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ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

Baseline Inventory of Aquatic Macrophyte Species Distributions in the AOSERP Study Area

Project LS 10.2

August 1980

Sponsored jointly by

Alberta ENVIRONMENT

Environment Canada Environnement Canada

15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta, Canada
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ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

RESEARCH REPORTS

These research reports describe the results of investigations funded under the Alberta Oil Sands Environmental Research Program, which was established by agreement between the Governments of Alberta and Canada in February 1975 (amended September 1977). This 10-year program is designed to direct and co-ordinate research projects concerned with the environmental effects of development of the Athabasca Oil Sands in Alberta.

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

Enquiries pertaining to the Canada-Alberta Agreement or other reports in the series should be directed to:

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Baseline Inventory of Aquatic Macrophyte

Species Distributions in the

AOSERP Study Area

Project LS 10.2

AOSERP Report 100

This report may be cited as:

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

and

The Hon. John Fraser
Minister of the Environment
Environment Canada
Ottawa, Ontario

Sirs:

Enclosed is the report "Baseline Inventory of Aquatic Macrophyte Species Distributions in the AOSERP Study Area".

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

Respectfully,

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

for
A.H. Macpherson, Ph.D.
Member, Steering Committee, AOSERP
Regional Director-General
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Western and Northern Region

BASELINE INVENTORY OF AQUATIC MACROPHYTE SPECIES DISTRIBUTIONS IN THE AOSERP STUDY AREA

DESCRIPTIVE SUMMARY

Aquatic macrophytes perform an important role in the food chain of invertebrates, fish, waterfowl, and mammals. In addition, they constitute an important element of aquatic ecosystems harbouring diverse populations of invertebrates, epiphytic algae, and bacteria. They provide protection for young fish and developing insects and nesting sites for a wide variety of birds.

This project was carried out in co-operation with Project LS 2.3.1 (Phase 1 Habitat Mapping of the AOSERP Study Area).

The objectives of this project were to:

1. Obtain baseline data on the distribution of aquatic macrophytes, including emergent, submergent, and floating species, as plant communities in lakes, rivers, and muskeg areas;
2. Relate these communities to the habitat types of inclusion on vegetation maps developed in Project LS 2.3.1, and to map the significant rooted communities on the 1:50 000 working maps; and
3. Define and quantify the relationships between community structure and aquatic habitat factors with the emphasis on providing a strategy for reclamation of these community types in areas disturbed by oil sands development.

This report has been reviewed and accepted by the Alberta Oil Sands Environmental Research Program. In view of the value of the document, AOSERP Management recommends that the report be published as soon as possible.

W.R. MacDonald
Director (1980-81)
Alberta Oil Sands Environmental
Research Program

BASELINE INVENTORY OF AQUATIC MACROPHYTE SPECIES DISTRIBUTIONS IN THE AOSERP STUDY AREA

by

M.S. THOMPSON

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BEAK Consultants Ltd.

for

ALBERTA OIL SANDS
ENVIRONMENTAL RESEARCH PROGRAM

Project LS 10.2

August 1980

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ABSTRACT

This study evaluates the growth of aquatic macrophytes in selected lakes within the AOSERP study area in terms of lake type, and the feasibility of mapping such aquatic macrophytes using the existing FCIR photography of the study area.

Field surveys were carried out during August 1978. Ten lakes or groups of lakes were examined in the field and the data utilized to establish three major classes of lakes within the study area: Class 1 (Eutrophic); Class 2 (Limited Growth); and Class 3 (Oligotrophic). Through examination of the 1:60 000 scale FCIR photographs, a legend for mapping aquatic macrophytes was developed which divided aquatic macrophytes into their three major classes (emergent, floating, and submergent) and allowed for species identification where possible. A complete description of each vegetation type included in the legend is presented, as well as a key for photo interpretation. Examples of the mapping are included.

