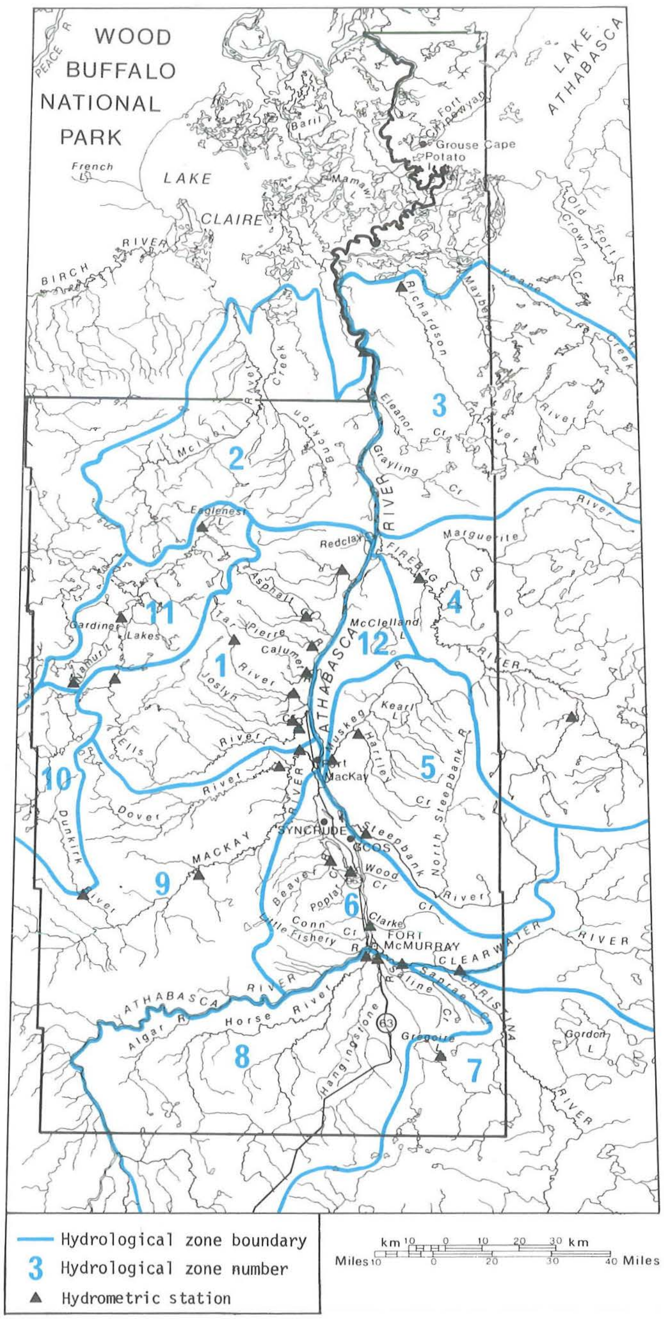


Figure 38. Hydrological zones within the AOSERP study area (83).

Two major geographical features affect the water characteristics for the study area. These two features, the Interior Plains and the Precambrian Shield, provide dramatically different hydrological processes. The Precambrian Shield consists chiefly of low bedrock hills with thin soil and plant cover interspersed with interconnecting lakes. Such a structure provides very little mineralization and suspended sediments to the water system. In addition, the storage capacity of the lakes causes a relatively stable discharge of water from Shield areas. In contrast the Interior Plains consist of sedimentary structures with interconnecting streams. Much more mineralization and suspended materials are available to surface water from these areas. In addition, the low storage capacity of stream structures combined with generally more pronounced geographical features cause a much wider variance in discharge. The existence of substantial subsurface aquifers interacting with the surface water compounds the complexity of the picture for the plains region.

On the basis of these considerations, the AOSERP study area can be broadly classified into two main input regions. Most of the study area is in the Interior Plains region and all rivers to the south and west and the smaller tributaries to the east flow through sedimentary type basins. However, the larger rivers reaching into Saskatchewan east of the Athabasca River have a substantial Precambrian Shield component.

One parameter that reflects the hydrological behavior of a tributary is its annual runoff. If annual tributary flow volumes are divided by the areas of the contributing drainage basins, they can be expressed as annual depths of runoff, averaged over the areas. The annual depths of each basin permit a comparison between basins. The basin average for 1976 and 1977 for all tributaries in the study area west of the Athabasca River is 60 mm, for those to the east of the Athabasca River and north of the Clearwater Basin, it is 100 mm, and for those east of the Athabasca River, including the Clearwater Basin and basins south of Fort McMurray, it is 140 mm (84). On the basis of these considerations there appear to be three distinct areas.

Taking the 1976-77 annual precipitation of 460 mm at Fort McMurray as representative of the study area, it can be seen that runoff, on the average, appears to amount to less than 20 percent of precipitation. The difference is accounted for by evaporation from the ground, snow, and vegetation surfaces, by transpiration by vegetation, and perhaps to a small degree by percolation to deeper groundwater. One implication of these figures is that runoff, representing a small residual between precipitation and evapotranspiration, may be quite sensitve to changes in vegetation cover, particularly in the zones west of the Athabasca River.

Basins in the study area may be further classified (83). For example, within the Interior Plains, a variance in topography results in an associated variance in rates of runoff and sedimentary load. Surficial material also affects the surface water by influencing the rates of water percolation and runoff, land erosion, types of vegetation cover, and amounts of groundwater storage. Hydrological effects are also caused by mining operations and so mining potential is a consideration in classifying basins. Table 14 lists 12 hydrologic zones of the study area based on physiographic features, surficial material, and oil sands development potential, and their general characteristics; Figure 38 shows the placement of hydrologic zones in relation to the study area.

Mean annual volumes of streamflow into, through, and out of the AOSERP study area are shown diagrammatically in Figure 39 (84). Inflows from the Athabasca River and Clearwater River average 17.2 and 4.3 Gm^3 (10^9 m^3) annually. Additions from the tributary streams average about 2.6 Gm^3 annually. The total outflow from the study area via the Athabasca River to the Athabasca Delta, therefore, averages about 23.9 Gm^3 annually. Thus, flows from portions of the Athabasca and Clearwater rivers upstream of the study area constitute about 90 percent of the total average contribution of the Athabasca River to the Peace-Athabasca Delta. Other inflows to Lake Athabasca average about 21.4 Gm^3 annually; thus the total contribution from Lake Athabasca to the Peace River to form the Slave River averages about 45.3 Gm^3 annually.

Annual variations in Athabasca River flow volumes are considerable. Over the period from 1958 to 1977, flow volumes below Fort McMurray, which average 21.9 Gm^3 annually, have ranged from a low of 15.3 Gm^3 in 1968 to a high of 27.9 Gm^3 in 1965 (84, 85).There is a 1 percent chance every year that the volume can be as low as 13.5 Gm^3 or as high as 30.3 Gm^3 (84).

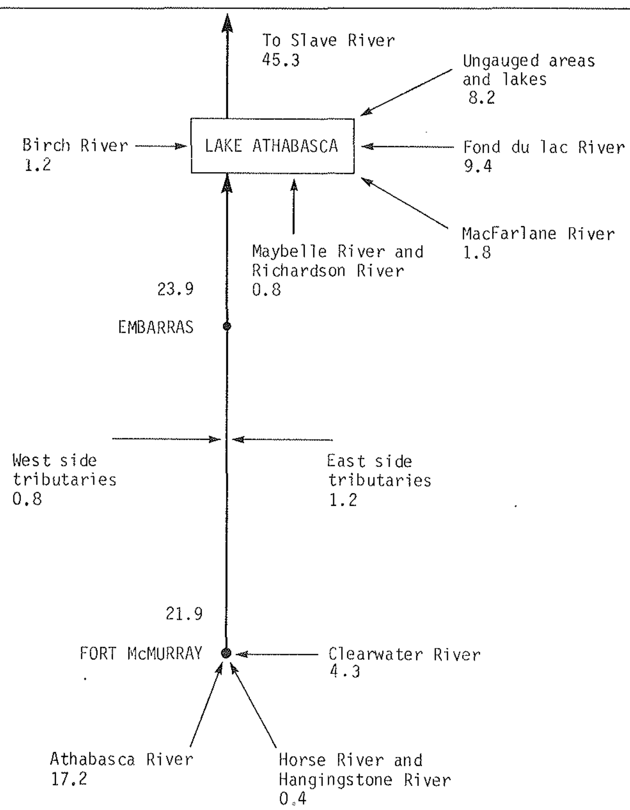
Tributary annual flow appears to be even more variable than flows in the Athabasca River. For comparison, reported annual volumes for the west side tributary MacKay River have ranged from a high of 0.85 Gm^3 to a low of 0.18 Gm^3 during a five year period (1973-77). On the east side, reported annual volumes from the Steepbank River have ranged from a high of 0.33 Gm^3 to a low of 0.1 Gm^3 over the same time span (85, 86).

Because flow in the Athabasca River and its tributaries within the study area originate from widely separated regions, high and low flow years in the various drainages do not necessarily coincide. For example, 1975 was a year of high runoff for most of the tributaries gauged at that time, but a below average year for the Athabasca River at Fort McMurray. Therefore, the portion of annual inflow originating from the tributaries in the study area, which averages less than 10 percent, can vary considerably from year to year.

Flow volumes constitute a valuable resource throughout the area for biological production as well as domestic, commercial, and recreational purposes. The Athabasca River is considered a prime resource for large volume users. For example, Syncrude Canada Ltd.'s estimate of their process requirements for water of less than 0.05

Table 14. Hydrological zones within the AOSERP study area (83).

Hydrological Zone	Physiographic Distribution	Surficial Material	Oil Sands Development Potential
1	Birch Mtns Upland Algar Plain Clearwater Lowland	Predominately clayey and silty till in upper regions; outwash sand deposits in lower regions	Nearly 100% developable; similar proportions available for open pit and in situ mining
2	Birch Mtns Upland	"	<25% developable; in situ mining only
3	Athabasca Delta	Aeolian sands in the lower reaches; sands and gravels in upper reaches	0% developable
4	Athabasca-Firebag Plain, Clearwater Lowland	Outwash sands and gravels	<10% developable open pit to in situ mining possible
5	Muskeg Mtns Upland	Outwash sands in lower regions; clayey and silty till in the upper regions	30-100% developable; negligible in situ mining potential
6	Algar Plain Clearwater Lowland	Clayey and silty material	100% developable; negligible in situ mining potential
7	Methy Portage Plain	Clayey and silty till in the lower region; ground moraine composed predominately of sand	<10% developable; open pit to in situ mining potential
8	Algar Plain Stony Mtn Upland	Clayey and silty till	Nearly 100% developable; predominately in situ mining potential
9	Algar Plain	Predominately clayey and silty till	Nearly 100% developable; 80% potentially suited to in situ mining
10	Birch Mtns Upland Algar Plain	Hummocky moraine; drift of sand, gravel, and silt	100% developable; in situ mining potential only
11	Birch Mtns Upland	Hummocky moraine	100% developable; in situ mining potential only
12	Clearwater Lowland	Outwash sands and gravels	90% developable; primarily open pit mining potential



Gm^3/ year (87) compares favourably with the range supplied by the Athabasca River; however, one cannot generalize these data from surface mining requirements to *in situ* recovery methods which may have quite different water use requirements (88).

Additional factors must be considered in evaluating availability of water. Duration of discharge levels and minimum flow for the Athabasca River are of particular concern because of its wide seasonal fluctuations in flow. During the years 1966-1976, for example, the yearly ratio of maximum daily discharge to minimum daily discharge varied from 11 to 37. The minimum measured daily discharge occurring in this period was 108 m^3/s. Therefore, an enormously higher impact either by withdrawing from or by discharging into the river system, would be felt during the low flow periods which generally occur during ice cover conditions.

◀Figure 39. Representation of annual streamflow balance based on average annual flow volumes. Amounts are shown in Gm^3/year (billion cubic metres/year) (84).

Water Quality

The determination of water quality baseline states in the AOSERP study area is not simple because of the high variability of most water quality parameters throughout the area. Runoff rates influence the amounts of both suspended and dissolved solids in streams. Precipitation and recharge of shallow groundwater aquifers may change the rate of leaching of organic materials from muskegs and influence their subsequent discharge to streams. Further, the mixing of different proportions of waters of differing composition and variability causes a complex situation. All these factors along with many others preclude construction of a simple water quality model and require, as well, that careful design precede establishment of any continuing water quality sampling programs.

Most water quality parameters are interrelated in the environment through physical, chemical, or biological processes. Thus, a detailed water quality intrepretation must take into consideration characterization of such processes operating in the surface waters. Analysis of water quality data to date has not reached this level of sophistication and must be viewed as descriptive, only indicating the kinds of processes that may be important. The discussion has been grouped under the catagories: major ions, suspended materials and sediments, nutrients, and dissolved metals.

MAJOR IONS

Generally, surface water moving through all the basins can be classed as calcium-bicarbonate with varying amounts of magnesium, sodium, chloride, and sulphate. Concentrations of all these ions vary from basin to basin according to the basin's surficial geology and physiography. The minimum and maximum measured equivalent concentration of these major ionic species for some selected sites is shown in Figure 40. Two kinds of tributary water are characteristic of the area: the less mineralized and less variable water from Precambrian Shield areas indicated by the Firebag River; and the highly loaded and variable water typified by the MacKay and Hangingstone rivers.

The Firebag River, which is the main watercourse of Hydrological Zone 4, rises in Precambrian Shield headwaters, similiar to Lake Athabasca, Richardson River (Zone 3), and the Clearwater River. The Firebag River loses some of its soft character by becoming mineralized at its lower reaches because of substantial water from Muskeg Mountain from both runoff and groundwater. Seepages on lower reaches of the Firebag are observable in winter and indicate such groundwater discharge. In addition, the river flows through shelves of Devonian limestone which would substantially contribute to its mineral content. The hardness, for example, was higher and more variable (78-124 ppm as calcium carbonate ($CaCO_3$)) than in the Richardson River (always less than 42

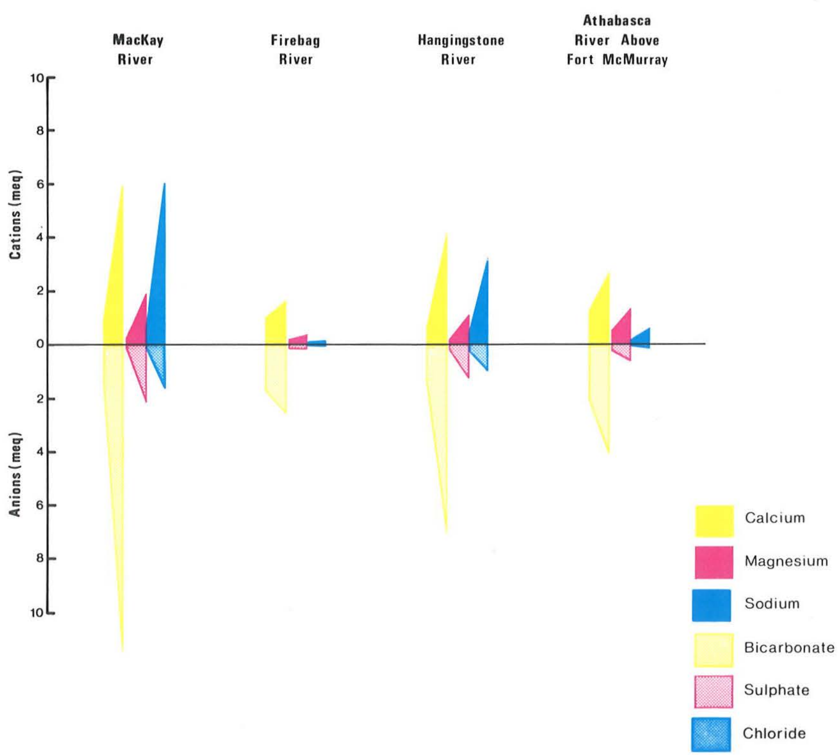


Figure 40. Measured minimum and maximum equivalent concentrations of major ionic species in 1977 for some selected tributaries (89).

ppm $CaCO_3$). The upper portion of the elongated and flat Richardson River basin consists of Precambrian Shield with a high density of lakes not found elsewhere in Alberta, while the lower portion consists of Precambrian Shield overlain by sand and sand dunes. The very stable and soft character of this water is illustrated by the low total dissolved solids (54-58 ppm).

The mixing occurring in Lake Athabasca also illustrates the change in character of water as it moves through the study area. Surface water taken close to the north shore of Lake Athabasca is consistently soft, ranging in hardness only from 34 to 35 ppm $CaCO_3$ and in bicarbonate from 37 to 41 ppm. In contrast, the water emptying from Lake Athabasca at Rivière des Rochers, which would have mixed with Athabasca River waters, shows much higher and variable characteristics: hardness from 49 to 92 ppm $CaCO_3$ and bicarbonate 57 to 103 ppm. Thus, a definite trend is noticed towards increased mineralization of water in the basins from north to south as the distance between the Precambrian Shield and the study area increases from north to south.

Surface water from the tributaries to the south and east (typified by the Hangingstone and MacKay rivers in Figure 40) shows a higher loading including significant sodium, chloride, and sulphate content which generally indicates a groundwater component. Such concentrations show wide temporal variation in that the varying amounts of surface (or new surface) runoff have a diluting effect on these ions.

The relationship of the specific conductance to discharge illustrates temporal variation (Figure 41). Specific conductance (a measure of electrical current that the water can conduct) is a function of the total ionic concentrations. The relationship for the MacKay River in Zone 9 shows the wide variation of flow and specific conductance with low conductance occurring at high flow. A comparison of this relationship with that of the Firebag River provides an illustration of the differences between the basins. The relationship for the Firebag River displays less variance in conductance with differing flow as a result of storage effects in the Precambrian Shield headwaters and is at a lower loading as a result of the lower mineralization.

Total hardness is another parameter in characterizing major ionic species by measuring combined calcium and magnesium content. Measurements of this parameter also indicate the degree of spatial and temporal variation. Fluctuations in total hardness during open water months for various points in Hydrological Zone 1 are shown in Figure 42 (83). The Ells River water entering Zone 1 reflects the moderating influence of the high headwater levels in Zone 11, the Namur-Gardiner group, by having a consistently softer character. Thus, water in the upper reaches of the Ells River shows low total hardness and very little variation, similar to that which is displaced by water from Precambrian Shield basins. However, water present in the lower reaches of the Ells River shows not only much wider temporal differences, but also higher values for total hardness, revealing combined influences of groundwater discharge and the influence of

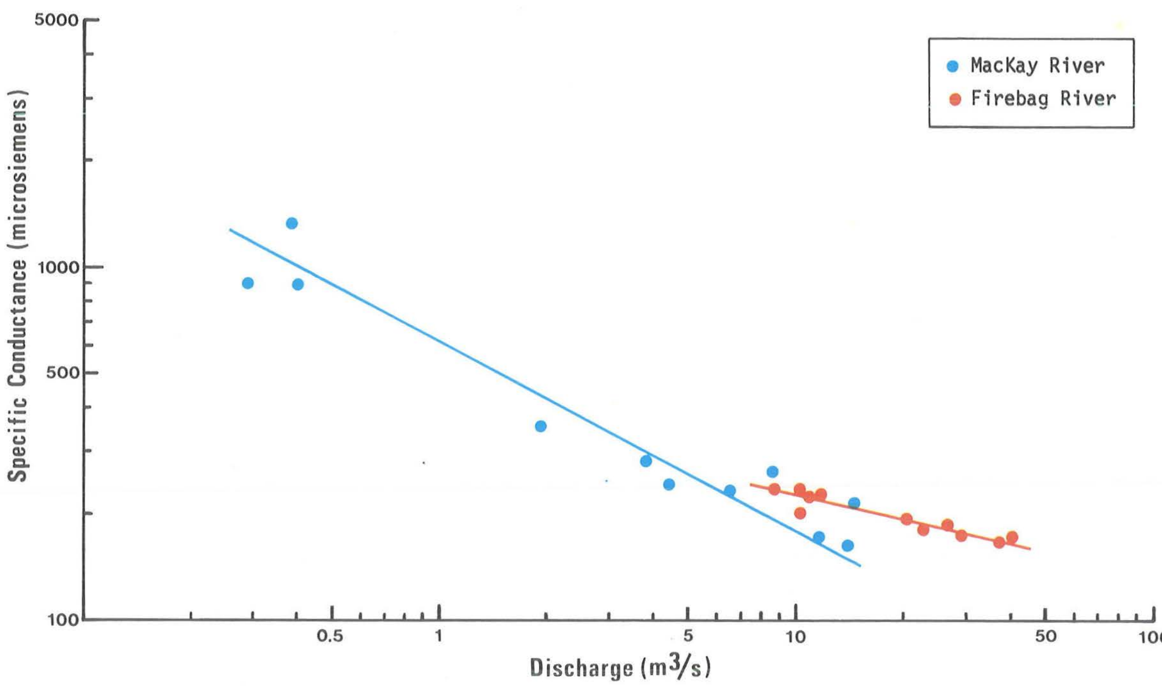


Figure 41. Relationship of specific conductance (microsiemens) with discharge for the MacKay and Firebag rivers for 1977 (89).

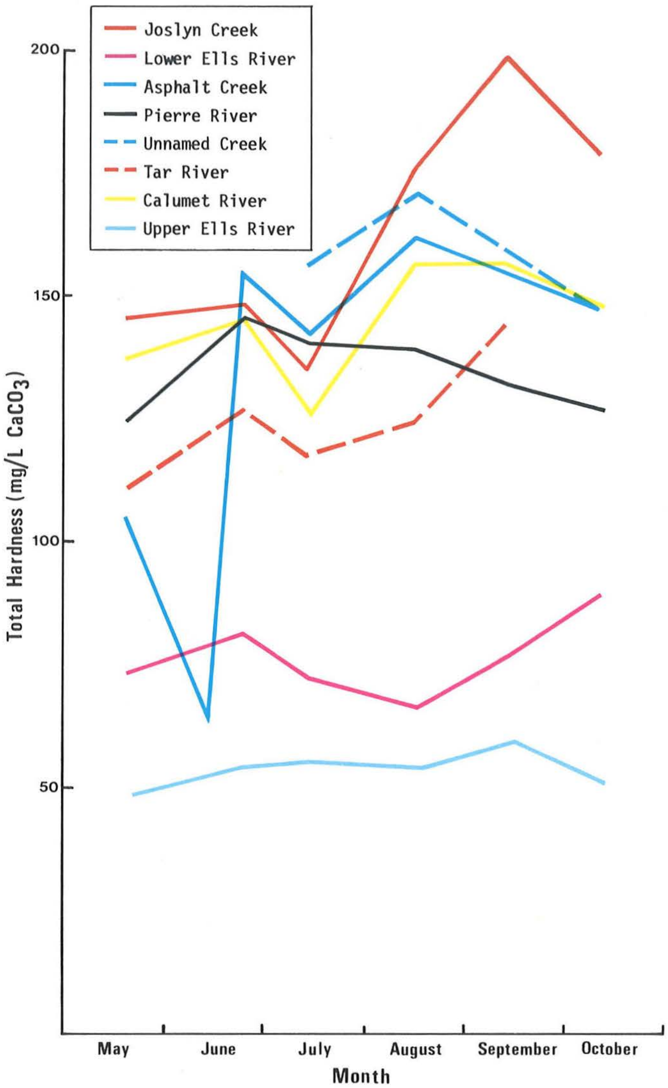


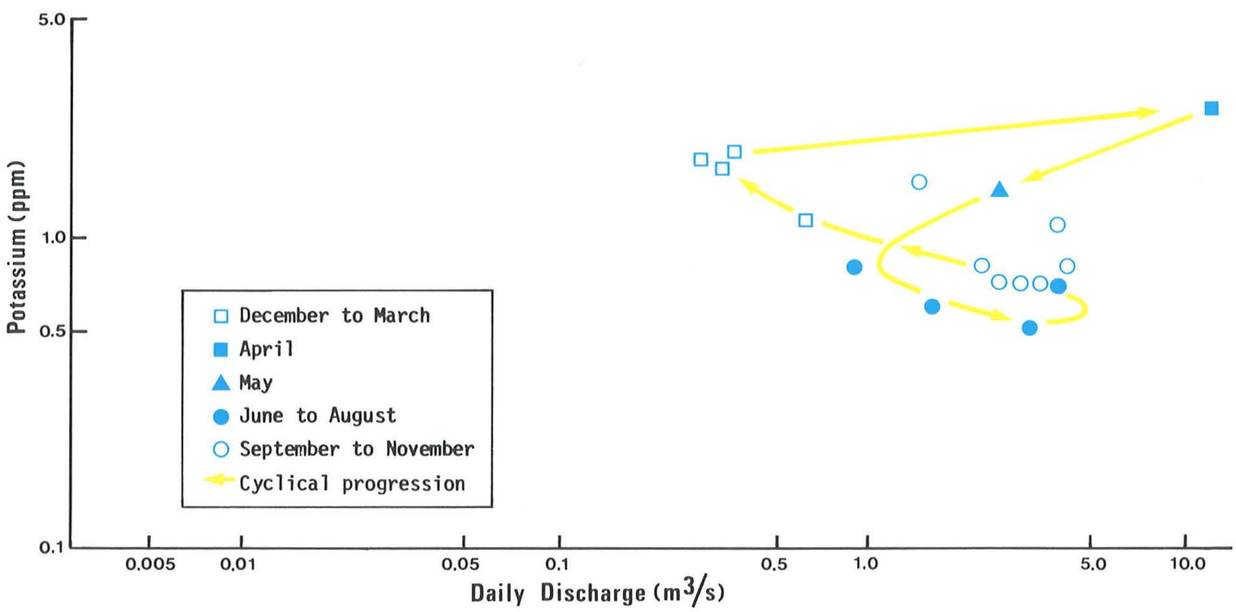
Figure 42. Fluctuations in total hardness in Zone 1 during open water months during 1977 (83).

runoff from the area. Underscoring this are the wide variations and much higher values present in the smaller basins adjacent to those lower reaches. These data also indicate remarkable similarities of these small basins throughout their hydrological zone.