The relationship between aquatic macrophyte growth and habitat factors as found in the AOSERP study area is outlined, as are some of the implications of aquatic macrophyte inventory for management and reclamation of such vegetation. Recommendations for further work state that mapping according to the developed legend should be carried out immediately, for inclusion on the vegetation overlay of the Ecological Habitat Maps.

Finally, an annotated bibliography includes literature on the growth, species, and habitat of aquatic macrophytes in the AOSERP and similar study areas, as well as on the use of remote sensing for identification and mapping of aquatic vegetation.

ACKNOWLEDGEMENTS

This research project LS 10.2 was funded by the Alberta Oil Sands Environmental Research Program, a joint Alberta-Canada research program established to fund, direct, and co-ordinate environmental research in the Athabasca Oil Sands area of northeastern Alberta.

Appreciation is extended to D. Hadler, Field Manager for AOSERP, Fort McMurray, for his assistance with the field equipment, and to the skin diving team, W. Johnson and T. Gates, Beak Consultants Ltd.

1. INTRODUCTION

This study is concerned with aquatic macrophytes in the Alberta Oil Sands Environmental Research Program (AOSERP) study area, their typical habitat, growth characteristics, and species, and the feasibility of mapping these macrophytes using the 1:60 000 scale false colour infrared (FCIR) photography available for the study area. The study has been limited to consideration of aquatic macrophytes in lotic habitat (lakes and ponds) rather than lentic habitats (rivers and streams), and generally may be said to include those plants found within the littoral zone (i.e., the shallow-water region of the lake or pond with light penetration to the bottom, typically occupied by rooted plants). The term "aquatic macrophytes" refers to the macroscopic forms of aquatic vegetation, and includes true angiosperms, a few species of pteridophytes (ferns), bryophytes (mosses) adapted to aquatic habitat, and macroalgae (e.g., *Chara*) (Wetzel 1975:357).

The AOSERP study area covers approximately 28 000 km^2 in northeastern Alberta (Figure 1). In 1977 and 1978, FCIR photography of the entire study area was obtained at a scale of 1:60 000 and a major mapping project carried out to map vegetation, surficial geology, land use, and drainage from these reconnaissance-scale photographs (Thompson et al. 1978; Thompson 1979). Previous studies have dealt with terrestrial vegetation (Stringer 1976), with fish and aquatic habitat related to fish (Bond and Machniak 1977; Renewable Resources Consulting Services Ltd. 1975a, 1975b, 1976, 1977; Turner 1968), and with present and anticipated water quality in the AOSERP study area (Lutz and Hendzel 1976; Machniak 1976; Jantzie 1977). Most of these studies have treated aquatic macrophytes superficially or not at all.

In an area such as the AOSERP study area where there are many water bodies of widely varying size and trophic level, and where anticipated changes from oil sands development to drainage and thus aquatic habitat for fish, semi-aquatic mammals and waterfowl are great, the implications for management and reclamation of this resource are important. In order to effectively manage or reclaim

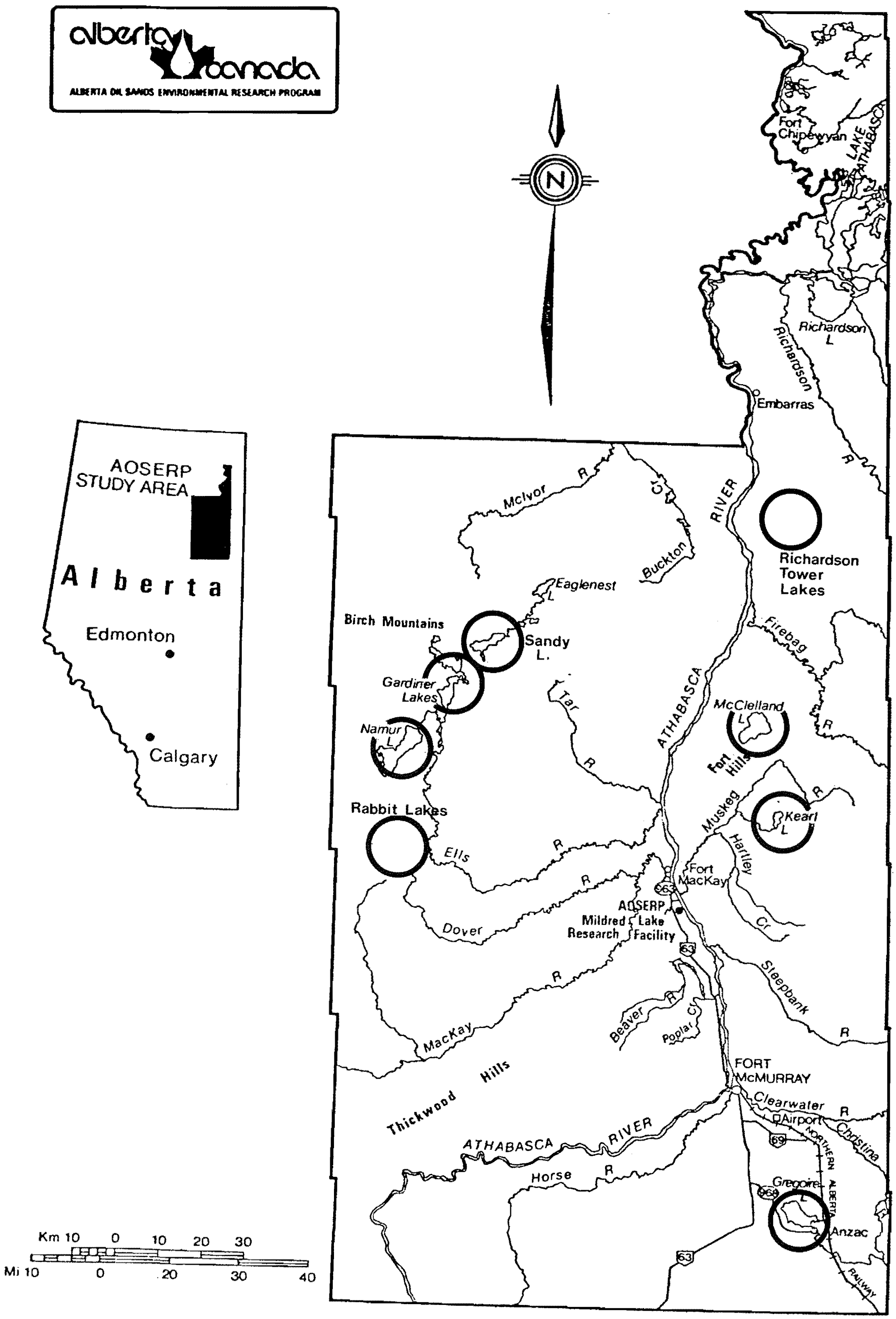

Figure 1. AOSERP study area and lakes selected (circled) for aquatic macrophyte study.

any resource, it is first necessary to inventory. In the AOSERP study area this has been done for terrestrial geology (Thompson et al. 1978) and soils (Alberta Research Council in prep.); this study examines the feasibility of doing the same for aquatic macrophytes.

Section 2 describes the field surveys and lake classification which were carried out during 1978 for the purpose of identifying and mapping aquatic macrophytes in selected lakes in the study area. Three classes of lakes in the area are identified, based on their trophic state as determined from presence and abundance of aquatic macrophytes.

Following the presentation of the field data, the feasibility of mapping aquatic macrophytes from remote sensing imagery is discussed (Section 3). A legend is presented for mapping of aquatic macrophytes using the 1:60 000 scale FCIR photography. The types of vegetation which can be mapped are given for each of three lake classes at the 1:60 000 scale, and one example of more detailed mapping at a scale of 1:15 000 is also included. Then, a description of the relationship between growth of aquatic macrophyte community and habitat factors as determined from the mapping and ground surveys is presented, and implications for management and reclamation within the AOSERP study area discussed. Finally, the result are summarized, conclusions drawn, and recommendations made.