The ionic regime of the Athabasca River (Figure 40) is similar to that of the tributaries to the south and west. Concentrations of dissolved solids peak in late winter, corresponding to minimum flows and the reverse situation occurs during spring runoff. This relatively high concentration of solids during minimum flow should be taken into account when considering development impacts. Also, there appears to be a general trend for the load of some dissolved inorganic ions (notably chloride) to increase slightly along some portions of the river. Further monitoring should provide a firmer definition of such spacial variations along the Athabasca River.

Other ionic species present in surface waters in smaller concentrations are fluoride and potassium, and their behaviour is more complex. For example, the concentration variation of potassium ion in samples collected from the Muskeg River in Zone 5 exhibits a complex hysteretic behaviour (Figure 43) (90). Potassium concentrations are relatively high during winter months, as are the other ionic species. However, during the high discharge period that accompanies spring-snowmelt, the potassium concentration tends to rise to a maximum for the year. In the period from June to August the concentration falls to a minimum only to rise slightly during the fall months. This increase in concentration, especially during the period of spring-snowmelt, probably is related to widespread surface runoff in the watershed.

Figure 43. Seasonal progressions of the potassium-discharge relationship for the Muskeg River in 1977 (90).



As waters move over soil surfaces, they readily accumulate potassium; at other times of the year, surface runoff is probably much less important. Cation exchange reactions reduce the mobility of potassium in groundwater and muskeg systems and, therefore, a concentration reduction is noticeable at these times.

SUSPENDED MATERIALS AND SEDIMENTS

Other constituents that follow a cyclic pattern are the undissolved suspended materials. However, in contrast to inorganic ions which are diluted to lower concentrations by high flows, suspended sediments are generally increased during high flows since the events that cause high flow also wash the sediments into the water system. The 1977 suspended sediment hydrograph for Hartley Creek (Figure 44) illustrates this relationship (91). The highest sediment concentrations correspond to spring runoff which is also the point of peak discharge. Thus, the load of suspended sediment, which is the product of concentration and discharge, is at a particularly high peak at this time.

A suspended sediment investigation is being conducted on the major tributaries and the Athabasca River (92). In general, concentrations of suspended sediments follow patterns of normally low loading with the occurrence of sharp peaks. For example, on 28 August 1977 in the Clearwater River, an unusual peak sediment concentration of 1,260 ppm occurred near a peak in discharge to cause a calculated load of suspended sediment of 35 tonnes into the Athabasca River. Typically the Clearwater River carried concentrations up to approximately 200 ppm and loads only up to about 4 tonnes.

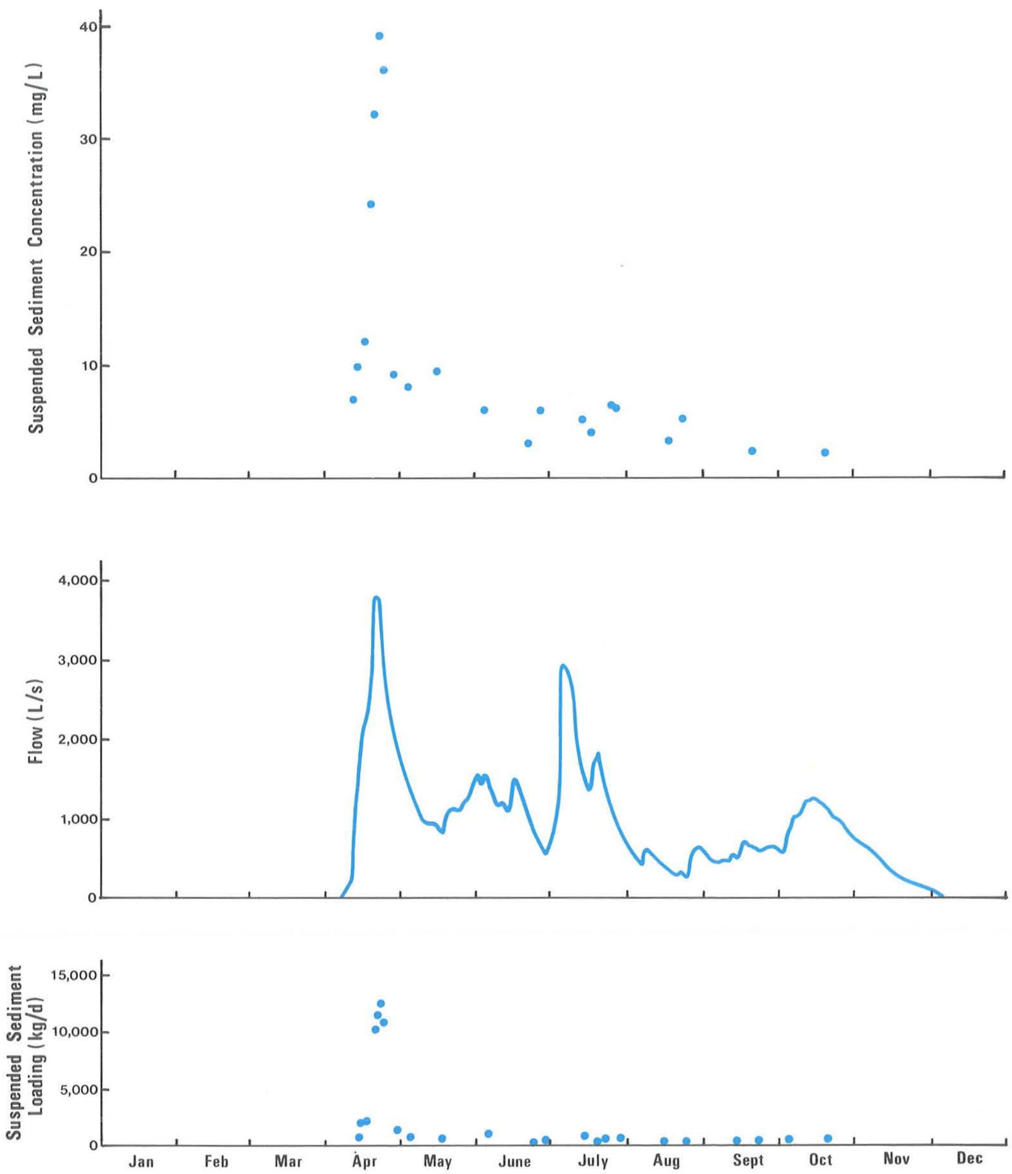


Figure 44. Suspended sediments in Hartley Creek in 1977 (91).

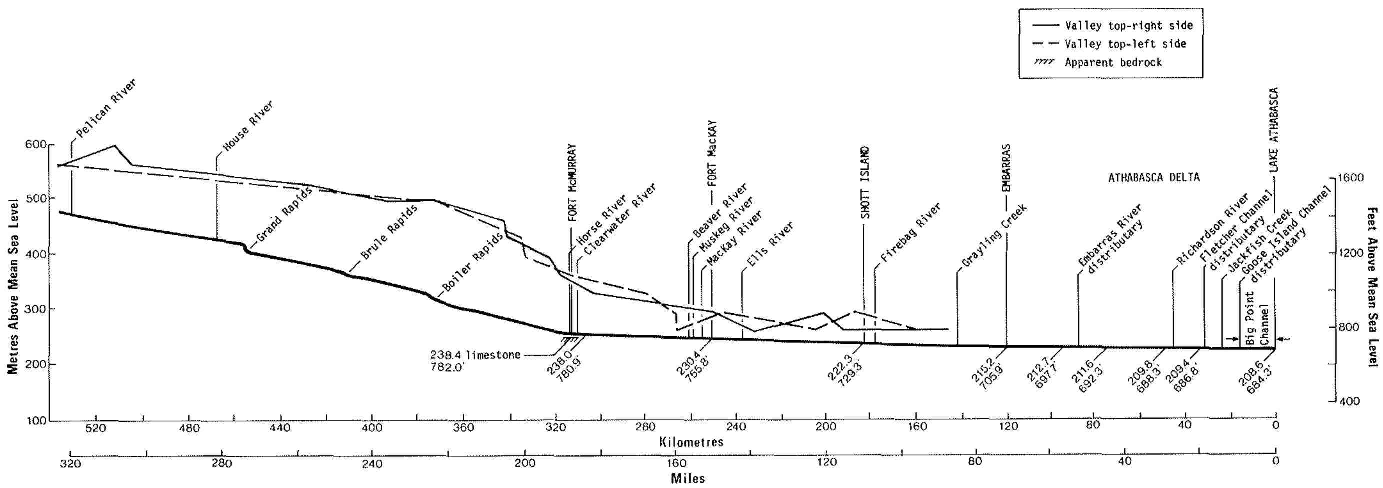


Figure 45. Longitudinal profile of the Athabasca River. Adapted from Research Council of Alberta (95).

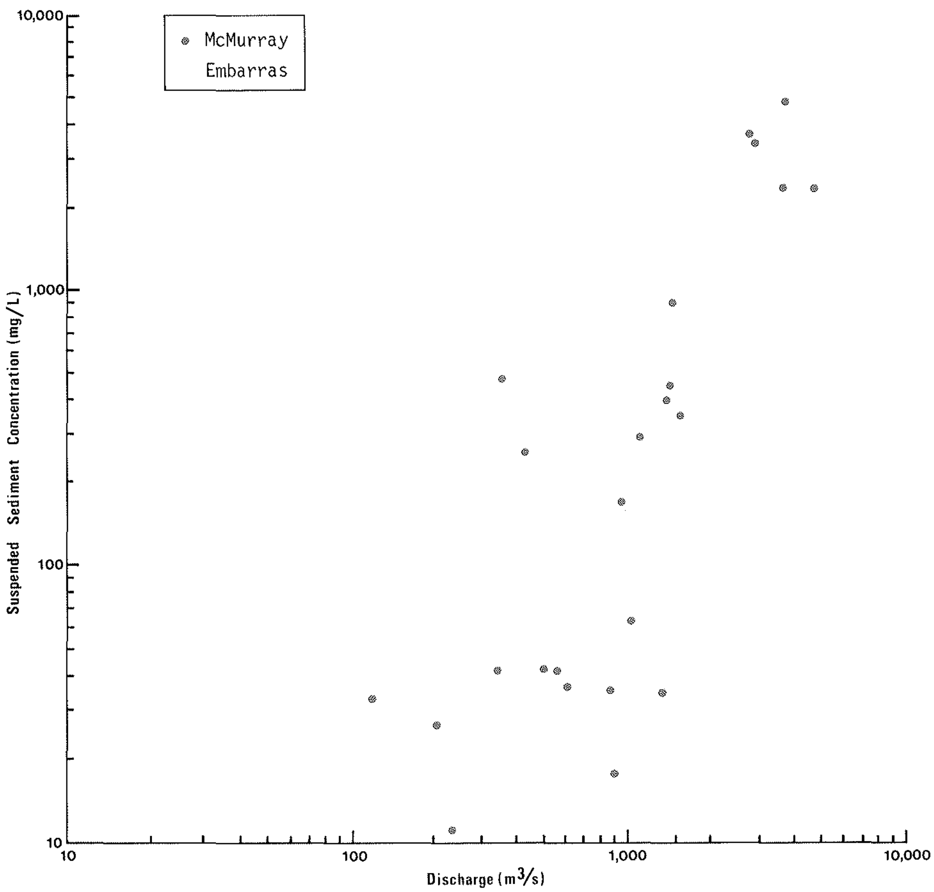


Figure 46. Suspended sediment rating curves at the WSC gauges below Fort McMurray and at Embarras using 1969-73 data. Adapted from Research Council of Alberta (94).

Physical features of the river channel determine greatly the capacity of that river to transport suspended material. Morphologically, the Athabasca River changes character dramatically at Fort McMurray (93). Upstream from Fort McMurray the river follows a relatively steep gradient, average 1 m/km. The meandering channel is deeply incised and there are many rapids. Downstream from Fort McMurray there is a relatively straight channel and a much lower gradient of about 0.1 m/km (Figure 45). This regime changes at the Peace-Athabasca Delta, where meanders start to occur over a very low gradient. These three differing sections of the river have differing sediment transport characteristics.

The differences between the steep section upstream of Fort McMurray and the placid section downstream are illustrated in the suspended sediment discharge relationships for the Athabasca River at Fort McMurray and at Embarras (Figure 46) (94). These relationships indicate that at higher flows the upstream section has a higher capacity to transport suspended sediments whereas at lower flow rates the downstream section has a higher capacity. During high flow periods a heavily loaded condition of relatively turbulent upstream sections brings in concentrations of suspended sediments that are supersaturated with respect to what the downstream section can carry and the sediments are deposited downstream of Fort McMurray. However, during low flows the upstream loading is not at a saturation with respect to the downstream section and deposited sediments are resuspended from that section. On the average some 75 percent of the suspended sediments is finer than 0.06 mm (92) and, thus,would stay in suspension and not be affected by deposition or erosion processes. Eventually the greater amount of suspended material is deposited in the Athabasca River Delta. In terms of loading, the tributary streams in the study area do not affect this picture appreciably. Relatively few suspended materials are loaded into the Athabasca River by the tributary streams in the study area and a distinct contrast in water is evident at the mouth of each tributary (Figure 47).

Superimposed on these processes operating on the sediments in the Athabasca River are those precipitating and redissolving organic and inorganic compounds. The overall effect of these processes, with regard to water quality, can be thought of as a "sink".

Investigations show that sediments act as sinks for metals associated with the oil sands deposit (96). The concentrations of such metals in sediments vary as a function not only of fluvial processes, but also geochemical processes relating to the texture, organic content, carbonate content, and ferrous mineral content of the sediments. Associated with higher amounts of precipitated heavy metals are the finer textured sediments which in turn relate to increases in surface area, amorphous inorganic-organic coatings, layer silicate concentrations, and organic content. Generally, there is a progression from lower to higher concentrations of metals in sediments downstream from Fort McMurray to the delta, to Lake Athabasca (Figure 48). The highest concentrations were found in the fine textured sediments from Lake Athabasca.

Concentrations of vanadium and nickel in the sediments are strongly correlated with each other, as well as with organic carbon (Figure 49). These metals appear to be present in an organic form that may be similar to that which occurs naturally in the oil sands deposits. Thus, they could have undergone relatively little chemical or bacteriological alterations between the source and site of deposition in bottom sediments.

Precipitation of organic compounds into the sediment regime is also an important process affecting the quality of watercourses. Such compounds are available to the river naturally or as a result of man's activities. A wide variety of compounds are available from native plants and their degradation products, in addition to the variety of compounds present as hydrocarbons in the oil sands deposit.

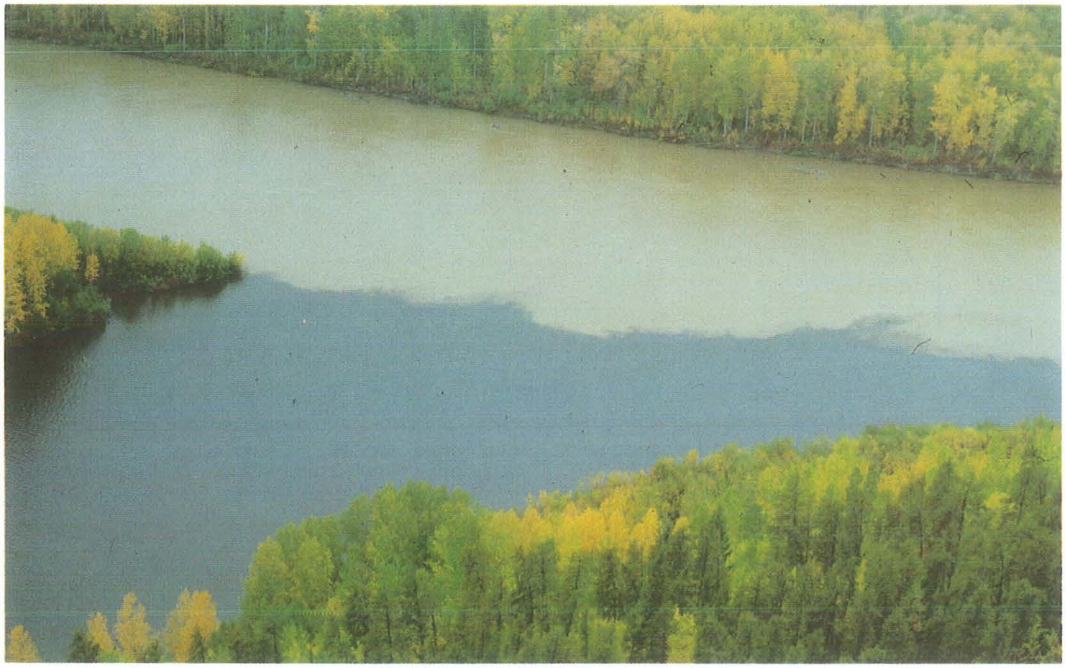


Figure 47. Mouth of the Firebag River as it enters a channel of the Athabasca River (photo: E. Harding).

Typically the organic component of suspended particulate material varies from 20-30 percent in most tributaries and from 10-20 percent in the Athabasca River (89).

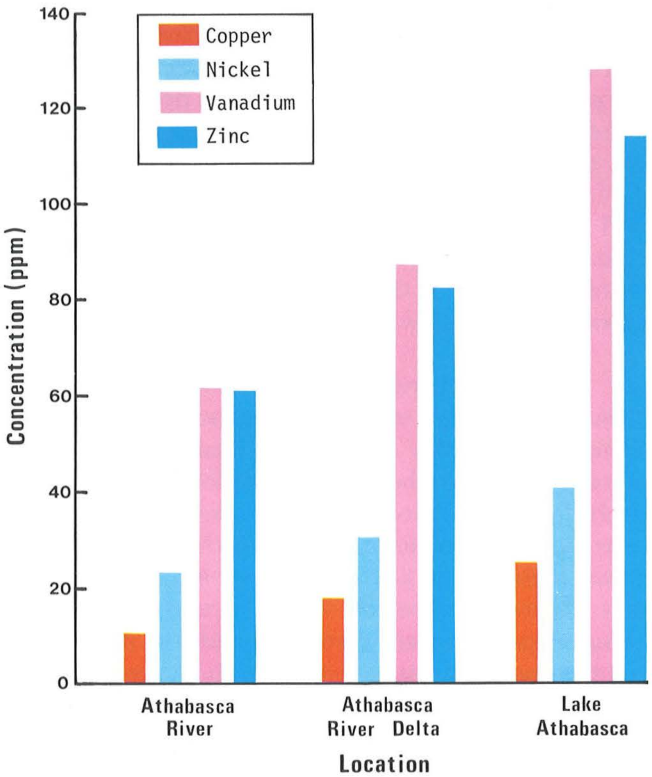


Figure 48. Mean heavy metal concentrations in sediments collected in 1976 (96).

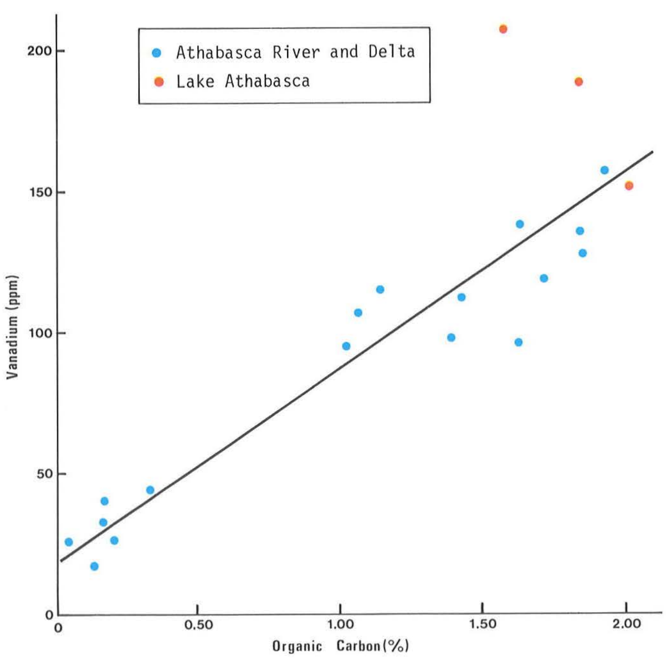


Figure 49. Correlation between total vanadium and organic carbon concentrations in bottom sediments collected in 1976 (96).

Deposited sediments from the Athabasca River sites, upstream of Fort McMurray, under winter conditions contain between 1 and 2 percent organic compounds (Table 15) (97). Most of the organic compounds cannot be extracted from the sediments by ordinary organic solvents and these represent plant-derived materials such as humic and fulvic acids, tannins, and lignins. The solvent-extractable portion, representing organic carbon derivatives from oil sands deposits, average only about 6 percent of the total. This extractable carbon component tends to increase proportionally downstream while the unextractable plant-based material proportionally decreases. Asphaltenes are the largest single proportion of extractable material, average 39 percent, which is twice that in oil sands (17-19 percent). This would indicate that the other compounds are more easily chemically or biologically taken up by natural processes.

Table 15. Organic carbon content in ppm of sediments from the Athabasca River upstream of Fort McMurray collected in winter 1977-78 (97).

Sample Location (km upstream from Fort McMurray)	Total Organic Content	Extractable Organic Carbon Content	Asphaltenes	Tannins and Lignins
100	20,000	740	267	308
55	11-14,000	880-910	311-403	335-421
1	16,000	1,180	454	470

NUTRIENTS

The term "nutrients" can be encompassing, involving not only major compounds utilized by the biota, but also dissolved forms of many metal ions, compounds of sulphur and silicon plus the particulate forms of most of these compounds. From the standpoint of the major components of biomass uptake by plants and animals, the compounds of carbon, nitrogen, and phosphorous are important (98). Levels of nutrients tend to be much less predictive than those of the major ions because of the biological activity associated with them. For each nutrient class there are numerous individual compounds, each with a characteristic biological activity and source, compounding the complexity of the situation, particularly in a spatial sense. However, some trends in the variation in classes can be discerned.

With few exceptions, total organic carbon in the tributaries generally declines during months of ice cover, with lowest concentrations occurring in April; this is followed by a sharp increase in concentration, usually during May. Subsequent fluctuations during the open water months are generally more stable, with concentrations of the same relative magnitude as during months with ice cover. Therefore, with the exception of spring breakup, substantial variation over the rest of the year is not apparent. Water from Precambrian headwaters is much lower in total organic carbon than water draining muskegs to the south and west. The Firebag River averages about 10 ppm whereas the MacKay River is about three times more concentrated in total organic carbon.

The Athabasca River averages about 10 ppm total organic carbon. Very few organic compounds, comprising this total organic carbon component, have actually been identified, and only types of compounds have been quantified. For a typical Athabasca River water sample under winter conditions, containing 9 ppm total organic carbon, only 1 ppm is extractable with organic solvents and represents constituents derived from oil sands; the remainder (8 ppm) is unextractable and represents larger water soluable natural products derived from plants (99). The extractable portion was fractionated into the classes of compounds shown in Table 16.

Table 16. Typical distribution of types of organic compounds in Athabasca River water (99).

Type of Organic Compound	Concentration (ppm)
Asphaltenes	0.25
Aliphatics	0.01
Aromatics	0.002
Polar compounds	0.004
Amphoteric compounds	0.001
Phenols	0.002
Organic acids	0.002
Amino acids	0.00005
Sulphur compounds	0.002
Elemental sulphur	0.0003
Phosphorus compounds	0.00004
Organic nitrogen compounds	0.0008
Chlorinated hydrocarbons	0.001
Chlorins	0.001
Amides	0.4
Tannins and lignins	0.4

A comparison of ranges of total phosphorus between open water and ice cover periods shows that concentrations during parts of ice cover conditions normally are greater than in summer, possibly due to response to biological activity (83). In most tributaries severe fluctuations occur during ice cover, usually peaking in January or February. A downward trend is generally observed during spring breakup (April, May), followed by an upward pulse in late May or early June. For the remainder of the summer months (June to August) total phosphorus generally declines in response to biological consumption while an upward pulse is observed in September or October. However, wide variations were not evident on the Ells River, where total phosphorus levels were fairly uniform for all sampling periods. This may be a reflection of the storage effects of the large headwater lakes of the Ells River.

Total Kjeldahl nitrogen ranges tended to show a slight decline before ice up and a similar decline just prior to ice out (83, 89). Other trends could not be discerned either spatially or temporally.

TRACE METALS

Concentrations of chromium, cadmium, copper, iron, lead, manganese, silver, zinc, vanadium, selenium, mercury, arsenic, nickel, and aluminum have been monitored (89). Some trace metals exceeding recommended limits (100) have been detected on occasion in the sedimentary waters. Iron invariably exceeds the recommended limit of 0.3 ppm in all samples to date and ranges as high as 9.6 ppm. Manganese and aluminum exceed limits of 0.5 ppm and 0.1 ppm, respectively, at practically all locations, ranging as high as 0.54 ppm and 11.2 ppm. Mercury exceeds the recommended limit of 0.0001 ppm sporadically at some points, and copper and arsenic occasionally approach their recommended respective limits of 0.02 ppm, and 0.01 ppm in some basins. Nickel also occasionally approaches 0.02 ppm.