Section 7 presents an annotated bibliography on two themes. Published material on aquatic macrophyte communities in the AOSERP study area and similar North American areas is first presented. Then, an annotated bibliography on the use of remote sensing for evaluation and mapping of aquatic macrophytes in similar areas is included.

2. FIELD SURVEYS AND LAKE CLASSIFICATION IN THE AOSERP STUDY AREA

2.1 METHODOLOGY

This study used false colour infrared aerial photographs (obtained in 1977 for the AOSERP study area) for initial selection of the lakes of interest. Following this selection, field studies were to be carried out to assess macrophyte growth and habitat characteristics in these selected lakes, where possible. A preliminary classification of lakes by type and abundance of macrophyte growth was conducted prior to and during the field surveys so that representative lake types would be included in the analysis. Following the field surveys and analysis of the field data, the aerial photographs were again examined and aquatic macrophytes mapped for selected lakes. The latter analysis is described in full in Section 3, while this section covers the selection and description of lakes for study, ground truthing techniques, and preliminary classification of lakes.

First, however, the three major classes of aquatic macrophytes discussed in the following sections should be defined. The first class, emergent aquatic macrophytes, consists of rooted plants with principal photosynthetic surfaces projecting above the water (Odum 1971); they grow where the water table is 0.5 m below the soil surface to where the sediment is covered by 1.5 m of water (Wetzel 1975). They are usually large and erect, with long narrow leaves (Mills 1972). Cattails (*Typha* sp.) are the most widespread and usually dominant, occurring over a wide latitudinal range. Also included in this class are bulrushes (*Scirpus*), horsetail (*Equisetum*), arrowhead (*Sagittaria*), spike rushes (*Eleocharis*), and others (Figure 2). Such emergent vegetation, together with the often adjacent wetland vegetation on the shore, links the land and water environments. It provides food and shelter for amphibious animals, and entry and exit to the water for aquatic insects.