The recommended limits of iron, manganese, and aluminum have been set considering both practical considerations of potability and handling quality, in addition to toxic considerations, whereas the limits for the other metals arise chiefly from their toxic properties. However, care has to be exercised in interpreting these findings because the metals can exist in more than just the dissolved ion form in natural waters. The metal can be part of the structure of, or adhering to, a suspended sediment particle. In addition, it should be noted that metals can react with naturally occurring organic compounds to form a soluble or semi-colloidal complex. The brown water tributary streams in the area provide ample organic compounds to complex with heavy metals, notably fulvic and humic acids which are leached into the water system from muskegs (101). The complexing capacity of some of the surface waters along with two other sites in Alberta are summarized in Table 17. Little direct correlation of complexing ability with the total amount of organic carbon compounds is evident showing that only a portion of these compounds have the complexing ability.

Table 17. Complexing capacity (μMoles/L copper) and dissolved organic carbon (ppm) of surface water from various points in Alberta (101).

Location	Complexing Capacity μMoles/Litre	Dissolved Organic Carbon (ppm)
Clearwater River above Waterways	2.8	20.0
Hangingstone River	2.4	31.0
Steepbank River	1.8	28.0
Muskeg River	4.1	24.0
Poplar Creek	4.9	32.0
Athabasca River at Fort MacKay	1.3	13.0
Ruth Lake	2.4	29.0
Bow River (Calgary, Alberta)	0.5	3.0
Pine Lake (Near Olds, Alberta)	2.1	16.0

Some metals, notably copper and nickel, regularly show high concentrations during months with ice cover in streams of the AOSERP study area, indicating groundwater discharge as a source of dissolved metals. However, high concentrations also occur during open water conditions and geographical or other temporal generalizations have not yet been made on all higher occurrences of trace metals. There also appears to be no direct correlation with occurrences of suspended sediments. Therefore, it appears that all three forms of the metals, dissolved, particulate, and complexed, are available to the tributaries in the area and thus, the total concentrations are subject to the vagaries of the types and rates of both paticulate and organic loading in water.

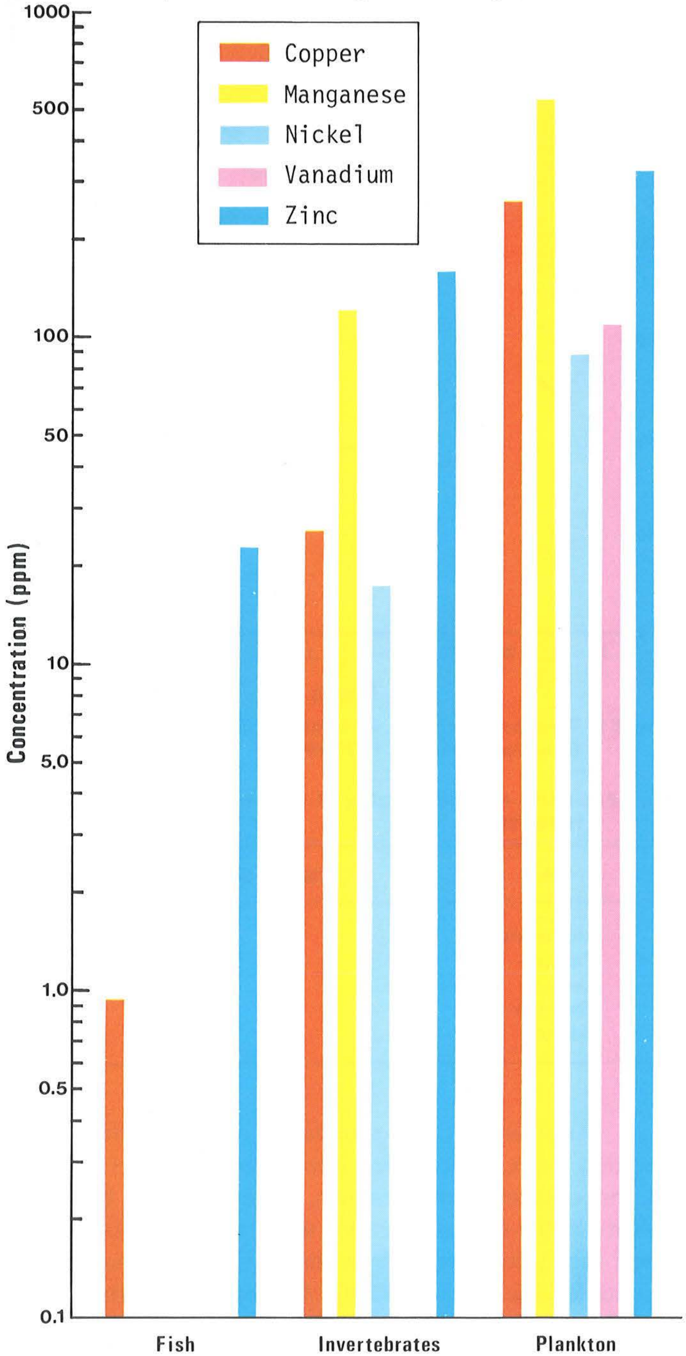


Figure 50. Mean heavy metal concentrations in fish and invertebrates from the AOSERP study area and plankton from the delta area (concentrations in ppm) collected in 1976 (102).

Evidence for bioaccumulation of metals has been investigated in the Athabasca River system (102). In fish from the study area most arsenic, chromium, nickel, vanadium, lead, and cadmium concentrations were low and close to detection limits. Copper, mercury, selenium, and zinc concentrations were not unusually high. However, some invertebrate species from the study area and plankton from the delta area showed notable traces of some of these metals (102) (Figure 50) as evidence of metal uptake by the biota. Fish are the last step in the aquatic food chain (Figure 59 in the Invertebrae Section) and since they did not show high amounts of metals, it is concluded that there is not a concentration effect or increase in accumulation along the food chain.

Lakes

As indicated earlier, a large number of lakes are contained within the boundaries of the AOSERP study area. Most of these are located in the regions north and south of Lake Athabasca. The only lakes grossly affected by oil sands development are Mildred and Ruth lakes on the Syncrude lease and very few are located near areas of current oil sands development. Thus, in general lakes have received less attention than other sectors of the Water System. The following description of the characteristics of lakes in the study area supplies only cursory information at this time.

The majority of the lakes in the study area are small, occupying less than 400 ha in surface areas. However, two significant groups of large lakes, in addition to Lake Athabasca and the lakes of the Peace-Athabasca Delta, can be identified. These are: the group of Gregoire, Gordon, Birch, and Gipsy lakes (800 to 7,700 ha) south of Fort McMurray, and the Namur Lake-Gardiner Lake group (1,200 to 4,500 ha) (103).

Most of the AOSERP study area lies within the "Zone of Forest Lakes" (104) which is transitional between the zone of mineral-rich saline lakes of more southern areas and the mineral-poor lakes of the northern (Precambrian Shield) regions. Lakes of the Forest Zone are characterized by an intermediate range of total dissolved solids and a mineral content of 200-500 ppm. The predominant lake types of this zone are eutrophic and mesotrophic. Eutrophic lakes are less than 20 m deep, having abundant dissolved plant nutrients and seasonal oxygen deficiency, whereas mesotrophic lakes are somewhat deeper than eutrophic lakes, having a moderate supply of nutrient matter and sufficient oxygen throughout the seasons.

Most of the lakes in the AOSERP study area are characterized by low mean depths, relatively high levels of nutrients, abundant macrophytic growth, and moderate to high productivities. Lakes such as Ruth Lake typify eutrophic conditions. Gregoire and Gardiner lakes are large with slightly greater mean depths and moderate productivities; they illustrate the mesotrophic condition. Two deep lakes of a different type (Namur Lake and a large unnamed lake north of Namur Lake) are found in this zone. The maximum depths of these two lakes are 28 m and 64 m, respectively, while the mean depths are 13 m and 16 m. Both are relatively unproductive and typify oligotrophic conditions. Oligotrophic lakes are generally more than 20 m deep, with limited nutrients and abundant dissolved oxygen.

Lakes in the area contiguous with the northern boundary of the AOSERP study area are located on the Precambrian Shield and are typically oligotrophic with a mineral content of less than 200 ppm. Dystrophic, shallow lakes with an abundant dissolved humic matter, high oxygen consumption, and little bottom fauna, are also distributed in this region (103).

BUFFERING CAPACITY

A key function provided by the dissolved ionic species in the lake water and by clays and silicates on the lake bottom is the capacity to buffer the lake ecosystem against acidification. Acid can be introduced into the lake by a number of physical and biological processes. Natural rain is slightly acid (pH approximately 5.4) arising from dissolved carbon dioxide and nitrogen oxides. However, such natural acid can be increased by sulphur oxides from industrial plant emissions, as discussed in the Air System section. If the acidity of a lake is increased, susceptible life forms are killed and eventually a point of no biological activity is reached. In addition, toxic metals can be released from the sediments by acidification. Lake acidification has become a world wide concern because many lakes in Scandinavia and eastern North America have become affected (105).

Total alkalinity is a key measure of the ability of the dissolved ion in a lake to handle acid input. The temporal variations in total alkalinity for surface waters in Namur, Eaglenest, and Gregoire lakes are shown in Figure 51 (89). A typical seasonal pattern is displayed by all three lakes. Relatively high alkalinity builds up during periods of ice cover when no precipitation is available to the lakes. During this period both plant respiration of dissolved carbon dioxide and the input of buffering salts would be operating to cause this increase. Spring break results in a reduction of alkalinity as snow melt and surface runoff are available to the lake. The stable period of relatively low alkalinity during the spring and summer is followed by a brief increase during fall lake turnover, when deeper water rich in buffering ions mix with the surface water. Inspection of Figure 51 also shows the relatively low alkalinity of Namur Lake compared to the other lakes indicating the possibility of it being susceptible to acidification.

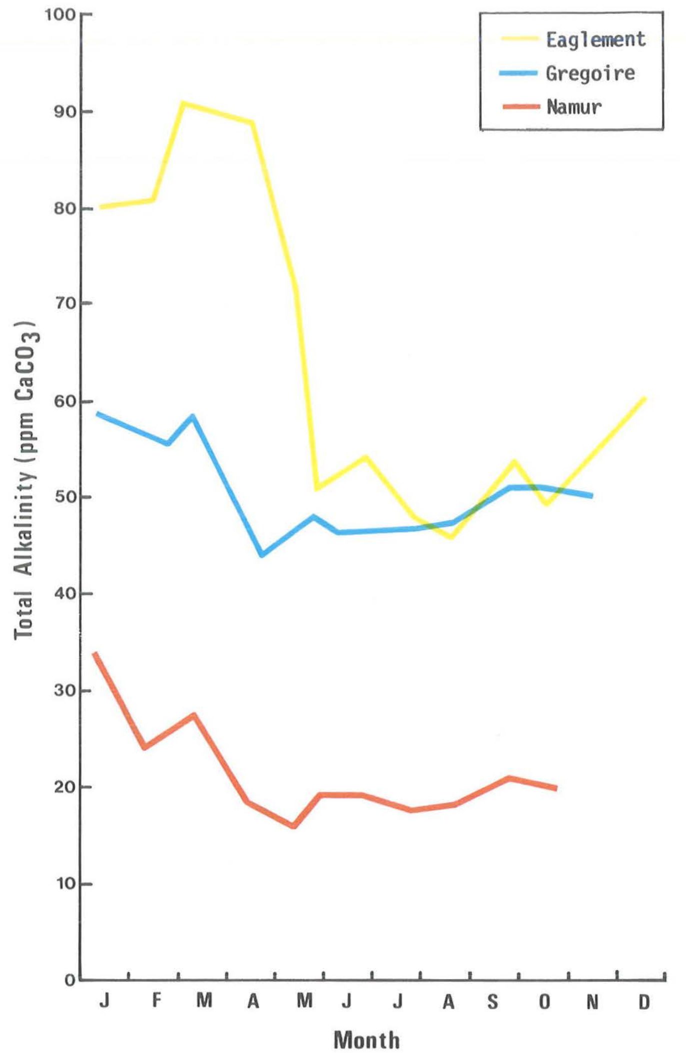


Figure 51. Temporal variation in total alkalinity of surface water from three lakes in 1977 (89).

Table 18. Calcite saturation index of selected lakes in autumn of 1976 (107).

Lake	Calcite Saturation Index
McClelland	0.0
Pearson	0.34
Laroque	0.69
Gregoire	1.15
Namur	2.27

Another indicator of buffering capacity is the calcite saturation index, which takes into account the pH (acidity) and the calcium concentrations, in addition to the total alkalinity. In the calcite saturation index scale it has been suggested that values over three show that a lake would be susceptible to acidification (106). A comparison of the calcite saturation index measured during fall turnover in 1976 is listed in Table 18 for various lakes (107). As expected, the more mineralized lakes are well below the danger point; however even the less mineralized Namur Lake appears below this point. It should be pointed out that in evaluating the susceptibility of a lake to acidification from an industrial development, it is necessary to take into consideration emission patterns and processes described in the Air System section.

Groundwater

SHALLOW GROUNDWATER

The most predominant shallow groundwater system in the AOSERP study area is provided by groundwater muskeg bogs adjacent to shallow systems in the glacial drift. In order to typify this regime throughout the region, the shallow groundwater of the Muskeg River basin was studied (107).

Typical waters taken from a number of test wells placed in muskeg terrain in the Muskeg River basin contain calcium and magnesium as dominant cations, and bicarbonate as the major anion. At almost all test wells, minimum mineralization occurs at the surface and there is a marked variation of all individual major ions with depth (Figure 52). Interestingly, not only does each well uniquely reflect its location by particular concentration of ions, but ionic species change concentrations with depth at differing rates, reflecting the unique set of processes provided by the soil at each location. In some deeper wells the influence of bedrock aquifers is reflected by higher sodium and chloride concentrations.

Water from both the standing muskeg and deeper sources is available to the surface streams in the basin. The relative influence of both components changes on a seasonal basis. During deep winter months when the surface muskeg is frozen, the base flow of Hartley Creek is provided by the deeper groundwater. However, during the summer months, up to 40 percent of the surface flow of Hartley Creek is provided by the standing bog water. This water, comprised of stored surface runoff and infused groundwater has a discrete chemical composition which substantially affects the character of the stream water. This storage effect of muskeg bogs is very pronounced, and is much higher than other types of surface water storage, such as lakes or reservoirs.

DEEP GROUNDWATER

The mechanisms of deep groundwater recharge have been studied for the area (108, 109). Water from deeper and larger units is typically high in chloride and total dissolved solids. However, the base winter flow in most tributaries displays low chloride concentrations (4-15 ppm) and the total dissolved solids range up to 670 ppm. Even major tributaries in the deeper-cut valleys, such as the Firebag, Ells, and Horse rivers, have relatively low chloride content. Notable exceptions are the Calumet, MacKay, and Hangingstone

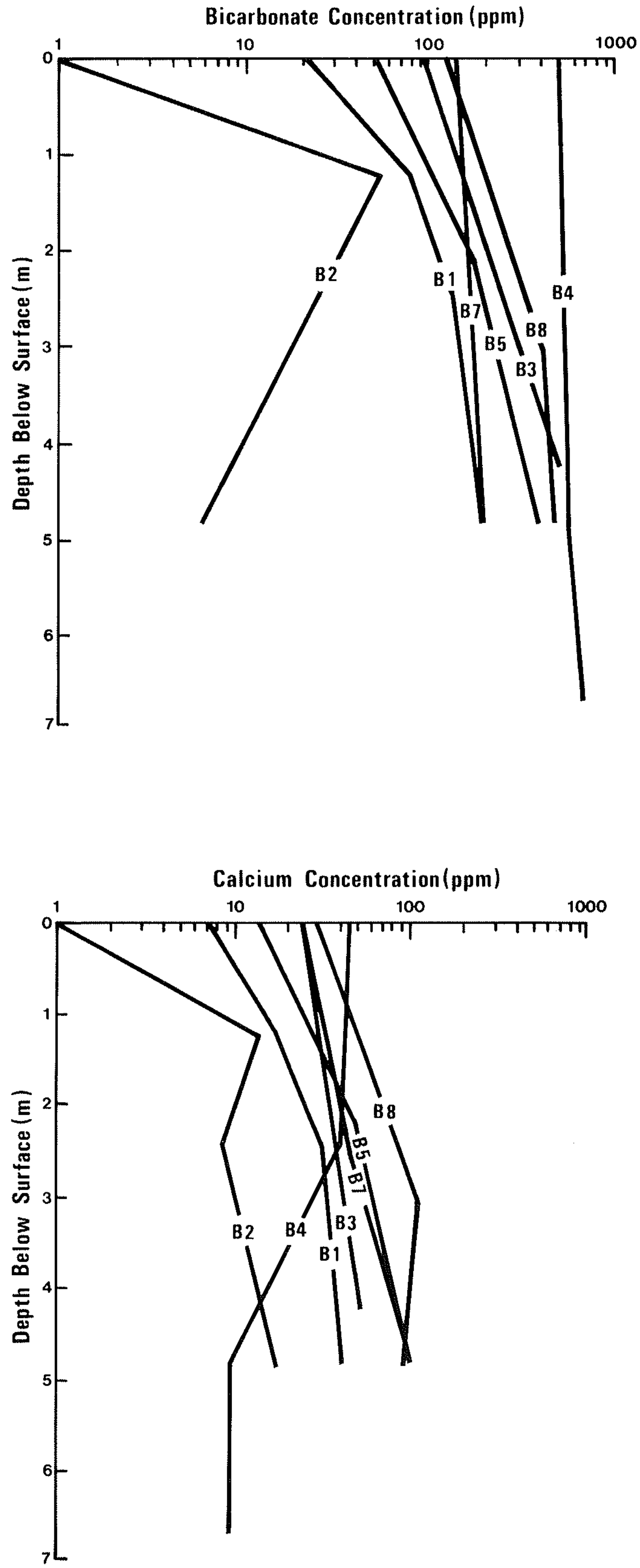


Figure 52. Calcium and bicarbonate concentrations (ppm) at various depths in shallow wells (B1 to B8) in a muskeg region of Hartley Creek, summer of 1977 (90).

rivers and Unnamed Creek, where measured chloride values ranged up to 96 ppm and total dissolved solids up to 864 ppm; it is concluded that these tributaries receive some discharge from deeper Cretaceous rock units. There is also some visual evidence of deeper groundwater located at the base of the Athabasca River valley such as La Saline Spring where chloride concentrations reach over 39,000 ppm (Figure 53). However, the Athabasca River itself does not appear to receive substantial direct groundwater discharge since there is no dramatic increase in salts or inflow rates that cannot be accounted for by tributary inflow.

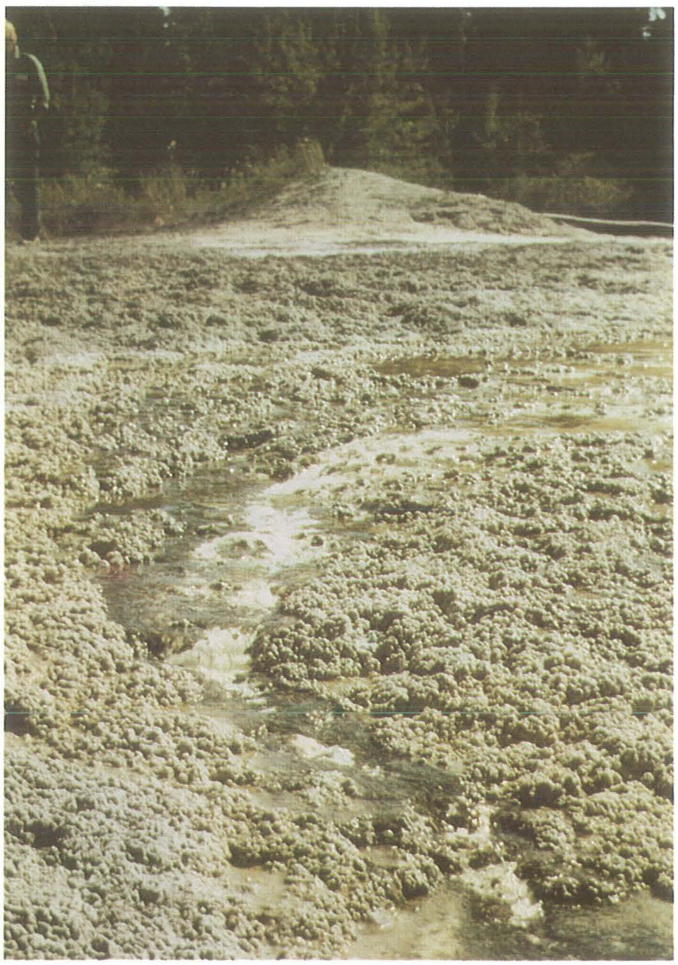


Figure 53. La Saline Spring near the Athabasca river (photo: G. Ozoray. Alberta Research Council).

The volume of deeper groundwater produced as a consequence of surface mining operations at oil sands plants may be of significance. The groundwater must be removed from zones below the ore body to facilitate mining in most areas. This process referred to as mine depressurization probably will have to be carried out at most sites throughout the course of mining operations because of the vertical and lateral continuity of the sandstone units. Such groundwater, once pumped out of the ground, must be disposed of either by impoundment, by discharge into existing water courses, or by reinjection into the subsurface.

The water produced by the wells at the Syncrude mining operations varies in chloride concentrations from 2,250 to over 10,000 ppm and total dissolved solids from 9,300 to over 19,000 ppm (110). Most surface mining operations in the area are expected to produce water of similar quality to the Syncrude operation with chlorides less than 5,000 ppm and total dissolved solids less than 10,000 ppm except for the northwest portion of the area. This area, near the Ells, Calumet, and Tar rivers in Zone 1 (Figure 38) is predicted to produce extremely poor quality mine depressurization water of up to 200,000 ppm total dissolved solids.

Microbiota

Quantitative biological inter-relationships of the tributary streams of the Athabasca River to the mainstem river have not yet been defined. However, studies to date appear to indicate a high level of productivity throughout the study area which may reflect high concentrations of dissolved organic and inorganic substances (111, 112). Most of the available energy for the sustenance of living organisms results from inputs from the surrounding land surface, in the form of surface runoff or groundwater containing particulate or dissolved organic or inorganic materials originating in plants or soils of the terrestrial ecosystem (113, 114, and 115). Thus, streams reflect the "state of health" of the surrounding land, and warrant special attention. Production of streams is of two types: autotrophic (production by plants utilizing only solar energy, carbon dioxide, and essential nutrients in the water) and heterotrophic (production by micro-organisms utilizing available nutrients from primary, autotrophic production, either within or outside the stream).

Algae are the only important autotrophic producers in streams of the AOSERP study area and form heterogeneous and complex associations on suitable stream substrates (112). The most abundant algae in terms of numbers, encountered in the Muskeg and Steepbank rivers are the blue-green algae, followed by diatoms and green algae. Figure 54 shows blue-green algae and diatoms from the Muskeg River and Figure 55 shows blue-green algae and green algae in the Ells River. Algae are an important food source for herbivorous organisms and comprise a source of organic and inorganic elements utilized by bacteria.

Studies for a complete yearly cycle on the Muskeg and Steepbank rivers have yielded 66 species of Bacillariophyta (diatoms), 30 species of Cyanophyta (blue-green algae), 20 species of Chlorophyta (green algae), and 3 species of Rhodophyta (red algae). Preliminary results have indicated the Muskeg River to be a much heavier primary producer than other tributaries. Factors which control the growth of each species of attached algae include temperature, current, scour, substrate, grazing, nutrients, and area available for colonization. The interaction of these factors upon the community is further complicated by the specific physiochemical requirements of taxonomic groups. Further definition of the comparative importance of algae to biological productivity of streams in the AOSERP study area will await completion of studies on several rivers.

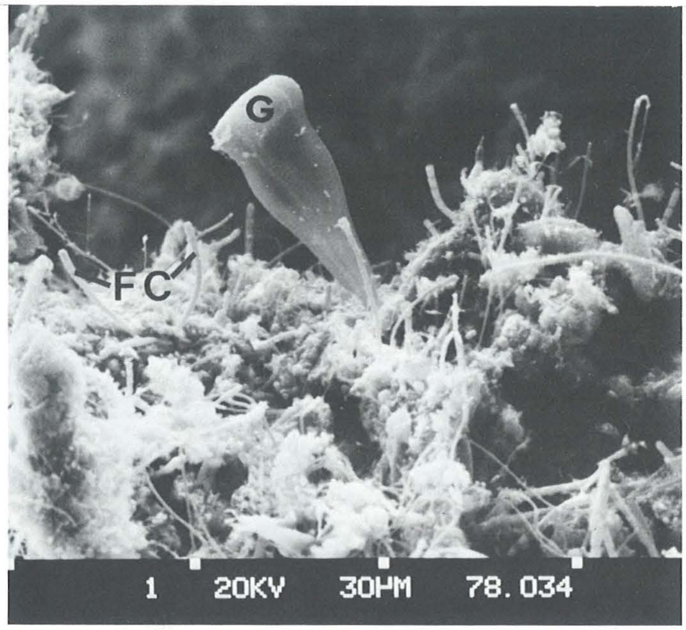


Figure 54. Scanning electron micrograph of material from the Muskeg River, October 1977, showing numerous filamentous cyanophycean algae (FC) and bacillariophycean algae, *Gomphonema* sp. (G) (112).

Figure 55. Blue-green algae, *Nostoc,* and green algae, *Cladophora,* in the Ells River, August 1978 (photo: S. Charlton, University of Alberta).

Heterotrophic production in streams accounts for the greatest proportion of the energy budget for stream ecosystems (116) and bacteria comprise the lowest levels of heterotrophic production. Although considerable work has been done elsewhere on stream energetics (116, 117), little is known quantitatively of processes of heterotrophic production in northern brownwater streams of the type prevalent in the AOSERP study area. Work to date in the AOSERP study area has been concentrated on identification of micro-organisms and their population status. Because of the importance of bacteria in fixing organic carbon in the food chain, the lack of a quantitative definition of carbon available to and used by bacteria is viewed as a deficiency in baseline research.