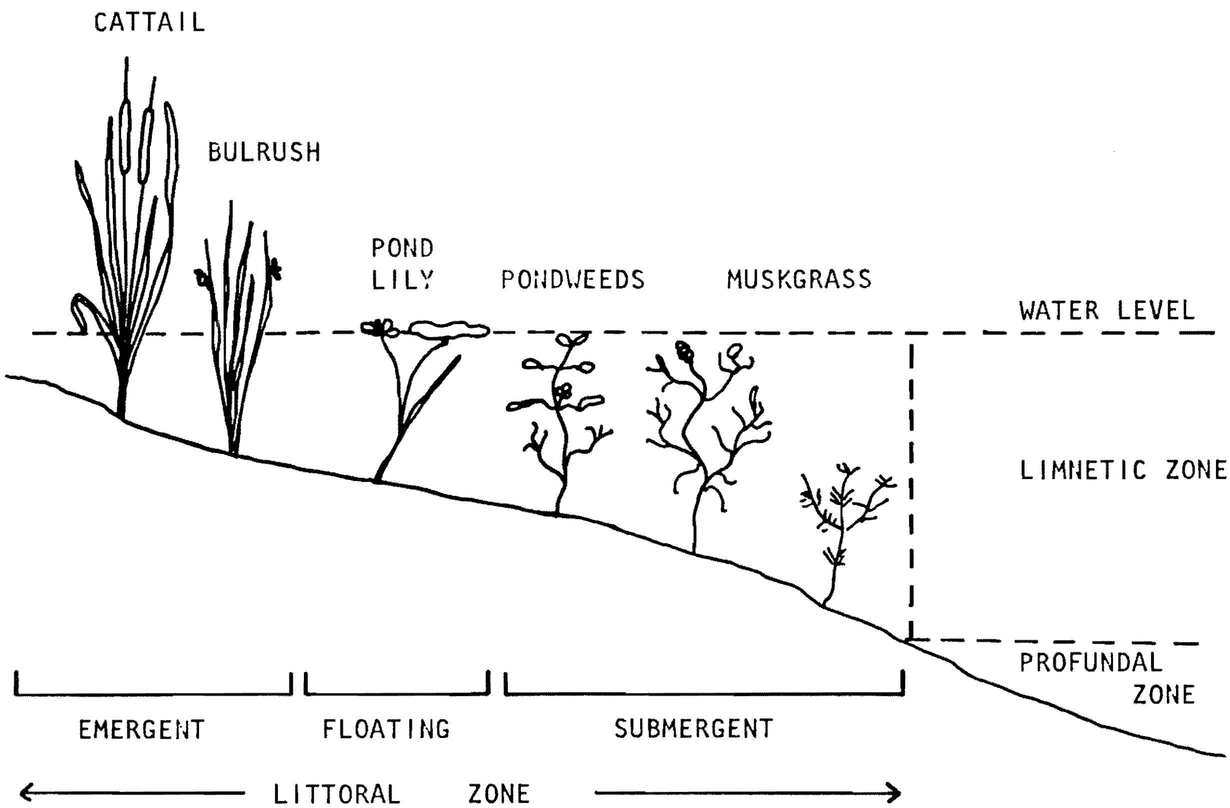

Figure 2. Aquatic macrophytes within the littoral zone (adapted from Odum 1971).

Second, floating aquatic macrophytes (primarily angiosperms) are usually rooted but have floating leaves, and are typified by the water or pond lily (*Nymphaea* and *Nuphar*) and some species of *Potamogeton*. They are found at water depths from 1.5 to 3 m (Wetzel 1975), slightly deeper in the littoral zone than the emergent plants (Figure 2). Their horizontal photosynthetic surfaces reduce light penetration into the water below.

Finally, submergent aquatic macrophytes (mostly angiosperms, but also mosses, charophytes, and pteridophytes) are completely or mostly submerged and usually rooted. They often have thin, finely divided leaves and typical genera include species of pondweeds (*Potamogeton*), water milfoil (*Myriophyllum*), water weed (*Elodea*), naiads (*Najas*), and muskgrass (*Chara*). The latter, although an alga, is sometimes ecologically classed with submerged macrophytes because of its life form resembling that of higher plants (Odum 1971). These macrophytes are usually found at depths from 1 to 5 m, occasionally as deep as 10 m in exceptionally clear water. The lowest depth generally defines the limit of the littoral zone (Figure 2).

2.1.1 Initial Selection of Lakes for Field Study

First, all of the summer FCIR photography (i.e., that obtained in July and August 1977) at scales of 1:60 000 (almost complete study area coverage), plus 1:30 000 and 1:15 000 (seven 32.2 km transects within the study area), was examined. Although October FCIR photography was available for the missing portions of the study area, it was not suitable for evaluation of aquatic macrophyte growth as most plants have senesced by that time of year. Further coverage (flown at 1:60 000 scale during summer of 1978) was not available prior to the field surveys, although it was examined following the field surveys.

When the photographs were first examined, all lakes showing macrophyte growth on the 1:60 000 scale photographs were considered. Then, a division was made according to the type of growth on or around the lake (based on probable species or community type, plus abundance or density), and the morphological characteristics of the lake as seen on the photographs. Three basic lake types emerged from this initial classification. A further selection for field survey purposes was made to include lakes of all types which were also found on one of the seven transects (i.e., for which larger scale photo coverage was available). It was felt that this would add a further dimension and detail to the analysis and mapping evaluation.

Using these criteria, two larger lakes and one set of smaller lakes, were chosen for intensive ground truthing. These were Gregoire Lake, Kearl Lake and Rabbit Lakes (local name, 57°10'N, 113°45'W).

Gregoire Lake is located about 30 km southeast of Fort McMurray, between 56°26' and 56°29'N, and 111°03' and 111°12'W (Figure 1). Surface area is approximately 3400 ha with a maximum length and width of 7.5 and 5.4 km, respectively. Most of the lake is surrounded by glaciolacustrine veneer with little relief, overlying glacial moraine, with the exception of the east end, which is glacial moraine with moderate relief (Thompson et al. 1978). It is a relatively large lake of moderate depth (Table 1). Approximately one-fifth of the shoreline (on the south) is bordered by Indian Reserve 176, and another small section of the west shore is occupied by Gregoire Lake Provincial Park, with campsites and boat launching facilities. Because of its accessibility, size, and relative uniqueness in the area close to Fort McMurray, it is becoming a fairly important area for recreational activity. Water quality in the lake is also of concern because of its proximity to the AMOCO Canada Plant (on the east side of the lake).

On the aerial photographs, aquatic macrophytes were seen in sheltered bays on the west and east sides, as well as along much of the south shore. Some sediment patterns were also noted in the water. Finally, since the west shore of Gregoire Lake is included on the larger scale photography from Flightline 20 (Thompson et al. 1978), it was decided that this lake was a suitable choice for detailed investigations.

Table 1. Selected physical and chemical characteristics of some lakes in the AOSERP area.

	Gregoire Lake	Kearl Lake	Namur Lake	McClelland Lake	Lower Gardiner Lake	Rabbit Lake
Max. Depth (m)	7.6[e]	1.8[e]	28.0[a]	6.7[e]	13.7[a]	-
Mean Depth (m)	4.2[e]	-	13.1[a]	3.1[e]	6.1[a]	
Surface Area (ha)	3387.7[e]	543.9[e]	4369.3[a]	2823.1[e]	2408.1[a]	-
Volume (m^3)	-	-	$578.5\text{x}10^{6}$[a]	-	$144.3\text{x}10^{1}$[a]	-
pH	7.6-7.8[b]	-	6.8-7.1[b] 6.0-7.1[a]	7.8-8.9[f] 8.4[c]	7.5[a] 7.5[b]	- -
D.O. Surface (ppm)	-	-	9.0[a]	10.3[c]	8.0[a]	-
Conductivity (ppmhos/cm^{-2}) at 18°C	-	-	40-48[a]	195-240[f] 204[c]	100[a] 96	-
Total Aklalinity (ppm $CaCO_3$)	50-55	-	20-30[a] 20-30[b]	54-126[f] 117[c]	45[c] 60-70[b] 60-75[a]	- -
Total Hardness (ppm $CaCO_3$)	-	-	25[a]	75-124[f] 104[c]	46[a] 45[a]	-
Calcium Hardness (ppm $CaCO_3$)	-	-	20[a]	-	40[a]	-

Continued...

Table 1. Concluded.

	Gregoire Lake	Kearl Lake	Namur Lake	McClelland Lake	Lower Gardiner Lake	Rabbit Lake
Ortho-PO (ppm)	-	-	-	< 0.05[c]	< 0.05[c]	-
Total PO (ppm)	-	-	-	< 0.1-0.45[f] < 0.05[c]	< 0.05[c]	-
Total N (ppm)	-	-	-	< 2.5[c]	0.34[c]	-
NO -N (ppm)	-	-	-	< 0.1[f] < 0.5	< 0.5[c]	-
Color (Co-Pt units)	20[d]	30[d]	-	5[c]	45[c] 20[d]	-
Turbidity (JTU)	2.2[d]	1.4	-	1[c]	1.4-1.5[c]	8.7[d]
Secchi	1.0	-	-	4.6[c]	1.52[c]	-
Non-filterable residue (ppm)	3[d]	5	-	-	2	9
Remarks:	Moderately eutrophic[d]	Shallow, highly productive, high coverage emergent and submergent aquatic vegetation	Oligotrophic	No fish, highly eutrophic, high winterkill potential	Moderately eutrophic	Shallow, very silty[d]