The majority of the aquatic bacteria observed in the Athabasca River and its tributaries are present as single cells or as members of coherent macro-colonies of between ten and several hundred cells. Diatoms often have bacterial attachments and irregular detritus particles are heavily colonized by adherent bacteria (111). Very few bacteria have been observed in association with clay or silt particles (Figure 56); however, irregular and amorphous debris are colonized (Figure 57). This suggests that the planar crystalline surface of the silt particles may minimize colonization because of movement of silt and detachment of bacteria by abrasion. In sediments where silt particles are stationary, sessile bacteria may colonize the particles. There is an apparent relationship between increasing bacterial numbers and an increasing concentration of total organic nitrogen in the waters, but there is not a similar relationship between bacterial numbers and increasing levels of dissolved organic carbon, indicating that organic carbon is not limiting for bacterial production. Another relationship measured in the interstitial water was that the standing stocks of bacteria increased with depth (Figure 58).

In the Athabasca River there is very little geographical variation in bacterial populations; however, seasonal variations were evident. Relatively constant populations were maintained during the period of ice cover when flow is constant and low and suspended silt load is low. In the spring high levels of bacteria populations corresponding to periods of high flow and relatively high suspended material load were detected. Such seasonal fluctuations generally correspond directly with the fluctuations of total organic carbon, except in summer when the bacteria-total organic carbon ratio increased.

The same pattern of high seasonal fluctuations and little geographical variation occurs in tributary streams studied to date. The epilithion (attached communities) of the Muskeg River and Hartley Creek are most similar and the Steepbank River is generally similar to them both. Populations in the Muskeg River and Hartley Creek increased after ice break-up to a maximum in July of 1.2×10^8 bacteria/cm^2, and then declined to a 1×10^7/cm^2 by mid-August. Populations

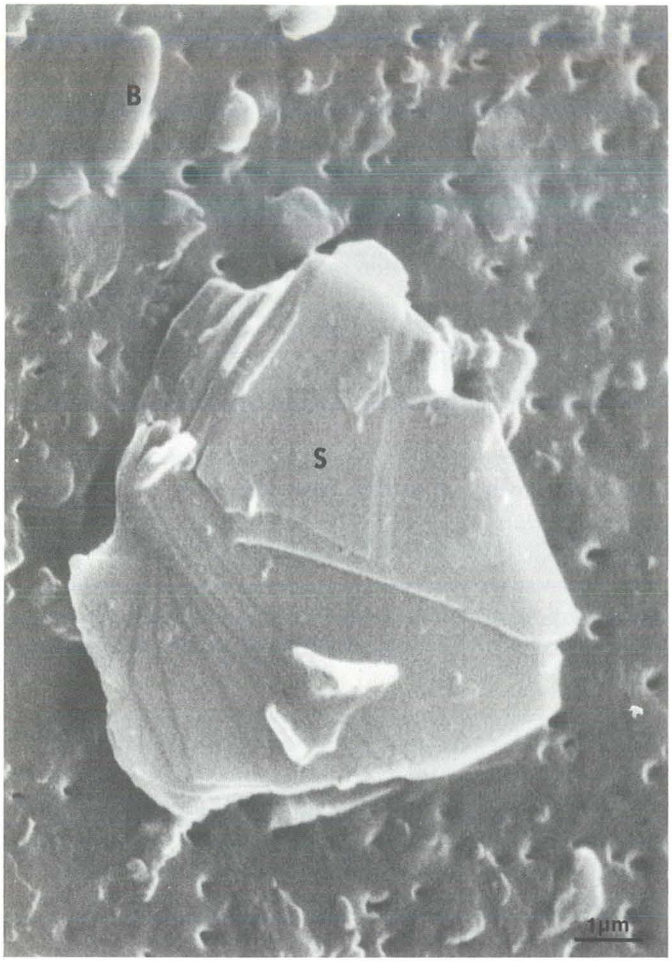


Figure 56. Scanning electron micrograph of material from the Athabasca River showing uncolonized silt particle (S) and free floating bacteria (B) (111).

Figure 57. Scanning electron micrograph of material from the Athabasca River showing detritus particle with complete colonization of surface by bacteria (B) (111).

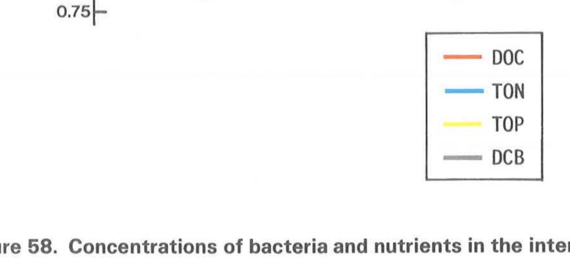


Figure 58. Concentrations of bacteria and nutrients in the interstitial water of the Muskeg River. DOC = dissolved organic carbon (ppm); TON = total organic carbon (ppm); TOP = total organic phosphorus (ppm); and DCB = direct counts of bacteria (bacteria per millilitre) x 10^4, 1977 data (112).

stabilized for two to three weeks and then rose to a maximum in late October of 1.3 x 10^8/cm^2 in the Muskeg River and 1 x 10^8/cm^2 in Hartley Creek. The substratum was frozen in December. The epilithic bacteria of the Steepbank River show a similar pattern with a peak in mid-July, a decline at the end of August, and increase by late October. The bacteria population curves for these waterways appears bimodal, with peaks in early summer and early winter, and a midsummer minimum.

Invertebrates

Studies of invertebrates in streams of the AOSERP study area are intended to provide an essential part of baseline knowledge of stream processes. Invertebrates (largely insects) provide the most diverse and quantitatively most important link in the food chain between the uppermost consumer levels and the lower levels of autotrophic (algal) and heterotrophic (bacterial) production. Figure 59 indicates in simplified form the energy flow in the aquatic food chain and

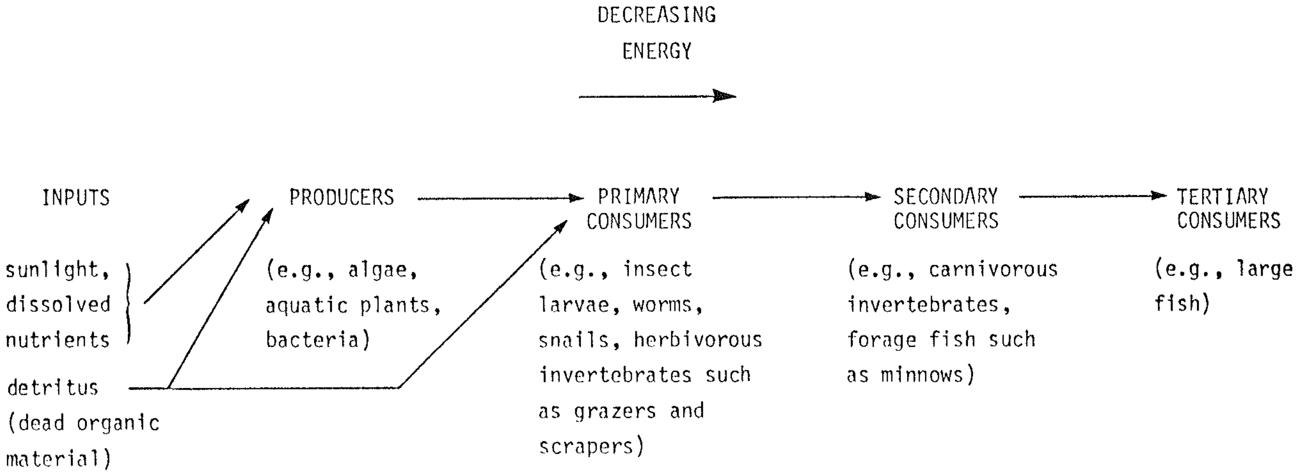


Figure 59. Trophic classification and enegy flow in the aquatic food chain.

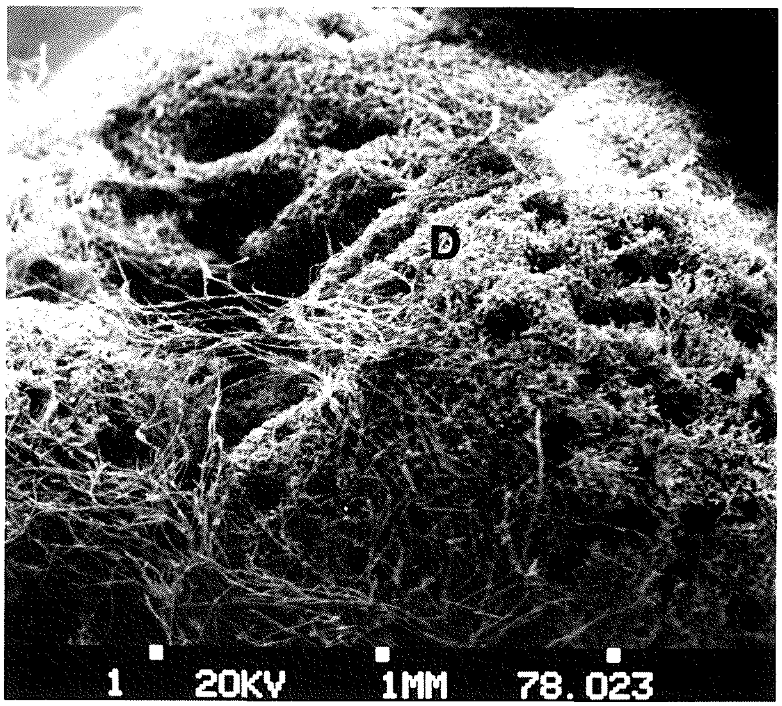


Figure 60. Scanning electron micrograph of material from the Muskeg River, October 1977, showing a thick mat (≃ 3 mm) of bacillariophycean algae (D) stalks perforated with holes possibly produced by grazing chironomid larvae (112).

Figures 60 and 61 illustrate types of food chain interaction involving invertebrates.

Initially, investigations concentrated on identifying and cataloguing taxonomic groups and focusing attention on relationships of invertebrates with one another (community association) and with various habitats (118, 119, 120, 121). The latter types of studies are necessary in order to gain some appreciation of the possible effects of stream perturbations on aquatic habitats and the living organisms which inhabit them.

Field studies designed to provide preliminary information which could lead to identification of major faunal groups of stream benthos have been completed. The taxonomic descriptions of benthos have been completed and no significant taxonomic anomalies have been revealed in relation to those groups which might be expected to occur in

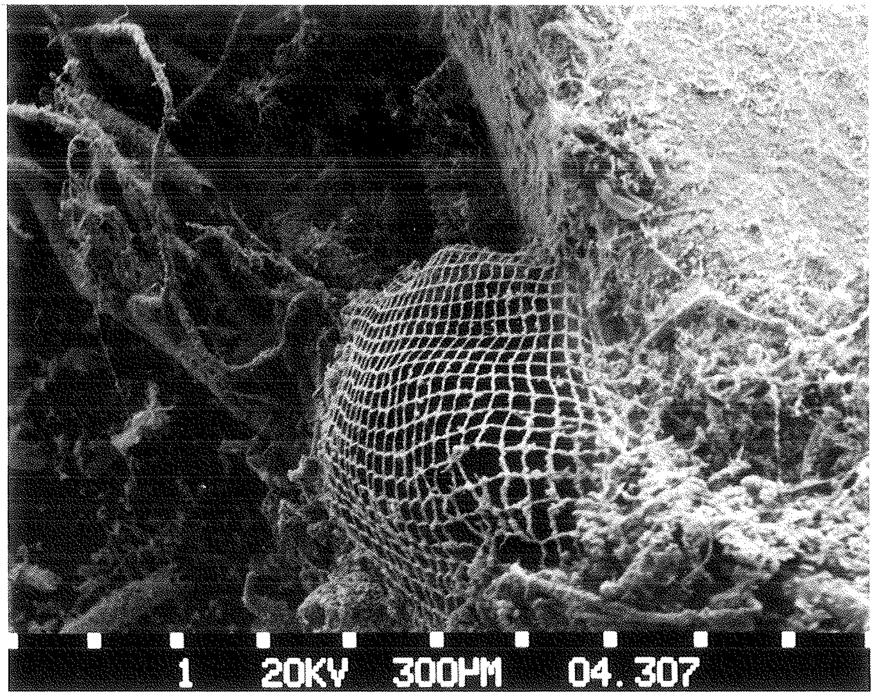


Figure 61. Scanning electron micrograph of material from the Steepbank River, October 1977, showing a food catching net, possibly of a trichopteran larva (112).

freshwater streams. Species of macrobenthos identified from streams in the AOSERP study area are listed with their scientific and common names in Appendix IV. It should be mentioned, however, that many of the streams of the AOSERP study area, particularly the brownwater tributaries of the Athabasca River, appear to have an exceedingly rich fauna.

Experiments have been performed to provide some indications of the effects of oil pollution on stream benthos by immersing oil soaked rocks in the Muskeg and Steepbank rivers (119). Effects of siltation on benthos were detected by comparing standing stocks of benthic organisms subjected to siltation in Beaver River and two of its tributaries (Poplar and Birch creeks) and the Syncrude west interceptor ditch to standing stocks of benthos in undisturbed habitats in the same streams and on the Muskeg River. Results indicate that siltation has more deleterious effects than does oil.

Studies were conducted to categorize invertebrate habitat types in a small tributary and a review of some of the main concepts of aquatic habitat mapping has been carried out (121). Ongoing studies are intended to develop appropriate procedures to catalogue reaches on the Athabasca River and its major tributaries. Quantification of major taxonomic groups of invertebrate types and their community relations are foreseen as a follow up of the habitat surveys and sampling of macrobenthos. The task of determining the distribution and relative members of invertebrates and assessing possible effects of oil sands development on these faunal groups should be a major activity to be pursued.

Fish

The surface waters of the AOSERP study area provide a wide variety of fish sought after for food by sport, domestic, and commercial fishermen. For example, a commercial fishery has been operating in the Peace-Athabasca Delta for a number of years (123). Figure 62 depicts the walleye catch from this fishery. The importance of fish is further emphasized by a comparison of this resource with oil sands mining: the fish resource has the potential of being renewable indefinitely, whereas oil sands mining ceases when the ore is exhausted.

Fishery surveys have been carried out by others in the AOSERP study area (124, 125, 126). Surveys under AOSERP have covered extensive areas of the Athabasca River (127, 128, 129, 130, 131) the Peace-Athabasca Delta (132), and the Steepbank and Muskeg rivers (133, 134, 135). The occurrence and distribution of fish species is considered typical for the northeast portion of Alberta (136). Studies are still underway or nearing completion for other major regions in the study area. In all, 27 species were captured and identified (a species checklist is given in Appendix V). It appears that generally most of the fish populations utilize extensive portions of the vast river-lake network. However, determination of a quantitative significance of the mainstem and various tributaries to fish stocks of the region can only be determined after completion of habitat definition and categorization.

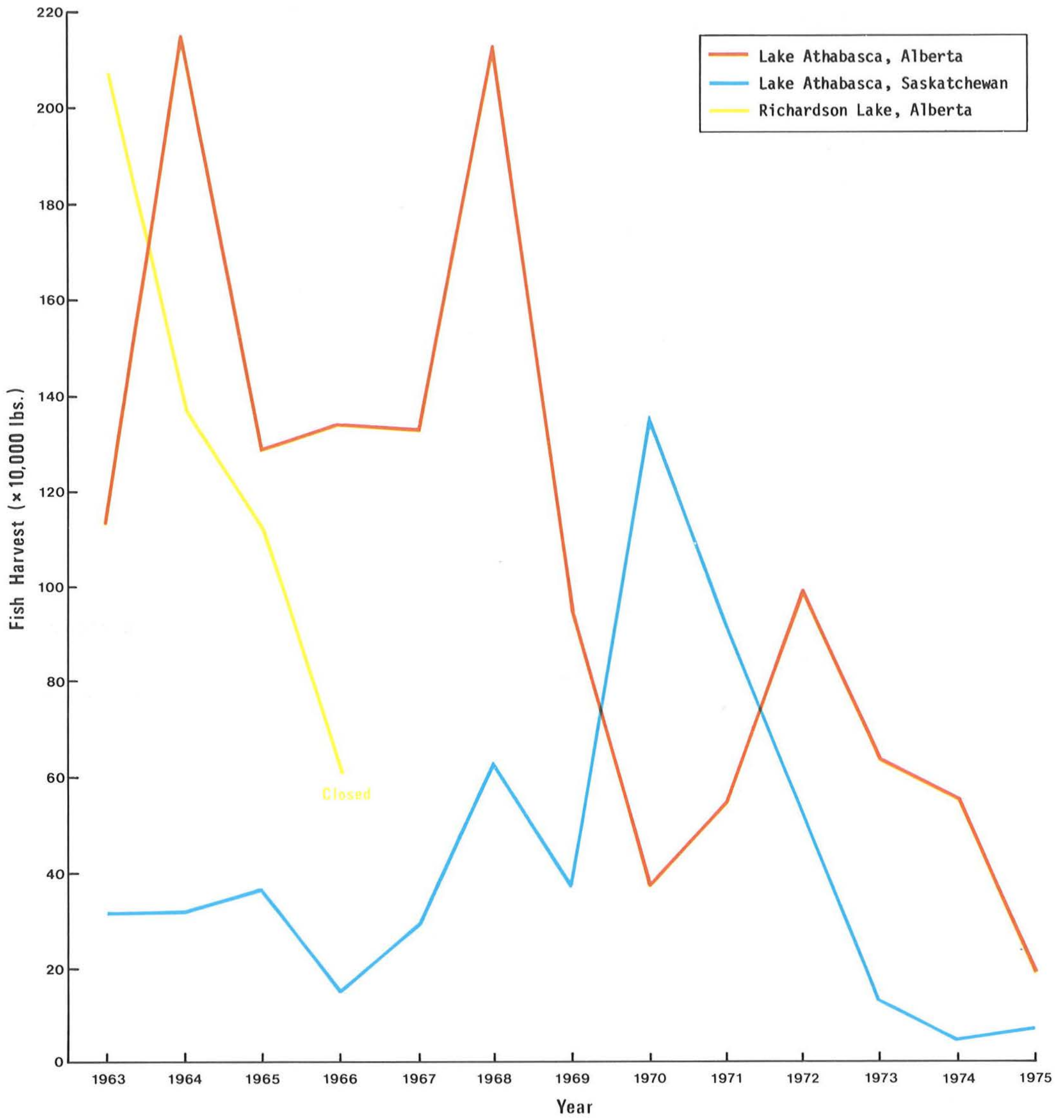


Figure 62. Commercial yearly catches of walleye in the Peace-Athabasca Delta fishery, 1963-1975 (123).

Because of the importance of many species of fish to people in the area for subsistence, for recreational fishing, and as a commercial harvestable resource, detailed discussions of several species now follow.

WALLEYE

Walleye are widely distributed in lakes and rivers throughout the AOSERP study area. They prefer lakes, large rivers, and the lower reaches of the larger tributary systems, such as the Christina, MacKay, Ells, and Firebag rivers. They are also found throughout the mid-reaches during spring spawning, but the majority return downstream immediately after spawning is completed.

Walleye are very important to the sport and commercial fishery of the AOSERP study area because of their excellent table quality. They have been fished commercially for a number of years in Lake Athabasa, Georges Lake, and Gregoire Lake. In 1978, commercial fishermen caught 81,663 kg of walleye in Lake Athabasca. Sportsmen fish for this species throughout the region and many of the tributary confluences of the Athabasca River provide excellent recreational angling. Walleye show a strong preference for back eddies and tributary confluences during the spring spawning migrations on the Athabasca River. During the summer and autumn, walleye utilize most areas of the river uniformly. Lakes such as Gregoire and Gardiner already play an important role in the recreational needs of the residents of Fort McMurray and walleye are one of the key species in this fishery.

The average size of walleye from the AOSERP study area is from 300 to 500 mm fork length. Such fish would be from 3 to 6 years old and weigh from 400 to 2,000 g. The growth rate of walleye in the study area varies from lake to lake and throughout the river drainage systems. Fish from Gardiner Lake are typical of fast growing populations where fish often weigh in excess of 3,000 g by 7 years of age. Conversely, fish captured in the Athabasca River near Fort McMurray have a growth rate that is considered to be intermediate compared with populations in Kehiwin Lake, Alberta or Lac Lac Ronge, Saskatchewan. Walleye from the MacKay River population have an even slower growth rate. It has also been reported that the walleye found in those slow growing populations reach a maximum age of 14 to 15 years while the fish in Gardiner Lake rarely exceed 7 to 8 years.

Male walleye are normally sexually mature and spawn for the first time at age 4 to 5, whereas females first mature at 6 to 8 years of age. Female walleye may produce over 100,000 eggs each year. They spawn in riffle areas of rivers and streams or over gravel shoals in lakes when available. The fish leave their over-wintering grounds and move to the spawning beds early in the spring. Often, this movement occurs under the ice or during break-up. Spawning areas can be found throughout the AOSERP study area. In most areas the spring spawning run provides the highlight of the fishing season for the sports fishermen. After spawning is completed, most of the spent fish migrate to the lower reaches of their spawning stream or return to lakes and large rivers such as the Athabasca.

Rearing of the young walleye occurs throughout the AOSERP study area. Young-of-the-year walleye are commonly found in most tributary mouths during the early summer. It appears that these areas provide ideal habitat for the feeding and rearing of young walleye. Growth of the young fish is rapid. In the Athabasca River, young-of-the-year walleye had already exceeded a mean fork length of 70 mm by late July. By 15 August the mean length had surpassed the 90 mm mark.

Lakes also pay an important role in the rearing of young walleye. One unique example occurs in the Peace-Athabasca Delta. Richardson Lake has been shown to be a major spawning and rearing area. Young-of-the-year fish remain in this shallow lake until late July, then they migrate through Jackfish Creek to the Athabasca River and eventually to Lake Athabasca. Previous work has shown that these fish provide much of the annual recruitment of the Lake Athabasca walleye population.

The larger rivers, as well as the lakes, are important both as summer feeding areas and as overwintering locations. As the season progresses the fish continue to move out of the rivers into the lakes. For example, in the Athabasca River an abrupt decrease in catches occurs early in June and low catches throughout the remainder of the summer indicate that most walleye do not remain in the river, but return downstream to the Athabasca Delta and Lake Athabasca. This slow migration to summer feeding and overwintering grounds is typical of the movements of walleye throughout the AOSERP study area.

An analysis of walleye stomachs reveals that 80 percent of their diet is fish. They eat a variety of fish species including suckers, burbot, Arctic grayling, trout-perch, and minnows. The remainder of the diet (20 percent) is usually composed of immature insects such as stoneflies, dragonflies, and mayflies.

NORTHERN PIKE

Northern pike are found throughout the AOSERP study area. In general, this species prefers the well-vegetated waters found in warm shallow lakes, in shallow bays of the larger lakes, and in slow-moving clear streams. They also occur in a wide range of lake and river habitats, often being caught in the silt-laden Athabasca River or in the deep offshore waters of Lake Athabasca.

Northern pike are important both as sport and commercial fish. Pike have been successfully harvested for a number of lakes in the AOSERP study area by commercial gillnetting operations in the past. However, reduced catches in the late 1960's limited commercial production. In 1978, the only major production of pike in the area was from Lake Athabasca where 3,886 kg were harvested. Northern pike are one of the more popular game fish found in the AOSERP study area. The peak harvest occurs during the spring spawning migrations when angling of northern pike by sportsmen is most concentrated.

The size of the pike found in the region is extremely variable and is dependent on habitat characteristics, water temperature, and food availability. The average size of the pike is from 400 to 600 mm. Fish from the Steepbank River, the Muskeg River, Gardiner Lake, and Gregoire Lake are similar in size. These fish are normally from 3 to 6 years old and weigh up to 2,500 g. By age 7 or 8, weights of 3.5 to 4.5 kg are common; however, most of the older and larger fish are females. The largest pike are found in Lake Athabasca where numbers have been caught over 1,000 mm in length, weighing 14 kg.

Northern pike spawn during April or early May in shallow bays, marshes, or weed-choked side channels and backwater sloughs along rivers and streams. In all these areas the presence of aquatic vegetation appears to be a requirement of the spawning site. Spawning sites are available in most of the lakes in the study area. In addition, suitable spawning sites can be found along many of the tributary streams of the Athabasca River. Few pike spawn in the Athabasca River proper.

Male pike mature earlier than female pike and are able to spawn at 2 to 3 years of age. Most of the females are mature by their 4th year. During 1976, the fecundity of mature female northern pike from the Athabasca River was examined. The fecundity of mature females sampled in the study area varied from 17,764 to 42,962 eggs.

Young pike in the AOSERP study area remain in shallow weedy areas for most of the summer. Immature pike have also been collected from the Athabasca River at tributary confluences. Growth of young fish is rapid. By late June young pike collected at the mouth of Leggett Creek had reached a mean fork length of 28 mm.

Apart from the spring migrations into marshes and tributary streams to spawn, adult northern pike are generally sedentary. Throughout the summer they remain in areas where food supplies are favourable and where cover is plentiful. In the AOSERP study area, pike can be found in most of the lakes during the summer, but the river populations are most prevalent in the lower reaches and mouth areas of the smaller streams. By late autumn many of the pike have left the smaller streams. Pike are known to overwinter in both large and small lakes, but the number of pike overwintering in the rivers has not been established to date.

Adult northern pike are opportunistic predators. Although they are generally piscivorous (fish make up 80-90 percent of their diet), they also feed on a variety of other organisms. Frogs, mice, and aquatic insects are also eaten on occasion.

GOLDEYE

Goldeye, which prefer water of high turbidity, are found in many lakes and rivers of the AOSERP study area. Large populations of goldeye are found throughout the Peace-Athabasca Delta and along the Athabasca River as far upstream as the Grand Rapids. Although they are less abundant in the tributaries of the Athabasca River, they have been collected in the Clearwater River 8 km upstream from the Athabasca River, in the Steepbank River 1 km upstream, and in the Ells River 12 km upstream.

Goldeye are important both as sport and commercial fish. They were commercially fished in the western part of Lake Athabasca and in Lake Claire for a number of years; this fishery was terminated in 1966 as a result of a decrease in population. Angling for this species has been successful at river mouths and in large back eddies. Goldeye prefer back eddy locations in the Athabasca River and, to a lesser extent, slack water areas behind islands; angling in these areas is productive.

The average size of goldeye from the Athabasca River system is from 210 to 320 mm. These fish are from 4 to 5 years old and weigh from 600 to 800 g. Fish from the Peace-Athabasca Delta are similar in size and weights. The larger size of goldeye caught in the AOSERP study area tend to be over 400 mm long and weigh over 600 g. These fish would be 8 to 9 years old.

Upon reaching sexual maturity it appears likely that goldeye from most of the AOSERP study area migrate to the Lake Claire-Mamawi area of the Peace-Athabasca Delta to spawn. Some spawning may occur in other locations in the region; however, it has generally been noted that most goldeye found in the Athabasca River and in tributary streams are sexually immature.

Rearing of the young goldeye is also prevalent in the Lake Claire-Mamawi area of the Peace-Athabasca Delta. Preliminary observations in Lake Claire suggest that shorelines are the preferred habitat of fry and that vegetation type usually influences distribution along the shoreline.

Goldeye are known to undertake long migrations from the spawning areas to summer feeding grounds. This movement into summer feeding grounds is believed to occur in early spring or summer. The mainstem of the Athabasca River, from the delta to the Cascade Rapids, is important as a feeding area for goldeye. During summer, while most goldeye generally move very little, some individuals may wander long distances. In September or October, with the onset of cooler water temperatures, goldeye move downstream out of the Athabasca River to overwintering areas in Lake Athabasca and the lower Peace River.

Goldeye feed mainly on immature insects, such as stoneflies, mayflies, and water bugs. Other items found frequently in goldeye stomachs are surface water insects, terrestrial insects as well as animal and vegetable matter.

GRAYLING

The grayling is widely distributed in the AOSERP study area where it is found in both large and small streams. Like those elsewhere, populations in the Athabasca drainage undertake extensive seasonal migrations. Typically, adults and juveniles overwinter in large streams such as the Athabasca River where there is an assured supply of well-oxygenated water through the winter. As the ice breaks up in April and May, mature fish leave the overwintering areas and move into smaller tributaries where they spawn.

Spawning takes place during the day over gravel or rocky substrates at water temperatures ranging from 4-11°C. Eggs, which may range from 4,000 to 16,000 per female, are shed into cracks in the substrate or are covered by fine materials. Young emerge from the gravel as little as two to three weeks after spawning and move to the stream edges and shallow backwaters where they begin to feed.

It appears that in the AOSERP study area, the majority of mature fish remain in the tributaries after spawning and feed throughout the summer. They are rarely taken in the mainstem of the Athabasca River until fall when a downstream migration begins. This downstream movement, which may also include young-of-the-year hatched from the previous spring's spawning as well as juveniles which have entered tributaries to feed during the summer, appears to be triggered by rapidly falling water temperatures.

The maximum age, reported for a grayling from the AOSERP study area is age 12. The growth is average for the species, about 300 mm at age 4 and 350 mm at ages 7 or more. The larger fish commonly encountered are about 380 mm.

Grayling have a widely varied diet. Young-of-the-year feed on crustacean zooplankton and the smaller larvae of aquatic insects. Juveniles and adults feed on a wide variety of aquatic insect larvae and terrestrial insects which fall on the water surface. They occasionally eat other fish and even such items as shrews.

LAKE WHITEFISH

As the name would suggest, most lake whitefish populations are closely associated with lakes throughout their life history. The lake whitefish which are found within the Athabasca River in the AOSERP study area are unusual in that spawning, one of the critical events in their life history, takes place in the river several hundred kilometres from the lake where they spend most of their adult life. The lake whitefish of the Athabasca River are an important resource. They are harvested by domestic fisheries as they move up and down the river on their spawning migration. It is also possible that they make a significant contribution to the commercial whitefish factory of Lake Athabasca.

While some fish may remain in the Athabasca River, it is thought that the majority, particularly the adult fish, overwinter in Lake Athabasca. During the summer, both juvenile and adult fish can be found in the river upstream as far as Fort McMurray and near the mouths of some of its tributaries, but catches are small. In late August, however, large numbers of mature fish begin to migrate through the Peace-Athabasca Delta and enter the Athabasca River enroute to their spawning grounds. (The number of migrant fish have not been reliably estimated, but probably number in tens of thousands.) The movement through the delta peaks in mid-September and by mid-October the main part of the run has reached the vicinity of Fort McMurray. Spawning appears to be restricted to the mainstem of the Athabasca River and is most heavily concentrated just below Mountain Rapids, on the Athabasca River about 25 km upstream of Fort McMurray. There are smaller concentrations at Cascade Rapids (32 km upstream of Fort McMurray) and, possibly, near the mouth of the Clearwater River.

The spawing period appears to be relatively short. In 1977, for example, the first ripe females were captured on 13 October; less than two weeks later lake whitefish had left the spawning areas and moved downstream toward Lake Athabasca. Water temperatures during spawning ranged from 3-6°C. Spawning cannot be directly observed because of the turbid water, but it is likely that, as with lake spawning populations, they are fertilized in midwater and drift downward to be deposited in crevasses along the bottom. Individual females taken from the Athabasca River ranged from 8,000 to 48,000 eggs, averaging about 24,000 eggs.

The eggs incubate through the winter and the young emerge from the stream bottom in the spring. The timing of emergence is not definitely known, but probably coincides with the spring flood in April and May. Although young-of-the-year are sometimes taken in backwaters of the Athabasca River during the summer, it is likely that at emergence, most migrate downstream to the Peace-Athabasca Delta and Lake Athabasca where most remain until they are 3 to 4 years of age.

Whitefish taken in the Athabasca River range in age from 1 to 13 years, but the majority belong to age groups 4 to 8, inclusive. Mature fish in the latter age groups range from about 300 to 450 mm in length. The largest fish, so far reported, was 483 mm and weighed 1,439 g.

Whitefish are primarily bottom feeders and take a wide variety of insect larvae along with clams and fish eggs. During the spawning run on the Athabasca River, a large percentage of the stomachs were empty (37-61 percent). On the spawning grounds, many of the post spawning fish eat eggs of their own species (65 percent in one sample).

MOUNTAIN WHITEFISH

The mountain whitefish has generally been considered to be only a minor species within the AOSERP study area. It makes only a small contribution to domestic and sports fisheries. Recent work, however, suggests that it is more abundant than previously supposed.

It appears that mountain whitefish overwinter in the deeper areas of the Athabasca River and migrate into tributaries, such as the Muskeg and Steepbank rivers, in April and May. During most of the open water season mountain whitefish are rarely taken in the Athabasca River itself. Some fish return downstream during the summer, but it is likely that there is a concerted downstream movement out of the tributaries and into the Athabasca River sometime during the fall. The species is a fall spawner (October in most parts of Alberta), but its spawning grounds and time of spawning in the AOSERP study area are unknown. Though mature fish are occasionally taken, only a few young-of-the-year have been captured.

Too few data are available to provide a good description of the growth of mountain whitefish in the AOSERP study area. The oldest fish captured have been age 7; the largest, just over 350 mm.

Like the lake whitefish, the mountain whitefish is primarily a bottom feeder, taking a variety of aquatic insect larvae, clams, and fish eggs.

YELLOW PERCH

Yellow perch in the AOSERP study area have not been the subject of extensive investigations. However, information has been gathered on this species during programs investigating other economically important fish. Perch can be found throughout the AOSERP study area. They adapt to a variety of habitats from large lakes to sloughs or meandering streams. They prefer warm, clear water and are most often found in small schools in association with aquatic vegetation.

The yellow perch is utilized both by recreational and commercial fisheries. Commercial fishing records indicate that perch was harvested from Georges Lake, along with other species, until the early 1960's. Sports fishermen favour this fish because of its excellent table quality. They are easily caught by bait or by spinning lures.

Perch from Gardiner Lake and other unnamed lakes located in the Birch Mountains are slow growing; they weigh only 140 to 150 g and have a fork length of approximately 200 mm at age 5. Perch have also been captured in the Athabasca, Clearwater, Steepbank, and Muskeg rivers. The majority of yellow perch taken from these rivers are young-of-the-year or juveniles and they are not thought to be part of resident populations. Rather, it is assumed that they are part of populations of headwater lakes which have streams descending through the study area.

Small yellow perch feed mainly on immature aquatic insects, such as fly larvae and pupae, stoneflies, and water bugs. They, in turn, are found in the diet of the larger predators such as pike and walleye and are, therefore, part of the food chain of these economically important species.

LONGNOSE SUCKER

The longnose sucker is one of two suckers common in the AOSERP study area and is one of the most abundant fish species in the region. It is taken, largely inadvertently, in domestic fisheries and is either used as dog food or thrown away. Thus, its greatest importance to anglers and commercial fishermen is as a forage fish, providing food for predaceous species, such as northern pike and walleye.

Tagging studies indicate that the longnose suckers in the AOSERP study area belong to Lake Athabasca populations passing through the Peace-Athabasca Delta apparently on a spawning migration to the Athabasca River where they congregate at the mouths of tributary streams, then moving upstream to spawn in late April and May. There is no evidence of spawning in the Athabasca River itself. Spawning is completed by late May or early June. Females deposit large numbers of eggs; in one sample, fecundity ranged from 19,000 to 44,000 eggs per female with an average of 29,000. The period of egg incubation is relatively short and young-of-the-year begin to appear by mid-June.

After spawning, some mature fish may remain in tributaries through the summer, but most move downstream into the Athabasca River, some continuing as far as Lake Athabasca. The mature fish remaining in the tributaries leave just prior to freeze-up.

Large numbers of young-of-the-year remain in tributaries throughout the summer. Most, however, eventually move downstream, apparently into Lake Athabasca.

Longnose suckers in the AOSERP study area are at least 5 years old before they become mature. They may live nearly 20 years and attain a length exceeding 250 mm and a weight of 1,800 g. Few, however, exceed 13 years and most (78 percent) are age 6-11, inclusive, with the largest percentage (89 percent) in the 350 to 469 mm range.

The stomach contents of suckers are difficult to identify, in part because of the work of the largest pharyngeal teeth which are found in their throat and which grind much of the food into a paste before it enters the stomach. No definite food analysis is available for longnose suckers from the AOSERP study area, but it has been determined that the species generally subsists almost entirely on invertebrates taken from the bottom.

WHITE SUCKER

Although the white sucker is probably less common than the longnose sucker, it is still one of the most abundant fishes in the AOSERP study area. Like the longnose sucker, it is thought to be part of the Lake Athabasca population.

In the spring of the year, mature white suckers which have overwintered in Lake Athabasca move through the Delta and enter the Athabasca River where they move upstream to tributary spawning streams. These include the Steepbank, Muskeg, and MacKay rivers. In late April and early May, they are abundant in the Athabasca River in the vicinity of tributaries. Ripe males may be taken as early as 24 April and ripe females as early as 2 May. Spawning is completed by mid-May. Mature females contain large numbers of eggs; the fecundity of one sample of 11 females ranged from 31,560 to 85,460 eggs with an average of 54,800 eggs.

After spawning, most white suckers leave the spawning streams and return downstream, probably to Lake Athabasca. Young-of-the-year have been sampled from the Athabasca River and its tributaries until autumn.

Young-of-the-year emerge from the substrate within a few weeks of spawning. Some remain in the spawning tributaries through the summer, but others drift downstream from the spawning tributaries, then down the Athabasca River. By mid-August most have left the Athabasca River.

Young are approximately 10 mm at hatching and grow to an average 47 mm by mid-August when growth ceases. Subsequent growth is greater than that of longnose suckers. White suckers taken at age 5 in the Muskeg River average 315 mm compared with 208 mm for longnose suckers. At age 10, the comparative values are 486 mm and 399 mm. The lengths of fish aged 10 or more frequently exceed 500 mm. A maximum length of over 585 mm has been recorded for a fish 3.2 kg in weight.

Like the longnose sucker, the white suckers are not an important component of sport or commercial fisheries, except as a forage species used as food by more valuable fishes, such as the pike, walleye, and lake trout.

TROUT

Lake trout are found only in the larger and deeper lakes in the AOSERP study area. Namur Lake and Lake Athabasca are two of the most important trout lakes in the region; both have excellent populations. Namur Lake has been established as one of Alberta's trophy lakes because of its lake trout population and anglers have been flying into this lake for many years. The trout can be easily caught in shallow waters in the spring or autumn. The most abundant age classes of lake trout in Namur Lake were the 7, 8, and 9 year olds. The oldest fish (12 to 13 years) were over 800 mm long and weighed 8.5 to 9.5 kg. The world record lake trout was caught in Lake Athabasca in 1961. This fish weighed 46.266 kg.

Dolly Varden are commonly found in the headwaters of the Athabasca River; however, they do not occur in large numbers in the AOSERP study area. Dolly Varden have been identified from the Steepbank and the Muskeg rivers. Dolly Varden captured during these studies range in size from 177 to 388 mm fork length. One specimen, has also been identifed from the Rivière des Rochers about 50 km north of Fort Chipewyan.

Rainbow trout are believed to be native to the headwaters of the Athabasca River; however, only one large specimen (578 mm) has been reported captured in the AOSERP study area, in the Athabasca River above Fort McMurray.

MINNOWS

A number of species of minnows are found in the AOSERP study area. Studies on the Athabasca River and some of its tributary streams have indicated that flathead chub, lake chub, emerald shiner, spottail shiner, longnose dace, and pearl dace are the most commonly found minnows. Fathead minnows, northern redbelly dace, and finescale dace are all present, but in much lower numbers. Brassy minnows were reported from the area for the first time in 1974. Further collections in 1976 confirmed the presence of this species and documented a considerable range extension. Previous records for this species are from the Milk River drainage in southeast Alberta and from northwest Alberta. This find, therefore, extends the known range in Alberta northward by 510 km.

Minnows are an important component of the aquatic food chain of the study area. They are classed as forage fish since they are a common prey of large predators. Game fish such as walleye and pike feed on minnows. For example, studies of the Athabasca River during the summer of 1976 showed that flathead chub made up 23.1 percent of the diet of northern pike.

Most of the minnows found in the study region are small. They range in size from 10 to 100 mm and few exceed 130 mm in length. The one exception is the flathead chub. Specimens with a fork length over 320 mm have been caught in the Athabasca River. These larger fish were 8 year old females.

Sexual maturity occurred at age 2 for spottail shiners, emerald shiners, pearl dace, and longnose dace, while flathead chub and lake chub matured at 3-4 years of age. Immature individuals of all species were most abundant in the Athabasca Delta region, while the majority of mature individuals were found in the Athabasca River and its tributaries.

Minnows were found to feed mainly on immature aquatic insects, including mayflies, water bugs, and true bugs.

OTHER SPECIES

Several other species of fish sampled from the AOSERP study area have not yet been the subject of extensive study. These include burbot, brook and ninespine sticklebacks, trout-perch, and slimy sculpin.

The burbot is the only entirely freshwater member of the cod family and is found throughout the Athabasca River and in the Delta. Fish as long as 750 mm have been taken and larger specimens probably occur. Burbot spawn under the ice in late winter and early spring. Young-of-the-year have been taken from the Athabasca River in the vicinity of Mildred Lake, suggesting that the species spawn in the area somewhere upstream. Once they reach a size sufficient to take other fish, burbot are almost entirely predaceous in their food habits. They tend to feed nocturnally. Burbot are edible, but are not at present sought after by the sport or commercial fisheries in the AOSERP study area.

Both brook and ninespine sticklebacks are found in the AOSERP study area. The former appears to be the most abundant, especially in boggy streams in the headwaters of tributaries to the Athabasca River. It is taken only rarely in the Athabasca River itself and it appears to be especially tolerant of high temperatures and low oxygen conditions. The ninespine stickleback is rare in both the Athabasca River and its tributaries. Both species are nest-building, spring and early summer spawners. Neither species is large — brook stickleback do not usually exceed 65 mm and ninespine, 90 mm. Sticklebacks may be important as forage fish for other species.

The trout-perch is one of the most common smaller species in the AOSERP study area, including the Athabasca River and some of its larger tributaries and in the Delta. This species is a spring and early summer spawner with an extended spawning period. Ripe fish have been taken in April, May, and early June. Spawning occurs in tributaries such as the Steepbank and Ells rivers and may also occur in the Athabasca River itself. Young-of-the-year first appear in early June. The trout-perch is a short-lived species and few, if any, of those found in the Athabasca River exceed 3 years of age. The largest fish are only about 90 mm. The trout-perch feeds almost exclusively on insect larvae (midge larvae are most common) and small crustaceans. The trout-perch is a forage species and is important as a food for economically valuable fish species, such as pike, walleye, and lake trout.

Two sculpins, the slimy and spoonhead sculpin, have been sampled from the study area. The former is only occasionally taken in the Athabasca River, but is widely distributed in tributaries throughout the Athabasca River system. The spoonhead sculpin seems to be largely confined to the Athabasca River and the Peace-Athabasca Delta, but even there it is not common. Both species appear to be spring spawners in Alberta. Elsewhere, the spoonhead sculpin may spawn in late summer and early fall. Neither species is large, with maximum lengths of 120 mm for the slimy sculpin and 107 mm for the spoonhead sculpin. Sculpins have no direct economic significance, but probably provide food for the larger and more valuable species.

Water System Status

From the foregoing it is evident that Water System research has concentrated on defining the baseline physical, chemical, and biological aquatic regime of the area. A reasonably adequate definition has largely been accomplished through the regional hydrometric network, water quality monitoring, and extensive biological sampling projects. However, a more useful interpretation of baseline states should involve not only a description but also an evaluation of the naturally occurring biophysical processes. With such an understanding, focus on biophysical response to probable oil sands development would be attainable, which is an advancement beyond just detecting changes in the environment after they occur.

Thus, it is anticipated that a number of projects of a more experimental nature will be carried out to test the environmental responses to anticipated impacts. Indeed, a number of studies along these lines have already been carried out, including some toxicological investigations (73, 74, 110, 120). But even though valuable information has been developed by these investigations, they are regarded as preliminary and further developments will await an appropriate framework for the development of research on possible toxicological impacts of oil sands operations. Some literature searches on the effects of the types of impacts expected from oil sands developments have also been carried out (77, 78, 79, 80) and some characterization of oil sands processing effluents has been completed (81).

Baseline studies to date have not flagged any areas of critical concern. For example, water quality parameters have not been detected significantly above background levels. It has, therefore, been concluded that present oil sands developments have not acutely affected the aquatic ecosystem. However, more subtle effects of a long term nature cannot yet be ruled out and so further advances in monitoring capabilities are being sought. Research into utilizing the indigenous aquatic biota for monitoring impacts is planned. Also, an evaluation of the applicability of the classical chemical indicators to oil sands impacts will be sought.

Human System

Many benefits will arise from development of the Athabasca Oil Sands, and population growth and industrial activities will alter both the physical and social environment. Such changes present the possibility of unknown effects on the quality of life in the region. Thus, AOSERP Human System research is designed to provide information which can be used to assess the consequences of any significant alterations in social conditions arising from oil sands development. The fundamental questions which underlie the Human System research program are: the identification of what is taking place, why it is taking place, whether the consequences are desirable or undesirable, and what modifications can reasonably be expected to be accomplished within the scope of public policy. Research required to address these questions includes the establishment of baseline states, to identify and quantify where possible social conditions; the interpretation and projection of patterns of change; and the identification of specific methods to encourage beneficial changes and consequences and to ameliorate undesirable changes and consequences. Accordingly, Human System research objectives are defined as follows (2):

1. To review and assess the available information pertaining to the Human System of the AOSERP study area;
2. To undertake studies which will establish the baseline states for social conditions of the study area that could be altered by oil sands development;
3. To identify and explain various direct and indirect impacts of the development on people in the region, including the relationship between changes in socio-economic conditions and social and personal adjustment;
4. To critically assess the relationship between people and the changing urban and natural environments of the region, including the use of various resources by the population and effects of changes in the environment upon people;
5. To derive a conceptual model which can be used to forecast the effects of oil sands development on the Human Systems and their capacity to absorb these effects without permanent or long lasting debilitation; and
6. To undertake studies which will identify alternative measures to rectify or prevent any negative effects of the development activities on people of the region.

Target Groups and Communities

Although some social groups in the region may be more affected than others, the principle of social equity in public policy development requires that the study of impacts (actual or potential, direct or indirect) be carried out with reference to all the people in the study area. Thus, the research includes all social groups, such as indigenous native and non-native, in-migrant native and non-native, and non-permanent native and non-native either residing or working in the region.

Most of these people live in four established communities in the AOSERP study area: (1) Fort McMurray which, since 1961, has rapidly become the population centre of industrial activity; (2) Anzac which has changed little, but where nearby development is imminent; (3) Fort MacKay, which is closest to the Syncrude plant; and (4) Fort Chipewyan, which, because of its geographical position, has been relatively isolated from the effects of oil sands development.

Research to Date

During the first two years, the main task of Human System research was to determine appropriate methods for the study of social impacts associated with oil sands development. The research activities included an overall assessment of the state of knowledge on social change in resource communities, an assessment of the quality of social data and information available for the study area, and an exploratory assessment of the current social conditions and processes in the region.

In March 1977, as a result of these preliminary studies, the research program was consolidated into three core activities: (1) defining baseline states for demographic patterns and social conditions in the study area in an historical and regional context; (2) identifying and measuring the impacts of oil sands development on the human environment over time; and (3) studying the relationships between people in the oil sands region and the changing urban and natural environment. Since the Athabasca Oil Sands development has resulted in rapid industrialization and urbanization of a formerly isolated region, Human System research has focussed on the historical and contemporary changes in the socio-economic structure of the region, and on the residents' perceptions of and the responses to these changes.

Historical Background

Activity related to the exploitation of natural resources is not new in the Athabasca Oil Sands region. Since the 18th century, the utilization of the resource base has included fur, transportation, timber, commercial fishing, and finally, oil (137).

The historic native people were of Chipewyan and Woodland Cree descent, the former being migratory, with their social organization based on the local band, and the latter hunting in small groups (Figure 63). Prior to contact with the white fur traders and missionaries, native Indian tribes maintained an economy based on hunting and fishing within a given region.

The fur trade reached the Athabasca country during the last two decades of the 18th century. The Frobisher brothers, with the aid of Louis Primeau, were instrumental in making the first approach to the Athabasca River. Peter Pond's initial Athabasca enterprise yielded him a small fortune in furs. Promises of riches such as this enticed other traders into the fur bearing region, where Fort Chipewyan began to occupy a strategic position.

The second wave of European civilization in the Athabasca Oil Sands region came with religious missionaries. Missionaries had three main functions: they assisted indigenous people in their material wants and spiritual needs, they became educators of and spokesmen for the Metis and Indians, and they tended to assist the extension of white authority over the land. The expansion of missionary activity also led to an increase in the need for supplies from outside the region. The rivers were used as transport routes for these supplies; York boats and canoes were the main modes of transport (Figure 64).

During the last three decades of the 19th century a considerable part of the lower Athabasca River region was surveyed and mapped. Government controls also expanded during this time. In 1875, the North West Territories Act established a form of government for western Canada. In 1882, four subdistricts were created by orders-in-council; the district of Athabasca was north of the 55th parallel and at that time, unorganized, untaxed, and unrepresented (137).

Figure 63. Location of tribes (map of land ceded in Treaty 8) (137).

Figure 64. York boat (photo: Julian Mills Collection, University of Alberta Archives).

In the late 19th Century, the area began to be policed by the North West Mounted Police and with improvements in transportation, commercial fishing advanced into the region. In 1883, the Hudson's Bay Company cut a road from Edmonton to Athabasca Landing, and launched the "S.S. Grahame" at Fort Chipewyan. The latter development sealed the fate of the old canoe and York boat. Subsequently, in 1921, the Alberta and Great Waterways Railway (later Northern Alberta Railway) was completed to the Clearwater River. The isolated north was connected to the expanding frontier of southern Canada.

Between the years 1894 and 1897, wells were drilled in the Athabasca Oil Sands area by Geological Survey of Canada. The first drilling close to Fort McMurray was in 1907. These exploratory drilling programs led to speculations by outsiders, and in 1913 the federal government decided to survey the oil sands. The provincial government also took an interest, as a result of which the Research Council of Alberta was formed to rationalize the problems of mineral development (137).

In 1930, an experimental hot-water extraction plant was established on the Clearwater River near Waterways. Between 1930 and 1940, the Abasands Oil Sands plant also became operational. The Abasands plant burned down in 1945; subsequently, the provincial government took over the R.C. Fitzsimmon's plant at Bitumount and established an experimental separation process. By 1951 this plant had proved the viability of separating bitumen from the sand.

Following the First Oil Sands Conference in 1951, the provincial government formulated regulations which enabled the major oil companies to acquire leases in the oil sands region. The oil sands were not commercially exploited until 1960, when the decision was made to build the Great Canadian Oil Sands (GCOS) plant. GCOS went on stream in 1967, and by 1971 Syncrude had begun planning and developing a plant. The first deliveries of synthetic crude via pipeline from the Syncrude plant arrived in Edmonton on 1 August 1978.

Socio-Economic Changes

The most significant changes associated with oil sands development took place in the following areas: demographic and economic structure, the employment opportunities and the composition of the labour force, the distribution of income, the supply of housing, the supply of services and of amenities made available to the existing and in-coming population. Since the AOSERP study area boundaries do not coincide with those of Statistic Canada Census enumeration districts, statistics on some of these changes must be either estimated or obtained by means of field research, most of which has yet to be completed.

Demographic Structure

In 1961, the population of the oil sands region was approximately 2,600. Approximately one-half of the people resided in Fort McMurray; the remaining population inhabited the communities of Fort Chipewyan, Fort MacKay, and Anzac. The population living on the Indian Reserves, on traplines, and at industrial sites was estimated to be 400 (138).

Following the decisions to allow GCOS in 1963 and Syncrude in 1972 to develop extraction plants, the population of the region has grown rapidly, and in June 1978 was estimated to be nearly 27,000. Most of this growth has been concentrated in Fort McMurray, which now comprises 94 percent of the total population. Growth outside of Fort McMurray has been modest, and the population is estimated to amount to approximately 1,800.

The population changes in the AOSERP study area between 1961 and 1978 are summarized in Table 19. These figures do not include the personnel engaged in the construction of oil sands plants who resided in camps at project sites, amounting to over 7,000 workers at the peak of construction of the Syncrude plant. The presence and fluctuating size of this population may have been quite significant to the socio-economic developments in the region.

Table 19. Regional populations in the AOSERP study area (138).

	1961	1966	1971	1976	1978
Fort McMurray	1,186	2,614	6,847	15,321	24,580
Unincorporated Communities					
Anzac	154	224	114	138	n/a
Fort Chipewyan	717	1,026	1,122	1,179	n/a
Fort MacKay	187	230	200	166	n/a
	1,058[a]	1,480[a]	1,436[a]	1,483[a]	1,500[a]
Remainder of area	400[a]	200[a]	300[a]	300[a]	300[a]
Total	2,644[a]	4,294[a]	8,583[a]	17,104[a]	26,380[a]

[a]Estimated

Existing data indicated that in 1971, Fort McMurray was a young and dynamic community. For instance, between 1961 and 1971, there was a marked increase in the population between 20 and 34 years of age; while between 1966 and 1971, young families began to migrate more actively to the community. In 1971, the families where the head was under 25 years of age amounted to 12.5 percent compared to 5.7 percent in 1961. Similarly, the proportion of families where the head was between 25 and 34 years of age increased from 23.0 percent in 1961 to 41.9 percent in 1971 (Figure 65).

The families living in Fort McMurray in 1971 had, on the average, fewer children than their 1961 counterparts (2.3 compared to 2.6 children; Table 20). However, there was an increase in the number of families with only two children, which is also indicative of younger family units in 1971, compared to 10 years earlier.

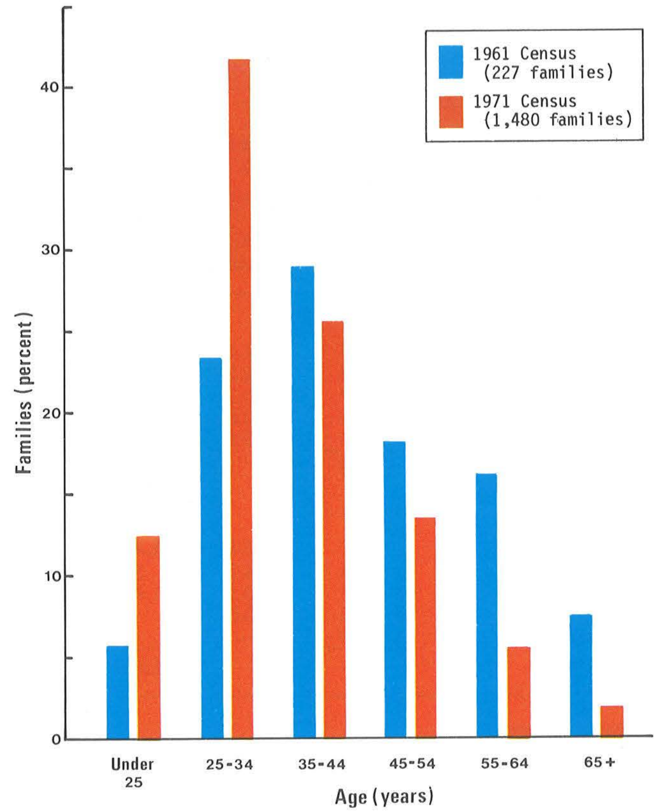


Figure 65. Percent of families by age of the head of the family, Fort McMurray, 1961 and 1967 (12).

The marital status of men and women in Fort McMurray for 1961 and 1971 is presented in Table 21. In 1961, nearly 62 percent of the male population and 57 percent of the female population were single. The majority of single persons in both cases was under the age of 14. This situation prevailed in 1971, though overall single population decreased about 4 percent for both men and women. The

Table 20. Families by number of unmarried children 0-24 years of age, Fort McMurray, 1961 and 1971 (12).

Number of unmarried children	FAMILIES			
	1961 Census		1971 Census	
	N	Percent	N	Percent
No children	46	7.7	275	6.7
1	46	7.7	285	8.4
2	33	5.5	420	12.4
3	30	5.0	260	7.7
4	29	4.8	165	4.9
5 +	43	7.2	75	2.2
Total Families	227		1,480	
Total number of children	598		3,375	

proportion of married men increased about 6 percent by 1971, the increase being approximately 4 percent for women. Although over the decade, there was a small increase in the number of divorced men in Fort McMurray, there was a greater increase in the number of divorced women (12).

Table 21. Population by marital status for males and females, Fort McMurray, 1961 and 1971 (13).

Marital Status by Sex	1961 Census N	1961 Census Percent	1971 Census N	1971 Census Percent
Males				
Single, under 15	274	42.5	1,485	41.8
Single, over 15	124	19.2	550	16.0
Married[a]	227	35.2	1,475	41.5
Widowed	16	2.5	15	0.4
Divorced	4	0.6	25	0.7
Totals	645		3,550[b]	
Females				
Single, under 15	232	42.8	1,460	44.4
Single, over 15	76	14.0	305	9.3
Married[a]	217	40.1	1,455	44.3
Widowed	16	3.0	45	1.4
Divorced	0	—	20	0.6
Totals	541		3,285[b]	

[a] Includes separated.

[b] The discrepancy between these totals and Statistics Canada data cannot be rectified.

Economic Structure

The main component of the economy of the region at present is oil sands extraction. Agriculture, forestry, fishing, trapping, and tourism represent a minimal percentage of economic activity. Concurrent with oil sands development, an increase in the complexity of the economy of the region has occurred, with the introduction of manufacturing, construction, and service industries. A review of changes in the economy of the region since 1961 follows.

AGRICULTURE

The agriculture sector in the AOSERP study area is insignificant. Current activity is at a low level and embraces some commerical egg production, privately cultivated vegetable gardens, and some recreational agricultural pursuits such as light horse clubs. No significant changes in the sector have been evident since 1961, and agriculture related regional employment probably does not exceed 10 to 20 persons at the present time (138).

FORESTRY

Economic activity in the forestry sector appears to have peaked in the late 1960's and early 1970's, and to have subsided significantly since then. Current production is less than 1 percent of the total Alberta production. Expansion of the timber industry in the region depends, among other factors, on the local demand for forest products. A viable timber industry, if feasible, would serve to diversify the economy and provide job opportunities for some residents.

In the northern part of the region, a sawmill was operated at Sweetgrass during the 1960's and until 1973 when it was relocated to Embarras. That operation was discontinued in 1976, and no commercial logging activities have occurred since in this area.

In the southern part of the region, a sawmill was operated by Primrose Lumber Co. at Fort McMurray until 1970, when it was purchased by Swanson Lumber Co. and expanded with a planer mill and kilns. The mill burned down in 1974, but milling operations continued for a short period through use of a contract mill. The operation has not reopened and timbering volume has been significantly curtailed in the area. Also, a sawmill belonging to Northland Forest Products has been operated in Fort McMurray for a few years, but this is a relatively small operation.

Employment in the industry appears to have peaked at about 100-125 persons in the early 1970's and to have declined to a current level of 10-20 persons in 1978 (138).

FISHING

Commercial fishing activities occurring in the region are presently concentrated on Lake Athabasca. During the mid-1960's some commercial fishing was also carried out at Namur and Gregoire Lakes, in the southern half of the region, and more importantly at Richardson Lake, which is located on the southern extremity of the Peace-Athabasca Delta.

Indices of active fishing in the region, such as volume and value of fish catches, employment, and number of fishing licenses issued, generally illustrate the annual fluctuations in the industry and also point to an apparent decline in its importance since the mid- to late-1960's. The organization of the fishing sector into cooperatives has undergone periodic difficulties and these disruptions have undoubtedly affected industry output and stability (138).

In general, the fishing industry appears to have declined in both actual and relative terms over the past 15 years, and is now relatively insignificant to the region's economic base. In the local Fort Chipewyan area, however, fishing is still a source of employment and supplementary income to a number of people.

TRAPPING

In 1975, there were 345 registered traplines in the northeast region of Alberta. Trapline registrations are shown in Table 22 (see also Figure 37 in the Land System section).

Information regarding activity levels in the trapping industry is limited because of the informal, unstructured, and part-time nature of trapping. Involvement in the industry is considered by many participants to be more a "way of life" than a source of employment and income. Studies of trapping within the AOSERP study area and other data that are available indicate that trapping activity has shown a general decline over the past several years (138).

Table 22. Registered traplines in the AOSERP study area, 1975 (14).

Place of Residence	No. of Traplines	No. of Trappers
Fort McMurray	58	67
Fort MacKay	32	40
Fort Chipewyan	53	46
Outside the area	59	—
Vacant	43	—

TOURISM

Private enterprise has provided limited recreational or tourist facilities and services in the region, partly because of initially relatively small population and the lack of extensive roads. While tourism is not expected to play a major role in the economic base of the region, it can contribute to economic diversification.

OIL SANDS EXTRACTION

Since 1961, the major source of economic stimulus and growth in the region has been oil sands development. Growth in all economic sectors has been related to the direct or indirect effects of oil sands development activities. Significant economic activity was associated with the construction of the GCOS plant and of the Syncrude plant. Employment in the operation of both these plants has grown from 0 in 1961 to 4,000 in 1978 (138).

MANUFACTURING INDUSTRIES

The manufacturing industry in the region is small and is located entirely within Fort McMurray. The four manufacturing establishments reported to be in the town in 1977 exclusively served local requirements. They were a cement ready-mix plant, a bakery, and two printing or publishing outlets. Total manufacturing employment is estimated to be about 50. Available data suggest that employment in this sector has increased over time, but has stabilized over the past three years. Statistical sources indicate, however, that employment may have reached a peak of 75-90 persons in the 1973-1975 period before stabilizing at the current level (138).

CONSTRUCTION INDUSTRY

The development of the two oil sands plants in the AOSERP region since 1961 has generated a considerable level of construction activity — both in terms of directly related plant construction and in terms of providing the necessary municipal and regional infrastructure.

Available employment figures for the industry reflect its growth during the past 7 years. In 1971, the construction industry employed less than 300 persons in Fort McMurray, by 1977 the number had increased to more than 3,000, and the latest 1978 figures show a decline to less than 1,900. Provincially, the number of persons employed in the construction industry amounts to about 8 percent; in Fort McMurray, the proportion has ranged since 1976 from a low of 12.6 percent to a high of 35.4 percent. The figures cited do not include the construction labour force domiciled at the actual plant site. The GCOS camp force peaked at more than 2,000 in the 1964-1967 period and the Syncrude camp force reached as many as 7,000 men in the period from 1975 to 1978.

The number of businesses operating in the construction field has also shown dramatic growth. Preliminary estimates indicate that the number of firms operating in Fort McMurray has grown from approximately 5 in 1961-1963, to 50 in 1974, and to 350 in 1978. Although one-third or more of the latter figure can be probably attributed to non-local businesses working locally on specific projects, the numbers still confirm the growth and importance of this particular sector of the local economic base (138).

SERVICE INDUSTRIES

The service sector has also grown substantially in support of the massive expansion in basic resource industries and employment in the region. However, a preliminary review of available data indicates that employment in the service sector generally has lagged behind that of other industries since 1971. This is partly due to the extraordinary expansion of the construction industry which has to some extent distorted the local economic structure. That industry is now reducing to more normal levels. Particular components of the service sector have lagged more than others in terms of employment: retail trade, health and welfare, accommodation and food services, transportation, communications and utilities. On the other hand, public administration (particularly local municipal administration), finance, insurance and real estate, and, more recently, business and personal service industries appear to be keeping pace with local community growth (138).

Retail trade activity in Fort McMurray has undergone significant changes since the beginning of the study period. The town had approximately 10 retail outlets in 1973; the number increased to about 35 in 1971, doubled to 70 outlets by 1974-1975, and in late 1978 is estimated to exceed 170. Retail development appears to be continuing at an unabated rate: occupied space in 1978 is almost double that of 1976 and, including space currently under construction, the retail area available (but not necessarily fully occupied) in 1979 will be triple the 1976 level. Detailed retail trade statistics for the Town are only available for the period 1971 to 1976, but some interesting points emerge from a comparative review of local statistics with provincial figures (Table 23).

Table 23. Retail trade statistics for Fort McMurray relative to the provincial average (138).

	1971	1973	1974	1975	1976
Revenue per outlet (%)	87	74	81	130	155
Employees per 1,000 population (%)	67	63	67	63	89
Outlets per 1,000 population (%)	73	88	107	67	80
Retail sales per capita (%)	63	65	86	87	125

Provincial Average = 100

1. Except in 1974, when the number of outlets jumped sharply in Fort McMurray (perhaps in anticipation of increased Syncrude activity), the number of outlets and employment per 1,000 population in the Town has lagged behind provincial averages. In the last year for which statistics are available, 1976, it appears that the gap with average provincial figures began to close.
2. Increasing local retail demand, which began to accelerate in 1974, was met initially through the increased number of outlets and, thereafter, primarily through increased sales turnover in available outlets. In 1976, sales turnover per outlet exceeded the provincial average by more than 50 percent.
3. Retail sales per capita jumped sharply in 1976, perhaps due to the large construction camp force located near Fort McMurray and which undoubtedly generated considerable retail demand in town.
4. The disproportionate increase in retail expenditures which occurred in 1976 was primarily attributable to food and automotive expenditures and, as previously indicated, those components were probably related to construction camp employment. In 1976, Fort McMurray retail food sales and automotive-related sales were 120 percent and 42 percent, respectively, higher than provincial averages.
5. Along with food and automotive sales, business equipment and supplies activity also increased substantially during the 1971-1976 period. Retail categories which appear to have lagged include general merchandise, clothing, and home furnishings (137).

Service trades which include such categories as personal services, accommodation and food services, and amusement and recreation, have shown little relative improvement in local availability or importance of service facilities between 1971 and 1976, although the absolute number of outlets increased substantially (from approximately 12 to 36 outlets during the 5 years). The presentation in Table 24 compares various indices of local service trade activity with provincial averages. However, evidence over the past 2 years suggests that the service trade sector is expanding very quickly and that the relative availability and range of services may now be improving. Between 1977 and 1978 the percentage of local labour force engaged in business and personal services (excluding accommodation and food services) increased to almost 6 percent from slightly more than 4 percent. Both office and commercial-service space appear to have doubled annually in each of the past 2 years (138).

Table 24. Service trade statistics for Fort McMurray relative to the provincial average (138).

	1971	1973	1974	1975	1976
Revenue per outlet (%)	109	105	95	109	88
Employees per 1,000 population (%)	74	62	56	58	50
Outlets per 1,000 population (%)	63	79	74	59	77
Receipts per capita (%)	71	84	69	68	68

Provincial Average = 100

Employment and The Labour Force

DISTRIBUTION OF EMPLOYMENT

Most of the labour force in the Athabasca Oil Sands region works either in the Athabasca Oil Sands industry or in jobs which are dependent on the oil industry. Table 25 illustrates the distribution of experienced labour force in the study area in 1961 and 1971. Since that time the economy of Fort McMurray has been dominated by activities directly and indirectly associated with the construction and operation of oil extraction plants. According to the 1977 Fort McMurray municipal census, about 22 percent of the labour force was engaged in mining; and an additional 35 percent was engaged in construction, much of which would have involved the Syncrude plant. The Census also found that

Table 25. Experienced labour force by industry, 1961 and 1971 (139).

Industry	1961	1971
Agriculture	—	20
Forestry	18	15
Fishing/Trapping	6	—
Mines/Quarries/Oil Wells	9	785
Manufacturing	18	50
Construction	20	280
Trans.Communic.Util.	120	255
Trade	34	220
Finance/Real Estate/Insur.	2	60
Commerc. Bus. Pers. Services	68	525
Public Defence	29	105
Undefined	6	315
Total	330	2,630

almost 40 percent of the labour force worked outside Fort McMurray. It may be assumed that almost all of these probably worked at the two oil sands plants.

The previous discussion indicates that the economic growth associated with oil sands development has been concentrated heavily in the Fort McMurray area. This is confirmed by available labour force statistics which suggest that the people outside Fort McMurray have not participated to a perceptible degree in the increased economic activity. Although statistics for sparsely populated rural areas are not particularly reliable, it does not appear that, excluding construction camps, employment materially increased between 1971 and 1976 in the rural area outside Fort McMurray. During that period, employment in Fort McMurray increased to two and one-half times the 1971 level.

Table 26. Labour force participation in 1971 and 1976 (138).

	Rural Area[a]		Fort McMurray		Alberta	
	I.D.143	EA 302, 305,306				
	1971	**1976**	**1971**	**1976**	**1971**	**1976**
Labour force participation (labour force as percent of population aged 15+)	43.3	56.0	67.7	69.3	59.5	66.5
Male	58.4	71.1	91.8	88.5	78.9	82.6
Female	22.6	35.6	40.0	46.9	39.4	50.2
Employed labour force as percent of population aged 15+	41.5	41.9	65.6	65.3	56.9	63.9

[a] Improvement District 143 and Enumeration Areas 302, 305, 306 do not exactly coincide with each other or with the AOSERP study area boundaries.

Comparative labour force participation data derived from 1971 and 1976 census statistics are shown in Table 26. The table indicates that, in terms of labour force participation and proportion of relevant population employed, Fort McMurray has remained above the provincial average during the rapid growth period between 1971 and 1976. The margin has narrowed because female participation lagged to some extent and male participation declined from the very high rates experienced in 1971. At the first glance, it would appear that labour force activity in the remainder of the region improved during the period, but this increase in the labour force participation is probably due to changes in survey interpretations and data collection procedures. In fact, the percentage of the potential labour force employed did not change significantly over the period and remained at less than two-thirds the Fort McMurray levels (138).

COMPOSITION OF THE LABOUR FORCE

Differences in the marital status of the labour force between 1961 and 1971 are presented in Table 27. Although there were more families in Fort McMurray in 1971 than in 1961, there was only a very small increase in the proportion of married male employees. There was, however, a radical change in the proportion of married female employees in 1971. The reason for these patterns cannot be determined on the basis of existing data, but several important factors can be identified. In the first place, more than 92 percent of all males 15 years of age and above were employed in 1971. This represents an improved employment situation of about 20 percent over 1961, when 72 percent of males over 15 were employed. Similarly, in 1961, 20 percent of all females 15 years of age and older, were employed in Fort McMurray. In 1971, nearly 40 percent were employed. This indicates that the employment situation had improved during that decade.

The second factor is of equal importance. In 1961, less than 11 percent of the married women were employed (30 of 217). By 1971, nearly 37 percent of the married women were employed (520 of 1,455). This is a significant change that would not be predicted based on the widely stated assumption that women cannot find employment in resource towns. It is yet to be determined whether the proportion of employed married women has maintained this pattern over the more recent period in Fort McMurray (13).

Table 27. Labour force by marital status for males and females, Fort McMurray, 1961 and 1971 (13).

Marital Status	1961 Census		1971 Census	
by Sex	N	Percent	N	Percent
Males				
Single	68	25.6	465	24.2
Married[a]	188	70.8	1410	73.2
Widowed / Divorced	10	3.8	40	2.1
Total	266		1925	(72.8)
Females				
Single	31	49.2	170	23.6
Married[a]	30	47.6	520	72.2
Widowed / Divorced	2	3.2	15	2.1
Total	63		720	

[a] Includes separated.

Income

Little information is available on income distribution, but Table 28 provides an indication of the distribution of family income in Fort McMurray in 1975, compared to the family incomes in Canada, in Alberta, and in the oil sands industry.

Available income statistics suggest that the area outside of Fort McMurray has lagged economically. Over the period 1967-1976 the average income of taxable returns for Fort McMurray increased from 113 percent to almost 125 percent of the provincial average. Meanwhile in selected unincorporated communities in the region, the average incomes decreased from 87 percent to 79 percent of the provincial average. The latter figures probably understate the real decline in relative incomes of the rural area because the information includes figures for Waterways which is now part of Fort McMurray. Furthermore, these figures relate to taxable returns; the proportion of returns that were non-taxable stood at 46 percent for the smaller, rural communities compared to proportions of 17 percent for Fort McMurray and 28 percent for the province (138).

Table 28. Distribution of family income, 1973 (140).

Family Income ($)	Canada	Alberta	Fort McMurray	Oil Sands Industry
0 - 2,999	10.5%	10.1%	5.0%	0.0%
3,000 - 5,999	16.9	14.1	8.5	0.0
6,000 - 9,999	30.9	23.6	22.5	25.0
10,000 and over	41.7	52.2	64.0	75.0

Housing

The magnitude of changes in the population, employment, and income in the Fort McMurray area has necessitated an increase in the housing supply. Table 29 presents data on dwellings by type and tenure for 1961 and 1971. As can be seen, most dwellings were owned in 1961 (70 percent). By 1971, there was an apparent decline in house ownership (to 55 percent). Similarly, while more than 90 percent of all dwellings were single detached units in 1961, the housing supply turned distinctly to temporary housing in the form of apartments (13 percent) and mobile homes (18 percent). Changes in ownership can be accounted for in the increase in rental units (13).

Table 29. Dwelling by tenure and type, Fort McMurray, 1961 and 1971 (13).

Tenure and Type	1961 Census N	1961 Census Percent	1971 Census N	1971 Census Percent
Tenure				
Owned	212	70.4	900	54.9
Rented	89	29.6	740	45.1
Total	1,301[a]		1,640[a]	
Type				
Single detached	276	90.2	1,030	62.0
Single attached	40	9.8	120	7.2
Apartment	—	—	215	13.0
Mobile home	—	—	295	17.8
Total	316[a]		1,660[a]	

[a] Unable to determine source of discrepancy.

A flourishing construction industry and mass distribution of mobile homes throughout and on the periphery of the town is evident. Housing permits for 1,000 new homes were issued in each of 1975 and 1976. Table 30 shows the changes in housing types between 1961 and 1977. The increase in dwelling units has been commensurate with the increase in population. The total number of dwelling units has increased from 610 (1966) to 5,684 (1977). Single detached homes now constitute only about a third of the total, just slightly more than the proportion of mobile homes. The proportion of apartments has doubled to about 22 percent since 1966, and much of the new construction is of this type. Figure 66 illustrates the changes in housing types over the last 50 years.

Like many resource communities, Fort McMurray is characterized by high housing costs. House prices and rents are substantially higher in Fort McMurray than in most communities of similar size in the province.

One of the results of the price of housing is the creation of two housing markets in the town. The first is the conventional open market, in which houses with floor space of 93 m^2 sell for approximately $100,000, while rents range from $500 to $700 a month. The second is the closed market, consisting of housing owned by the oil companies and some smaller companies, which is rented to employees at perhaps less than half open market value. Employees entitled to buy homes in this market can purchase at much less than open market value, and receive interest-free loans and similar assistance. Also government employees are assisted through either special housing allowance or subsidized housing. No reliable data are available to indicate the relationship between the supply and demand for housing (139).

Table 30. Housing types in Fort McMurray, 1961-1977 (percent in brackets) (139).

Year	DWELLING TYPE Single Detached	Single Attached	Apartment	Mobile Home	Total
1961	276(90)	40(10)	—	—	316(100)
1966	373(61)	32(5)	64(10)	142(24)	611(100)
1971	1,025(62)	120(7)	215(13)	295(18)	1,655(100)
1976	1,575(37)	450(11)	905(21)	1,290(31)	4,220(100)
1977	1,955(34)	881(15)	1,245(22)	1,603(29)	5,684(100)

Resident Opinions

In 1969, one survey attempted to obtain representative resident opinions concerning the quality of life in Fort McMurray. Every fourth household was sampled; the final sample consisted of 233 males and 235 females. The director of the study has published two reports. The first report (1970) is based on the response of residents to those things

Figure 66. Old and new housing developments in Fort McMurray, 1978 (photo: F. Edwards, AOSERP).

"making life enjoyable", in "need of improvement", and brief descriptions of life in Fort McMurray. The respondents gave the highest priority to entertainment and recreation, income, adequate housing, and relatively easy access to Edmonton. The lowest priority was given to retail facilities. Among areas identified as "in need of improvement", transportation to Edmonton was top priority. The other important areas for improvement included communications, medical facilities, entertainment, and recreation. The responses of males and females did not significantly differ except that women ranked medical facilities as the major priority for improvement. The words used to describe life in Fort McMurray reflect both satisfaction and frustration: friendly, expensive, challenging, and isolated (141).

The second report (1971) specifically examined issues pertinent to labour turnover. Well over 50 percent of the sample has moved more than five times prior to coming to Fort McMurray. Only 10 percent had moved once previously. About 35 percent of the sample expected to stay more than five years. Nearly 40 percent expected to be gone within two years. The majority said they moved to Fort McMurray because of employment opportunities (77 percent). The second most important reason for coming, "to obtain a new life", was held by less than 20 percent. With respect to dissatisfaction and leaving, only 25 percent were distinctly dissatisfied. The most prominent reasons had to do with weather and related conditions or unfulfilled expectations. About half were specifically satisfied with labour-management relations, local government, union activities, working conditions, opportunities for advancement, salaries, fringe benefits, vacation time, and job security. Nearly one-fourth of the sample did not respond to questions concerned with motivations for staying or leaving. One of the surprising findings was that women were more satisfied with the life style in Fort McMurray than the men (142).

In general, the study seemed to reflect a posture of realistic appraisal among residents, with a heavy emphasis on basic satisfaction with work roles. Community concerns emphasized isolation and amenities, both of which are problems to be expected in most resources towns (13).

A study of criminal justice needs conducted in 1975 (143) also included a public opinion survey of 75 persons in the Fort McMurray area. The technique was an open-ended interview of a random sample of community members serving on various organizational boards and committees. The average length of residence was 6.5 years. Fifty of the persons interviewed lived in Fort McMurray. The other 25 persons lived in Fort Chipewyan, Fort MacKay, Anzac, and Janvier. Group interview discussions were also held in Fort McMurray with high school classes grades 10, 11, and 12.

The findings are reported in descriptive form without reference to the percentage holding certain opinions. The desirable features of Fort McMurray were defined as the small-town atmosphere, closeness to nature, and the marked employment opportunities. The issues identified were similar in content and scope to the findings of the study discussed previously. The youth in particular, complained about the inadequate recreational facilities and services available. Most agreed that large department stores and supermarkets were needed. Most also agreed that the overcrowded conditions and other social constraints were leading to increasingly higher levels of family discord. Some felt that others believed that boom towns attract people with a hard-drinking life style. They described the community of Fort McMurray as being made up of three basic, but not exclusive, types of people: (1) a small core of active and committed residents; (2) those out to make a "fast buck" who will remain for a year or two; and (3) a large group that are apathetic and bewildered (143).

Another study in the Fort McMurray area conducted in the winter of 1976-77, involved the collection of opinions from a non-random and non-representative sample of 43 persons (15). Largely informal interviews were conducted to obtain opinions on the various types of social and personal problems characteristic of the resource community at the time of construction of the Syncrude plant. The opinions, collectively, probably reflect both strongly held biases and unique insights into the meaning of life in Fort McMurray. The accuracy of certain of the opinions, at this point, cannot be assessed. The study results were used to identify topics for statistically based research on social and personal adjustment to the conditions of life in Fort McMurray.

The opinions voiced include such perceived problems as the emasculation of local government initiative by the provincial government, geographical isolation, the confrontation of people of differing national and ethnic groups, and a meeting place for failures from other communities. Also noted were the high levels of transience, inadequate physical amenities, extended work periods and household absence among employed men, and inadequate employment opportunities for women.

These characteristics were said to cause or influence various social and personal problems, which included personal debt, mental illness, household boredom, and related psychological stress conditions, alcohol and drug abuse, criminal behaviour, and family breakdown. Typical reasons given for family breakdown emphasized the development of loose sexual attitudes, separation from neighbourhoods where others can exercise personal control over one's behaviour, differences in expectations between husbands and wives, and the extended absence of husbands. Additional problems included inadequate community involvement opportunities for wives and children, child neglect, inadequate sources of identification for the young, and easy credit.

Several arguments can be levied against the validity of this study's findings. The very small size of the sample, over-representation of housewives in the sample, subjective nature of information obtained, lack of statistical content analysis of the responses, and lack of a broader perspective which would place the results within the context of social phenomena found in other resource communities mean that the study may not be scientifically valid. Since the study depicts the concerns that may have existed among a small group of people at the peak of construction of the Syncrude plant, it constitutes an historical document of limited reliability.

In general, it must be concluded that little is known at present about human responses to change in the oil sands region. Most of the existing material reflects an exploratory and often impressionistic examination of opinions about the effects of resource development and the consequences of these effects on people.

Human System Status

The information obtained to date on the structural socio-economic changes in the region illustrates the large growth in such areas as population, employment, and income. Data must still be generated on the extent to which the growing demand for various goods and services was met by the existing supply.

Similarly, the information has not been obtained on characteristics of the incoming population, such as education, ethnic and cultural backgrounds, religion, last permanent place of residence, and work history. Together with age, sex, and marital status, these characteristics are very important to the social structure of the community.

Little is known about human adjustment to the changes associated with oil sands development in the region, for example, about resident's perceptions of socio-economic changes, and their responses to these changes. Assessment of the adjustment of the native population is still incomplete. Preliminary findings of a study of native employment patterns in the area indicate that the participants in training-employment programs, which are run for the native residents by Syncrude, GCOS, and Keyano College, give preference to permanent, full-time employment as opposed to a seasonal job (144). Thus, it cannot be assumed that native people in the AOSERP study area perceive the oil sands development only as an intrusion in their environment. Further studies are in progress to obtain more information on the integration of native workers into the industrial labour force.

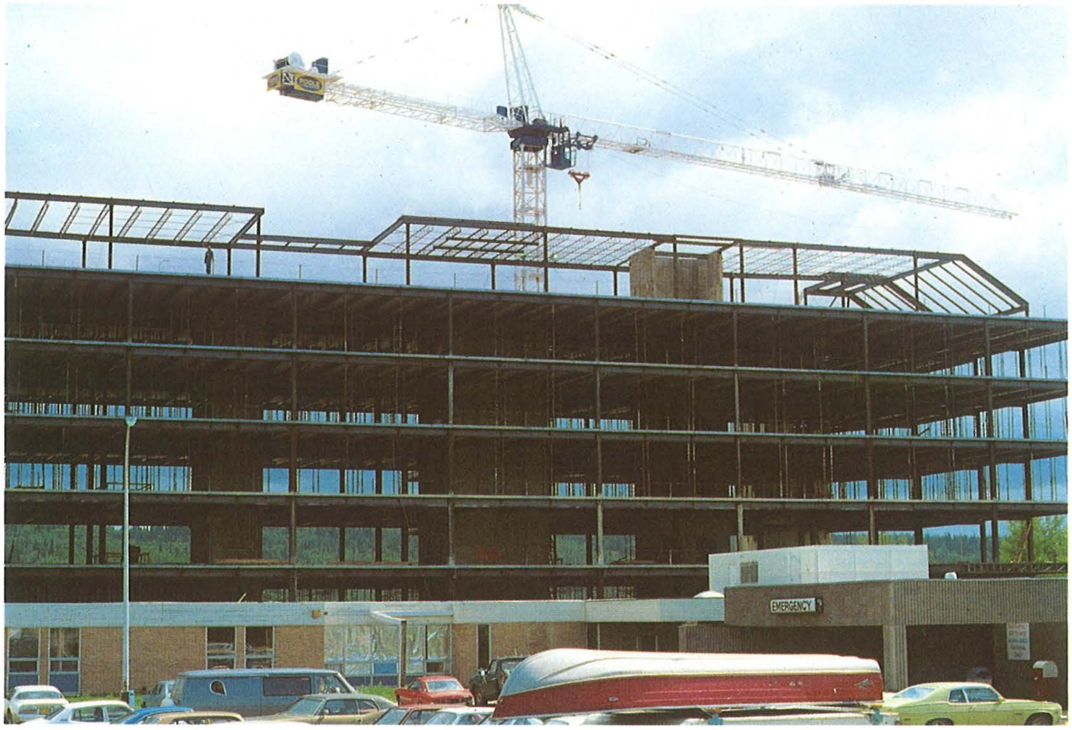


Figure 67. New hospital under construction in Fort McMurray, 1978 (photo: F. Edwards, AOSERP).

Whether life in the region is perceived by non-native residents as an opportunity for economic and social advancement and a challenge or as a stress is yet to be determined. At present, largely impressionistic knowledge and only some historical survey data exist on resident's opinions about life in Fort McMurray prior to and during the construction of the Syncrude plant.

Despite the occasionally dismal opinions that were reported to be voiced at that time, it is unrealistic to assume that local residents perceive life in Fort McMurray as an unbroken chain of social problems. The attitudes of people who stay in Fort McMurray for any length of time, and the incentives that make them stay are still to be ascertained.

Further studies are required to assess whether social problems in the region have been as prevalent as they were reported to be in 1976. The existing data on such phenomena as alcohol consumption, divorce rate, child abuse, and criminal behaviour are too inconclusive to substantiate any claims. However, Fort McMurray was found to have only 33 percent of the 1967 population remaining in 1972. Despite the fact that in 1972, the out-migration levelled off, it was greater than in such comparable communities as Whitehorse and Yellowknife, which have acquired considerable maturity, or Lynn Lake and Flin Flon which are facing a phasedown period (13).

The high out-migration may explain in part why, according to the vital statistics, the number of live births and marriages in Fort McMurray dropped marginally between 1972 and 1974. It is possible that people either do not remain in Fort McMurray long enough to experience the significant events in their lives or prefer to go elsewhere when such events are imminent, and that a large number of the residents do not consider the town to be their home (139).

An analysis of human responses to the consequences of the unprecedented growth in the region must also include the efforts made by local communities, local government, industry, and representatives of the provincial and federal governments to rectify any negative effects of the development. Already these efforts have resulted in many successful ventures, such as the construction of a new hospital in Fort McMurray (Figure 67), of new schools, for example in Fort MacKay, and the provision of various public programs and services aimed at enhancing the quality of life in the region.

Appendix I

Canada-Alberta Agreement for The Alberta Oil Sands Environmental Research Program, Amended-September 1977

alberta canada

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

CANADA — ALBERTA AGREEMENT

for the

Alberta Oil Sands Environmental

Research Program

Amended - September 1977

OFFICE COMPILATION

Sponsored jointly by

Alberta ENVIRONMENT

Environment Canada Environnement Canada

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

THIS AGREEMENT made on the 26th day of September, 1977.

BETWEEN:

THE GOVERNMENT OF CANADA represented herein by the Minister of the Environment (hereinafter called "Canada")

OF THE FIRST PART

AND:

THE GOVERNMENT OF ALBERTA represented herein by the Minister of the Environment (hereinafter called "Alberta")

OF THE SECOND PART

WHEREAS Canada and Alberta have agreed to identify, undertake or encourage and assist research into environmental aspects of the renewable resources involved in the development of oil sands in the area in Alberta described in Schedule "C" hereto, and wish by this agreement to provide for the coordinated planning, funding and implementation of such research; and

WHEREAS initial development is now occurring with expansion imminent and decisions on several industrial proposals now are pending; and

WHEREAS the large scale industrial development of the area will have immense economic, social and environmental effects; and

WHEREAS Canada and Alberta recognize the necessity of improving the scientific understanding of the effects of the oil sands development on the human and natural environment of the oil sands area; and

WHEREAS the results of an intensive study of the area will be useful in predicting the effects of any proposed development, as a basis for considering future proposals; and

WHEREAS the results of the study program will be utilized by Alberta in the approval process for future developments and in the environmental design of any project which might be implemented; and

WHEREAS Canada and Alberta are agreed on the objectives, general strategy and procedures which would govern the identification and selection of such research and the methods of encouragement and assistance; and

WHEREAS His Honour, The Lieutenant Governor-in-Council by Order-in-Council No. 887/77 dated 31st August, 1977, has authorized the Minister of the Environment for Alberta to execute this agreement on behalf of Alberta;

NOW THEREFORE THIS AGREEMENT WITNESSETH that in consideration of the premises, covenants and agreements herein contained, the parties covenant and agree with each other as follows:

I. DEFINITIONS

In this agreement

(a) "area" means that part of the Province of Alberta described in Schedule "C" to this Agreement;

(b) "environmental research" means a fundamental investigation of a potential or actual man-induced change in environmental systems, which could result in identifiable benefits or adverse effects to society;

(c) "Federal Minister" means the Minister of the Environment of Canada;

(d) "fiscal year" means the period commencing on April 1st of any year and terminating on March 31st of the immediately following year;

(e) "industry" means an individual company or an aggregate or any number thereof of industrial companies who seek to develop the oil sands;

(f) "Ministers" means the Federal Minister and the Provincial Minister;

(g) "non-renewable resources" means minerals, mineral fuels; and similar resources;

(h) "oil sands" means sands and other rock materials which contain crude bitumen and includes all other mineral substances in association therewith;

(i) "oil sands deposit" means a natural reservoir containing or appearing to contain an accumulation of oil sands;

(j) "Program" means the research activities resulting from this agreement;

(k) "Provincial Minister" means the Minister of the Environment of Alberta;

(l) "renewable resources" means biological resources and resources such as terrain, water, and climate that support biological systems;

(m) "research project" or "project" means a project that is entirely or primarily devoted to conducting research on renewable resources in the area in relation to any matter pertaining to the environment;

(n) "Steering Committee" means the committee established pursuant to paragraph IV (2);

(o) "Senior Advisory Board" means the board established pursuant to paragraph IV (3).

II PURPOSE

(1) The purpose of this agreement is to continue the "Alberta Oil Sands Environmental Research Program".

(2) The purpose of the Program is to provide timely information about factors that will aid the parties in establishing guidelines for socially acceptable limits of damage to present and potential uses of biotic and abiotic resources.

(3) In support of this purpose, Canada and Alberta agree that this agreement is confined to research only and does not involve the management of renewable resources.

(4) The objectives of the Program are attached as Schedule "A" hereto. These objectives may be added to or amended from time to time upon agreement of both parties.

III. TERMS OF REFERENCE

The Terms of Reference relating to the Program are contained in Schedule "B" hereto.

IV. ADMINISTRATIVE ARRANGEMENTS

(1) The Ministers shall approve the terms of specific research in the fields of hydrology, hydrogeology, terrestrial fauna, land matters, vegetation, human environment, aquatic fauna, meteorology, and others to which they may mutually agree.

(2) There shall be established a Steering Committee, which, under the direction of the Ministers, shall be responsible for the composition, coordination and conduct of the Program and shall consist of one member appointed by Alberta who shall have the functions normally performed by a chairman, and one member appointed by Canada. The Steering Committee shall:

(a) meet as its members may determine but in any event shall meet at least once every fiscal year during the currency of this agreement,
(b) recommend to the Ministers for approval any news releases respecting any matter concerning or relating to this agreement or the Program,
(c) annually, and at such other times as it or the Ministers may consider appropriate, reports to the Ministers upon the projects carried out under the Program and the progress accomplished in respect thereto,
(d) arrange a meeting of the Senior Advisory Board at least once each fiscal year or as often as is required in order that policy guidance may be provided for on behalf of interested Government departments of Alberta and Canada,
(e) recommend to the Ministers those technical reports prepared for publication,
(f) assume such other duties and administrative responsibilities as the Ministers may from time to time agree and prescribe.

Each Steering Committee member shall appoint an alternate to represent him at meetings which he cannot attend and shall in writing notify the other member the name of the person so appointed. In the event that the Steering Committee is unable to agree upon any matter, the same shall be submitted to the Ministers for resolution.

(3) The Ministers shall appoint a Senior Advisory Board, as recommended by the Steering Committee. The Chairman of the Steering Committee or a member so designated by him in writing shall be the Chairman of the Senior Advisory Board. Senior Advisory Board representation shall be from the Government departments listed in Schedule "D".

The Senior Advisory Board shall:

(a) assist the Steering Committee in evaluating the relevance and timeliness of existing and proposed research efforts relative to the needs of the departments listed in Schedule "D",
(b) provide the Steering Committee with advice on the purpose, objectives and priorities of the research program,
(c) identify areas of interrelationship with research programs other than those provided for in this agreement.

(4) Alberta shall in consultation with Canada appoint a Program Director and such other supporting staff as may be required from time to time to meet the objectives of the Program. The Program Director:

(a) subject ot the approval of the Steering Committee, may establish technical advisory committees or groups as he may consider necessary to assist specific portions of the Program,
(b) shall be responsible to the Steering Committee for the development and implementation of the research projects aimed at meeting the objectives of the Program,
(c) shall arrange for the provision of field services common to all field research projects involved in the Program including, without limitation, laboratory

space, logistics, vehicles and accommodation,

(d) shall be responsible for scheduling project work to ensure the results thereof are available to the parties hereto as soon as practicable,

(e) shall, subject to the direction and approval of the Steering Committee, be responsible for the preparation of news releases and reports for technical and public information,

(f) may recommend to the Steering Committee that the respective parties hereto, as the case may be, enter into contracts or other arrangements required to meet the objectives of the Program,

(5) The parties hereto shall have regard to any existing programs of Alberta or Canada concerning oil sands environmental research for which the Departments of the Environment of Alberta and Canada are individually or jointly responsible, and agree to coordinate these programs as closely as possible with the implementation of the Program.

(6) Subject to paragraph V (8), Alberta shall be the contact with industry and Alberta universities in matters pertaining to this agreement and which have been recommended by the Steering Committee.

(7) Any provision of this agreement may be amended by mutual agreement.

V. FINANCING

(1) The total cost of the Program is estimated to approximate $40,000,000 expended over a period of ten years. For the purpose of this agreement, but subject to paragraphs (2) and (3) of this Article, the terms of this agreement shall be five years from April 1, 1975, unless this agreement is extended or terminated pursuant to Article VI hereof.

(2) Subject to the terms and conditions of this agreement and to funds being appropriated by Parliament, the sum for which Canada shall be liable hereunder shall approximate $2,000,000 annually for five years from the date hereof and thereafter shall approximate $2,000,000 annually for a further period not exceeding five years where the term of the program is extended pursuant to Article VI hereof.

(3) Subject to the terms and conditions of this agreement and to funds being appropriated by the Legislative Assembly of Alberta, the sum for which Alberta shall be liable hereunder shall approximate $2,000,000 or more annually for five years from the date hereof and thereafter shall approximate $2,000,000 or more annually for a further period not exceeding five years where the term of the program is extended pursuant to Article VI hereof.

(4) Prior to the beginning of each fiscal year, the projects to be undertaken by Alberta, Canada, or jointly, for that fiscal year shall be recommended by the Steering Committee for the approval of the Ministers. The Steering Committee may recommend a joint project between the parties hereto, the cost of which shall be borne equally by the parties or as otherwise mutually agreed. Alberta will provide the initial funding for all research projects on the basis of monthly progress claims reviewed and approved by the Program Director on behalf of the Steering Committee. Alberta will submit claims and will be reimbursed on a quarterly basis by Canada for those projects undertaken by Federal agencies and for the Canada share of jointly funded projects up to a limit of $2,000,000 in any one fiscal year. If any capital goods are purchased for a joint project, on the completion or otherwise termination of that project they may be sold or otherwise disposed of by mutual agreement, and any proceeds thereof divided pro rata between the parties.

(5) Salaries, travelling expenses and related costs of employees of the parties engaged in the Program and related committee duties shall not be paid from funds approved under this agreement except for salaries, travelling expenses and related costs of staff specifically assigned to or engaged in studies carried out on behalf of the Steering Committee by department or agencies of the parties.

(6) The salaries, travelling expenses and other costs incurred by Steering Committee members, their alternates and other government officials appointed to represent those party to the agreement on committees established or approved by the Steering Committee shall be paid for by their respective government.

(7) Where goods or services in respect of the Program (including, without limitation, equipment, office space or facilities specifically required for the Program) are provided by a party hereto or its agencies and are used or utilized by the other party or its agencies, any cost charged in respect thereto by the party or agency so providing shall be the actual cost to that last-mentioned party.

(8) As between the parties hereto, Alberta alone shall bear the responsibility for negotiating contributions to the Program by industry, to a level and upon such conditions deemed appropriate by the Ministers.

(9) Each party hereto shall, for audit purposes, keep appropriate records of expenditures made hereunder and, if requested by the other party, shall make available to the other party those records.

VI **DURATION AND TERMINATION**

For the purposes of this agreement, the term of the Program shall be five years, which said term may be renewed for a further period of up to five years. Either party may, however, at the end of any fiscal year during the currency hereof, terminate this agreement by giving to the other party by registered mail at least one clear year's notice thereof, it being agreed that no such notice may be given which would result in such termination prior to March 31, 1979.

VII. **SCIENTIFIC INFORMATION PUBLICATION**

The parties hereto acknowledge hereby that they are committed to the principle that scientific work performed as part of the Program may be published in appropriate journals and/or technical reports. Save as aforesaid, all information obtained in the Program shall be considered to be in the public domain.

VIII. **NOTICES**

Any notice to be given hereunder shall be addressed to the Provincial Minister or the Federal Minister, as the case may be, and shall be deemed to have been given upon the day it is received.

IX. **GENERAL**

No Member of Parliament shall hold or be admitted to any share or part of any contract, agreement or commission arising out of this agreement.

IN WITNESS WHEREOF the Honourable Romeo LeBlanc, Minister of the Environment, has hereunto set his hand on behalf of Canada, and the Honourable David J. Russell, Minister of the Environment of Alberta, has hereunto set his hand on behalf of Alberta.

In the Presence of:

____

Signed on behalf of
Canada

____
Date

In the Presence of:

____

Signed on behalf of
Alberta

____
Date

This agreement is hereby approved and ratified as a binding Intergovernmental Agreement of the Government of Alberta as evidence by the signature of the Minister of Federal and Intergovernmental Affairs.

____

Minister of Federal and Intergovernmental
Affairs for Alberta

SCHEDULE "A"

GENERAL OBJECTIVE

To undertake environmental research relative to the renewable resources on the designated area which will make information available to the parties hereto to ensure an acceptable quality of the environment during and after operations for the recovery, transport, and processing of oil sands products. This research will be directed to the solution of practical social and technical environmental problems resulting from oil sands development.

SPECIFIC OBJECTIVES

1. To identify the baseline states, processes, and absorptive capacity of the biotic and abiotic resources that may be affected by oil sands development activities;
2. To identify the nature of interactions between the various components of the biotic and abiotic environment and the various components of proposed development activities;
3. To predict, in part from information obtained by meeting objectives (1) and (2), the individual and cumulative effects of anticipated developments on the biotic and abiotic environment;
4. To develop the methods necessary to protect the biotic and abiotic environment and finally return the biotic environment to a productive state;
5. To advise regulatory and management agencies and the industry of new scientific and technological information pertinent to their jurisdictions, to minimize adverse environmental effects and maximize beneficial environmental effects;
6. To use existing agencies within the administration of the parties hereto where possible and to use other sources when necessary. Taking inventories will not be considered as part of the objectives under this Program, except where necessary to provide research information;
7. To establish priorities in areas of research, and assign these priorities in the light of an Alberta development strategy for the oil sands;
8. To coordinate the projects within the Program so as to provide an interdisciplinary study of environmental problems;
9. To promote an environmental research program which will ensure cooperation among the governments of Alberta and Canada, industry, universities and other institutions.
10. To compile, assess, and disseminate research reports resulting from this Program.

SCHEDULE "B"

TERMS OF REFERENCE

The Program will be broad and comprehensive, except insofar as industry has the sole responsibility for detailed work on leased portions of the area and associated sites for installations or works, but it will not apply to any research and inventories concerning non-renewable resources in the area.

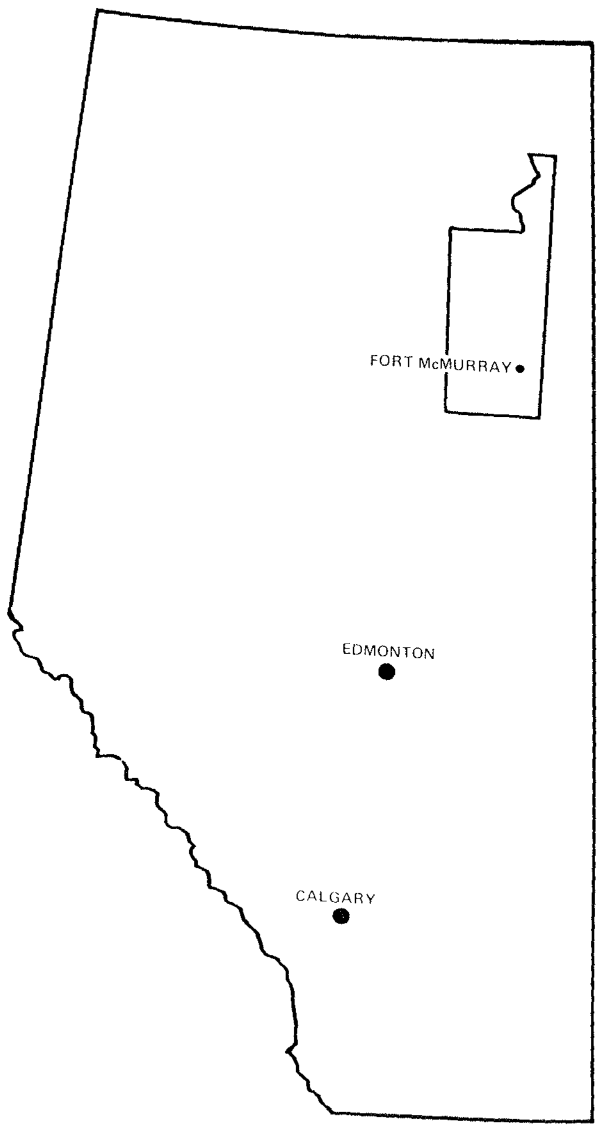
When research information is obtained under this program it shall be available to both parties.

Where Canada conducts research pursuant to those presents and incidentally obtains data respecting non-renewable resources, Canada shall provide Alberta with all such information and shall not use these data nor disclose them to anyone except with the written consent of the Provincial Minister.

SCHEDULE "C"

The area under consideration will be the lands comprised within

Townships 84 to 104, in Ranges 6 to 18 West of the Fourth Meridian, and Townships 105 to 115, in Ranges 6 to 9, excluding Wood Buffalo National Park in the Province of Alberta.



SCHEDULE "D"

SENIOR ADVISORY BOARD MEMBERSHIP

The following departments of Alberta and Canada shall be invited to membership on the Senior Advisory Board:

ALBERTA ENVIRONMENT

ENVIRONMENT CANADA

ALBERTA ENERGY AND NATURAL RESOURCES

ALBERTA RECREATION, PARKS AND WILDLIFE

NORTHEAST ALBERTA REGION COMMISSIONER

ALBERTA BUSINESS DEVELOPMENT AND TOURISM

CANADIAN INDIAN AFFAIRS AND NORTHERN DEVELOPMENT

Appendix II

Vegetation Species Identified in The AOSERP Study Area

Table 31. Vegetation species identified in the AOSERP study area and mentioned in the text of this report.[a]

Common Names	Scientific Names
Trees	
Alder	*Alnus* spp.
Black spruce	*Picea mariana*
Balsam fir	*Abies balsamea*
Balsam poplar	*Populus banksiana*
Jack pine	*Pinus banksiana*
Paper or white birch	*Betula papyrifera*
Swamp birch	*Betul pumila* var. *glandulifera*
Tamarack	*Larix larincina*
Trembling aspen	*Populus tremuloides*
White spruce	*Picea glauca*
Willow	*Salix spp.*
Shrubs	
Bear berry	*Arctostaphylos uvaursi*
Blueberry	*Vaccinium myrtilloides*
Bog Rosemary	*Andromeda polifolia*
Labrador tea	*Ledum groenlandicum*
Mountain laurel	*Kalmia polyfolia* var. *microphylla*
Grasses/Sedges	
Rice grass	*Oryzopsis pungens*
Sedge	*Carex* spp.

[a] Additional information on scientific nomenclature may be obtained from Moss (145).

Appendix III

Wildlife Identified in The AOSERP Study Area and Mentioned in The Text of This Report

Table 32. Wildlife identified in the AOSERP study area and mentioned in the text of this report.

Common Names	Scientific Names
Mammals	
Beaver	*Castor canadensis*
Black Bear	*Ursus americanus*
Cinereous or Masked Shrew	*Sorex cinereus*
Coyote	*Canis latrans*
Deer Mouse	*Peromyscus maniculatus*
Ermine	*Mustela erminea*
Fisher	*Martes pennanti*
Lynx	*Lynx lynx*
Martin	*Martes americana*
Mink	*Mustela vison*
Moose	*Alces alces*
Mule Deer	*Odocoilius hemionus*
Muskrat	*Ondrata zibethicus*
Northern Flying Squirrel	*Glaucomys sabrinus*
Red-backed Vole	*Clethrionomys gapperi*
Red Fox	*Vulpes vulpes*
Red Squirrel	*Tamiasciurus hudsonicus*
River Otter	*Lutra lutra*
Snowshoe Hare	*Lepus americanus*
Timber Wolf	*Canis lupus*
Weasel	*Mustela nivalis*
White-tailed Deer	*Odocoilius virginianus*
Wolverine	*Gulo luscus*
Woodland Caribou	*Rangifer tarandus*
Avifauna	
Arctic Tern	*Sterna paradisaea*
Bald Eagle	*Haliaeetus leucocephalus*
Blue-winged Teal	*Anas discors*
Bonaparte's Gull	*Larus philadelphia*
Bufflehead	*Bucephala albeola*
California Gull	*Larus californicus*
Canada Goose	*Branta canadensis*
Caspian Tern	*Sterna caspia*
Common Loon	*Gavia immer*
Common Tern	*Sterna hirundo*
Common Yellowthroat	*Geothlypis trichas*
Franklin's Gull	*Larus pipixcan*
Golden Eagle	*Aquila chrysaetos*
Goldeneye	*Bucephala clangula*
Gray Jay	*Perisoreus canadensis*
Great Horned Owl	*Bubo virginianis*
Green-winged Teal	*Anas crecca*
Mallard	*Anas platyrhyncos*
Osprey	*Pandion haliaetus*
Peregrine Falcon	*Falco peregrinus*
Ringneck	*Aythya collaris*
Ruby-throated Hummingbird	*Archilochus colubris*
Ruffed Grouse	*Bonasa umbellus*
Sandhill Crane	*Grus canadensis*
Scaup	*Aythya affinis*
Sharp-tailed Grouse	*Pedioecetes phasianellus*
Shoveler	*Anas clypeata*
Snow Goose	*Chen caerulescens*
Spruce Grouse	*Canachites canadensis*
Tennessee Warbler	*Vermivora peregrina*
Whistling Swan	*Olor columbianus*
White-fronted Goose	*Anser albifrons*
White Pelican	*Pelecanus erythrorhynchos*
Widgeon	*Anas amerciana*
Willow Ptarmigan	*Lagopus lagopus*
Yellow Warbler	*Dendroica petechia*
Amphibians	
Boreal Chorus Frog	*Pseudacris triseriata*
Canadian Toad	*Bufo hemiophrys*
Wood Frog	*Rana sylvatica*

[a] Additional information on scientific nomenclature may be obtained from (146, 147, 148).

Appendix IV

Macrobenthos Collected from The AOSERP Study Area, 1976-1977

Table 33. Macrobenthos collected from streams in the AOSERP study area, 1976-77.

PORIFERA
- *Spongilla* Lamarack

CNIDARIA
- *Hydra*

TURBELLARIA
- Alloecoela
- Tricladida
- *Dugesia ?tigrina* (Girard)

NEMATODA
NEMATOMORPHA
HIRUDINOIDEA
- *?Dina* Blanchard
- *Erpobdella punctata* (Leidy)
- *Glossiphonia complanata* (Linnaeus)
- *G. heteroclita*
- *Haemopis grandis* (Verrill)
- *Helobdella stagnalis* (Linnaeus)
- *Nephelopsis obscura* Verrill
- *Piscicola* Blainville
- *?Placobdella papillifera* (Verrill)

OLIGOCHAETA
- Lumbriculidae
- *Lumbriculus variegatus* (Müller)
- Enchytraeidae
- Aeolosomatidae
- *Aeolosoma* sp. Ehrenberg
- Tubificidae
- *Limnodrilus ?claparedianus* Ratzel
- *L. hoffmeisteri* Claparede
- *Peloscolex* spp. Leidy
- *Tubifex ?tubifex* (Müller)
- Naididae
- *Amphichaeta* n r., *americana* Chen
- *Arcteonais lomondi* (Martin)
- *Chaetogaster diaphanus* (Guuithuisen)
- *C. langi* (Bretscher)
- *C. limnaei* von Baer
- *Dero digitata* (Müller)
- *Nais behningi* Michaelson
- *N. communis/variabilis*
- *N. pardalis* Piquet
- *N. pseudobtusa* Piquet
- *N. simplex* Piquet
- *Pristina breviseta* Bourne
- *P. foreli* (Piquet)
- *P. longiseta* Ehrenberg
- *Slavina appendiculata* d'Udekem
- *Specaria josinae* (Vejdovsky)
- *Stylaria lacustris* (Linnaeus)
- *Uncinais uncinata* (Ørsted)
- *Vejdovskyella comata* (Vejdovsky)

MOLLUSCA
Pelycepoda
- Sphaeriidae
- *Musculium* Link
- *Pisidium* spp. Pfeiffer
- *Sphaerium* spp. Scopoli
- Unionidae
- *Lampsilis* sp. Rafinesque

Gastropoda
- *Amnicola ?limosa* (Say)
- *Ferrissia* Walker
- *Helisoma* Swainson
- *Gyraulus parvus* (Say)
- *Lymnaea* spp. Lamarack
- *Physa* Draparnaud
- *Promenetus* Baker
- *Valvata ?levisii* Currier

BRYOZOA
TARDIGRADA
CRUSTACEA
Copepoda
Ostracoda
Amphipoda
- Gammaridae
- *Gammarus lacustris* Sars
- Talitridae
- *Hyalella azteca* (Saussure)

INSECTA
Ephemeroptera
- Siphlonuridae
- *Ameletus* Eaton
- *Parameletus* Bengtsson
- *Siphlonurus* Eaton
- *S. alternatus* (Say)
- *Analetris eximia* Edmunds
- *Isonychia* Eaton
- Metretopodidae
- *Metretopus borealis* Eaton
- *Siphloplecton basale* (Walker)
- Ametropodidae
- *Ametropus neavei* McDunnough
- Baetidae
- *Baetis* Leach
- *Callibaetis coloradensis* Banks
- *Centroptilum* Eaton
- *Cloeon* Leach
- *C. implicatum* McDunnough
- *Pseudocloeon* Klapalek
- Heptageniidae
- *Epeorus (Iron) ?albertae* (McDunnough)
- *Heptagenia* spp. Walsh
- *Rhithrogena* Eaton
- *Stenacron interpunctatum* (Say)
- *Stenonema vicarium* (Walker)
- *Pseudiron* McDunnough
- Leptophlebiidae
- *Leptophlebia cupid* (Say)
- *L. nebulosa* (Walker)
- *Paraleptophlebia* Lestage
- Ephemerellidae
- *Ephemerella margarita* Needham
- *E. simplex* McDunnough
- *E. spinifera* Needham
- *E. aurivillii* Bengtsson
- *E. inermis* Eaton
- *E. tibialis* McDunnough
- Tricorythidae
- *Tricorythodes ?minutus* Traver
- Caenidae
- *Brachycercus* Curtis

Continued . . .

Table 33. Continued

Caenis spp. Stephens
Baetiscidae
Baetisca ?columbiana Edmunds
B. obesa (Say)
Ephemeridae
Ephemera cf. *simulans* Walker
Hexagenia Walsh
Odonata
Anisoptera
Aeshnidae
Aeshna eremita Scudder
A. nr. *interrupta* Walker
A. ?umbrosa Walker
Gomphidae
Gomphus ?notatus Rambur
Ophiogomphus colubrinus Selys
Corduliidae
Cordulia shurtleffi Scudder
Epitheca canis McLachlan
Somatochlora minor Calvert
Libellulidae
Leucorrhinia borealis Hagen
L. hudsonica (Selys)
L. intacta Hagen
Libellula julia Uhler
L. quadrimaculata Linneaus
Zygoptera
Agrionidae
Agrion aequabile (Say)
Coenagrion resolutum (Hagen)
Enallagma boreale Selys
Ischnura Charpentier
Plecoptera
Nemouridae
Nemoura (Amphinemura) linda Ricker
N. (Nemoura) arctica Esben-Peterson
N. (Shipsa) rotunda Claassen
N. (Zapada) cinctipes Banks
Leuctridae
Leuctra ?sara Claassen
Capniidae
Capnia vernalis (Newport)
Tainiopterygidae
Oenopteryx fosketti (Newport)
Taeniopteryx nivalis (Fitch)
T. parvula Banks
Pteronarcidae
Pteronarcella regularis (Hagen)
Pteronarcys dorsata Say
Perlodidae
Arcynopteryx Klapalek
Isogens (Isogenoides) frontalis colubrinus (Hagen)
Isoperla nr. *fulva* Claassen
I. ?fusca Needham and Claassen
I. longiseta Banks
I. ?sordida (Banks)
Chloroperlidae
Hastaperla brevis (Banks)
Perlidae
Acroneuria abnormis (Newman)
A. lycorias (Newman)
Claassenia sabulosa Banks
Megaloptera
Sialidae
Sialis Latreille
Tricoptera
Philopotamidae
Wormaldia gabrielia (Banks)
Polycentropodidae
Polycentropus cinereus Hagen
P. flavus (Banks)
P. remotus Banks
Hydropsychidae
Arctopsyche McLachlan
Cheumatopsyche spp. Wallengren
C. speciosa (Banks)
Hydropsyche spp. Pictet
H. bifida Banks
H. slossonae Banks
Rhyacophilidae
Rhyacophila spp. Pictet
Glossosomatidae
Agapetus Curtis
Glossosoma Curtis
Protoptila Banks
Hydroptilidae
Agraylea Curtis
Dibusa Ross
Hydroptila Dalman
Mayatrichia Mosely
Neotrichia Morton
Ochrotrichia Mosely
?Orthotrichia Eaton
Oxyethira Eaton
Phryganeidae
Agrypnia Curtis
Banksiola crotchi Banks
Fabria Milne
Phryganea Linnaeus
Ptilostomis semifasciata (Say)
Brachycentridae
Brachycentrus Curtis
B. americanus (Banks)
Micrasema McLachlan
Limnephilidae
Anabolia bimaculata (Walker)
Asynarchus McLachlan
Glyphopsyche irrorata (Fabricius)
Grammotaulius Kolenati
Hesperophylax Banks
Limnephilus spp. Leach
L. minusculus (Banks)
Nemotaulius hostilis (Hagen)
Onocosmoecus Banks
Psychoglypha subborealis (Banks)
Pycnopsyche Banks
Lepidostomatidae
Lepidostoma Rambur
Molannidae
Molannna Curtis
Helicopsychidae
Helicopsyche borealis Banks
Leptoceridae
Ceraclea annulicornis (Stephens)
C. tarsipunctata (Vorhies)
Nectopsyche Müller
Oecetis avara Banks
Triaenodes McLachlan
Lepidoptera
Pyralidae
Nymphula Schank
Hempitera
Corixidae
Arctocorixa sutilis (Uhler)
Callicorixa audeni Hungerford
C. alaskensis (Hungerford)
Cenocorixa dakotensis (Hungerford)
Hesperocorixa atopodonta (Hungerford)
H. michiganensis (Hungerford)
H. minorella (Hungerford)
Sigara alternata (Say)
S. bicoloripennis (Walley)
S. conocephala (Hungerford)
S. decoratella (Hungerford)
S. fallenoidea (Hungerford)
S. grossolineata Hungerford

Continued . . .

Table 33. Continued

S. lineata (Forester)
S. mullettensis (Hungerford)
S. penniensis (Hungerford)
S. solensis (Hungerford)
S. trilineata (Provancher)
S. washintonensis Hungerford
Trichocorixa borealis Sailer
T. naias (Kirkaldy and Bueno)
T. verticalis interiores Sailer
Notenectidae
Notonecta borealis Bueno and Hussey
N. kirbyi Hungerford
N. undulata (Say)
Coleoptera
Haliplidae
Brychius Thomson
Haliplus Latreille
Dytiscidae
Agabus spp. Leach
A. seriatus (Say)
Carrhydrus crassipes Fall
Deronectes Sharp
Dytiscus dauricus Gebler
D. harrissi Kirby
Hydaticus Leach
Hydroporus Clairville
Ilybius Erichson
Neoscutopterus Balfour-Browne
Gyrinidae
Gyrinus affinis Aube
G. maculiventris LeConte
G. minutus Fabricius
G. ?opacus Sahlberg
G. ?pectoralis LeConte
Hydrophilidae
Elmidae
Dubiraphia robusta Hilsenhoff
Optioservus fastiditus (LeConte)
Diptera
Tipulidae
Antocha Osten Sacken
Dicranota Zetterstedt
Eriocera Macquart
Holorusia Loew
Prionocera Loew
Tipula Linnaeus
Psychodidae
Pericoma Walker
Telmatoscopus Eaton
Dixidae
Paradixa Tonnoir
Chaoboridae
Chaoborus Lichtenstein
Simuliidae
Simulium arcticum Malloch
S. prob. *aureum* Fries
S. decorum Walker
S. euryadminiculum Davies
S. prob. *tuberosum* Lundström
S. tuberosum-complex
S. venustum-complex
S. vittatum Zetterstedt
Ceratopogonidae
Atrichopogon Kieffer
Chironomidae
Podonominae
Trichotanypus posticalis (Lundbeck)
Tanypodinae
Ablabesmyia spp. Johannsen
Conchapelopia Fittkau
Labrundinia Fittkau
Larsia Fittkau
Nilotanypus Kieffer
Paramerina Fittkau
Procladius Skuse
Rheopelopia Fittkau
Thienemannimyia Fittkau
Thienemannimyia-gp
Chironominae - Chironomini
Beckiella tethys (Townes)
Chernovskiia orbicus (Townes)
Chironomus annularis-gp
C. fluviatilis-gp.
C. cf. *decorus* (Johannsen)
C. plumosus-gp.
C. salinarius-gp.
C. thummi-gp.
Cladopelma Kieffer
Cryptochironomus Kieffer
"Cryptochironomus" rolli Kirpitshenko
Cyptocladopelma Lenz
Cryptotendipes Lenz
Cyphomella cf. *gibbera* Saether
Demicryptochironomus Lenz
Dicrotendipes cf. *fumidus* (Johannsen)
D. cf. *modestus* (Say)
D. cf. *neomodestus* (Malloch)
D. cf. *nervosus* (Staeger)
Endochironomus cf. *subtendens* (Townes)
Glyptotendipes Kieffer
Kiefferulus Goetghebuer
Microtendipes cf. *pedellus* (DeGeer)
Pagastiella
Parachironomus Lenz
Paracladopelma spp. Harnisch
Paralauterbourniella Lenz
Paratendipes Kieffer
Phaenopsectra Kieffer
Polypedilum Kieffer
P. breviantennatum-gp.
P. fallax-gp.
P. scalaenum-gp.
Robackia claviger (Townes)
R. demeijerei (Kruseman)
Stenochironomus Kieffer
Stictochironomus spp. Kieffer
Xenochironomus zenolabis (Kieffer)
Tanytarsini
Cladotanytarsus Kieffer
Constempellina Brundin
Micropsectra Kieffer
Paratanytarsus Kieffer
Rheotanytarsus (Bause)
Stempellina spp. Bause
Tanytarsus van-der Wulp
Zavrelia Kieffer
Diamesinae
Diamesa (Meigen)
Monodiamesa cf. *tuberculata* Saether
Potthastia cf. *gaedi*
P. longimanus-type
Protanypus Kieffer
Pseudodiamesa Goetghebeur
Orthocladiinae
Acricotopus cf. *senex* (Johannsen)
Brillia Kieffer
Cardiocladius Kieffer
Corynoneura Winnertz
Cricotopus bicinctus (Meigen)
C. cylindraceus-gp.
C. fuscus-gp.
C. tremulus-gp.
C. nr. *curtus* Hirvenoja
C. cf. *triannulatus* Goetghebuer
C. trifascia-gp.
Cricotopus nostocicola Wirth

Continued . . .

Table 33. Concluded

C. festivellus-gp.
C. sylvestris-gp.
C. cf. *laetus* Hirvenoja
Diplocladius cf. *cultriger* (Kieffer)
Eurkiefferiella spp. Thienemann
E. cf. *brevicalcar* Kieffer
E. cf. *claripennis* (Lundbeck)
Eurcnemus van der Wulp
Heterotrissocladius cf. *latilaminus* Saether
Krenosmittia Thienemann
Limnophyes Eaton
Metricocnemus van der Wulp
Nanocladius cf. *balticus* (Palmen)
N. cf. *distinctus* (Malloch)
N. cf. *rectinervis* (Kieffer)
Orthocladius spp. (van der Wulp)
Parakiefferiella spp. (Thienemann)
Parametriocnemus spp. Goetghebuer
P. cf. *graminicola* (Lundback)
P. cf. *lundbecki* (Johannsen)
Paraphanocladius Thienemann
Paratrichocladius Thienemann
Psectrocladius spp. (Kieffer)
P. cf. *simulans* (Johannsen)
Pseudosmittia (Goetghebuer)
Rheocricotopus (Thienemann and Harnisch)
R. nr. *kenorensis* Saether
Synorthocladius Thienemann
Thienemanniella Kieffer
? Genus *acutilabis* Pankratova
Orthocladiinae A
Orthocladiinae B
Orthocladiinae D
Stratiomyidae
Sratiomyia Geoffroy
Rhagionidae
Atherix pachypus Bigot
Tabanidae
Chrysops Meigen
Dolichopodidae
Empididae
Chelifera Macquart
Hemerodromia Meigen
H. rogatoris Coquillett
Rhamphomyia (Megacyttarus) Meigen
Wiedemannia Zetterstedt
Syrphidae
Helophilus Meigen
Anthomyiidae
Limnophora Robineau - Desvoidy
Ephydridae
Psilopa Fallen

Appendix V

Fish Found In The AOSERP Study Area

Table 34. Fish found in the AOSERP study area.

Family and Generic Names	Common Names
Family Salmonidae	
Salvelinus malma (Walbaum)	Dolly Varden
Salvelinus namaycush	Lake trout
Salvelinus gairdneri	Rainbow trout
Family Coregonidae	
Coregonus clupeaformis (Mitchill)	Lake whitefish
Prosopium williamsoni (Girard)	Mountain whitefish
Family Thymallidae	
Thymallus arcticus (Pallas)	Arctic grayling
Family Hiodontidae	
Hiodon alosoides (Rafinesque)	Goldeye
Family Esocidae	
Esox lucius Linnaeus	Northern pike
Family Cyprinidae	
Chrosomus eos Cope	Northern redbelly dace
Chrosomus neogaeus (Cope)	Finescale dace
Couesius plumbeus (Agassiz)	Lake chub
Hybognathus hankinsoni Hubbs*	Brassy minnow
Notropis atherinoides Rafinesque	Emerald shiner
Notropis hudsonius (Clinton)	Spottail shiner
Pimephales promelas Rafinesque	Fathead minnow
Platygobio gracilis (Richardson)	Flathead chub
Rhinichthys cataractae (Valenciennes)	Longnose dace
Semotilus margarita (Cope)*	Pearl dace
Family Catostomidae	
Catostomus catostomus (Forster)	Lognose sucker
Catostomus commersoni (Lacépède)	White sucker
Family Gadidae	
Lota lota (Linnaeus)	Burbot
Family Gasterosteidae	
Culaea inconstans (Kirtland)	Brook stickleback
Pungitius pungitius (Linnaeus)	Ninespine stickleback
Family Percopsidae	
Percopsis omiscomaycus (Walbaum)	Trout-perch
Family Percidae	
Perca flavescens (Mitchill)	Yellow perch
Stizostedion vitreum (Mitchill)	Walleye
Etheostoma exile (Girard)*	Iowa darter

Appendix VI

Financial Statement

With the signing of the Canada-Alberta Agreement in February 1975, provision was made for funding the Alberta Oil Sands Environmental Research Program with up to $4.0 million. The agreement stated that Alberta's contribution would be at least $2.0 million and Canada's contribution would not exceed $2.0 million.

Under the terms of the original agreement, Alberta was charged with the responsibility for managing the Program. Federal funds were allocated to the various services in Fisheries and Environment Canada, to be spent on AOSERP-related projects as directed by the Program Management Office. Funds were allocated directly to AOSERP through the Alberta Department of Environment, which had been assigned responsibility for program management.

The Amended Agreement (September 1977) made provisions for Alberta to be the "banker", whereby Alberta funded all contract research in the first instance and provided research support to all projects. Hence, Alberta's budget for 1978-79 was $4.0 million, of which $2.0 million is recoverable from the Federal Government.

Initially, during early development of AOSERP, most of the Program budget was spent within Provincial or Federal government line agencies. However, as can be seen from Table 35, allocation of funds has shifted toward contract, rather than "in house" activities. This trend is expected to increase in the future.

Table 36 provides information on the Program budget and expenditures since inception of the Program. The Alberta contribution to the budget in 1977-78 was reduced from $2.5 million to $2.0 million; however, an additional $660,000 was received as a special warrant to offset payments received from the Federal Government for support services provided by the Program for Federal projects. In the 1978-79 budget, funds have been provided to obviate the need for further special warrants.

Table 35. Distribution of AOSERP research project funds during the years 1975-76, 1976-77, 1977-78, and 1978-79.

Recipient	Year							
	1975-76		1976-77		1977-78		1978-79[a]	
	Amount (approx.)	%	Amount (approx.)	%	Amount (approx.)	%	Amount (approx.)	%
Government	$2,872,298	82	$3,230,368	72	$2,057,275	62	$1,506,700	48
University	302,707	9	788,017	18	468,822	14	187,000	6
Consultant	340,594	10	481,615	11	785,808	24	1,478,000	47

[a]Projected distribution.

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Fiscal Year	System	FEDERAL Budget	FEDERAL Expenditure	PROVINCIAL Budget	PROVINCIAL Expenditure
1975-76	Human	-	-	$ 58,000.00	$ 35,713.00
	Water	$998,000.00	$442,932.00	737,000.00	158,501.00
	Land	286,000.00	197,247.00	1,078,000.00	951,940.00
	Air	716,000.00	529,800.00	347,000.00	119,842.00
	Program Management	-	-	280,000.00	947,655.00
	TOTAL	$2,000,000.00	$1,169,979.00	$2,500,000.00	$2,213,651.00
1976-77	Human	-	-	$ 131,000.00	$ 64,974.00
	Water	$ 735,000.00	$ 490,737.00	362,000.00	322,067.00
	Land	590,000.00	366,518.00	1,284,000.00	1,031,711.00
	Air	573,000.00	470,674.00	357,000.00	307,300.00
	Program Management	102,000.00	-	366,000.00	528,295.00
	TOTAL	$2,000,000.00	$1,327,929.00	$2,500,000.00	$2,254,347.00
1977-78	Human		-	$ 140,000.00	$ 38,520.00
	Water	$ 767,353.00	$ 701,707.00	271,300.00	207,332.00
	Land	248,775.00	226,412.00	1,086,878.00	652,493.00
	Air	495,900.00	406,245.00	272,970.00	204,295.00
	Program Management	487,972.00	10,084.00	888,852.00	1,074,373.00
	TOTAL	$2,000,000.00	$1,344,448.00	$2,660,000.00	$2,177,013.00

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5. HY 3.1 The Evaluation of Wastewaters from an Oil Sands Extraction Plant
6. Housing for the North — The Stackwell System
7. AF 3.1.1 A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8. AF 1.2.1 The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9. ME 3.3 Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
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11. AF 2.2.1 Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
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23. AF 1.1.2 Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
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25. ME 3.5.1 Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area
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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
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32. AOSERP Third Annual Report, 1977-78
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36. AF 4.8.1 Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
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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. VE 7.1 Interim Report on Reclamation for Afforestation by Suitable Native and Introduced Tree and Shrub Species
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