[a] Turner 1968
[b] INTEG 1973
[c] Renewable Resources Consulting Services Ltd. 1974
[d] Beak, present study
[e] Renewable Resources Consulting Services Ltd. 1975b
[f] Renewable Resources Consulting Services Ltd. 1977

Kearl Lake is found about 65 km north-northeast of Fort McMurray, between 57°16' and 57°18'N, and 111°14' and 111°16'W (Figure 1). Its surface area is about 500 ha with maximum length and width of 4.2 and 2.1 km, respectively (Table 1). About one-half of the lake (the east side) is surrounded by fen and bog (glacio-lacustrine blanket over fluvioglacial outwash plain deposits) while the north and west sides are better drained (inclined glaciofluvial kame deposits). Although seismic cuts run near the lake, it is essentially inaccessible except by air.

The lake has been studied by other researchers, primarily for wildlife habitat (Dr. F. Gilbert, Department of Zoology, University of Guelph, personal communication, December 1978). In addition, the east side of Kearl Lake is covered on the larger scale photography from Flightline 19.

On the aerial photographs, abundant aquatic macrophyte growth could be seen in and around this shallow lake. Emergent, floating, and submergent species could be seen extensively, so that it appeared to be a good choice for detailed sampling. It also was obviously a different type of lake from Gregoire, typical of the shallow, vegetation-choked eutrophic lake type.

The Rabbit Lakes are found about 75 km northwest of Fort McMurray and south of Namur Lake, between 57°10' and 57°15'N and 112°35' and 112°45'W (Figure 1). There are eight small lakes in this set, the largest about 350 ha and the smallest 20 ha in area. The most northern is known locally as Rabbit Lake, and its maximum length and width are both 1.9 km. All of these lakes are relatively shallow, even more so than Kearl Lake. Most are bordered by wetland bog or fen, and a few are interconnected by a drainage course. The northernmost lake which lies in hummocky glacial moraine with moderate relief (Thompson et al. 1978) drains into the Snipe River drainage system, while the rest either drain internally or are connected to the Dover River drainage. The latter lakes are found on a gentle glaciolacustrine blanket overlying glacial moraine (ibid.). Although one seismic line runs into the smallest, most southern lake, the area is inaccessible except by air. The northernmost lake was an important pelican nesting area in 1978. These lakes are covered on the larger scale photography of Flightline 15.

These lakes appeared to be of interest for this study because of their small size (as compared with Gregoire and Kearl), their close promiximity to each other, and their obvious differences in aquatic macrophyte growth, both with respect to species and abundance. Some showed abundant submergent growth in relatively clear water, others heavy floating macrophyte growth in centre, one heavy floating macrophyte growth near the edges, one sparse submergent growth only, and still others only emergent macrophytes around the periphery.

It was felt that the above-described lakes (Gregoire, Kearl, and the Rabbit lakes) included the range of lakes with abundant aquatic macrophyte growth encountered within the AOSERP study area. For the field survey, enlargements were made of the relevant FCIR 1:60 000 scale photographs in black and white. This enabled exact location in the field and comparison of aquatic macrophytes seen in the field with those seen on the photographs.

In addition to investigations of the above lakes, consultations with AOSERP staff and other researchers led to the inclusion of a number of other lakes of interest within the AOSERP study area. These were important for recreational purposes, as well as for wildlife studies and other reasons.

The Richardson Tower Lakes are located at about 57°55'N and 111°11'W, northeast of the Richardson Fire Tower. In the area covered by a sandy eolian veneer, there are numerous relatively small lakes, most of which are notable for their white sand beaches, very clear, relatively shallow water, and absence of macrophytes. Recreation potential for these lakes is considered very high, in view of their physical characteristics, even though their location is remote.

Sandy Lake is the local name for the lake located at 57°40'N, 112°25'W, north of the upper and lower Gardiner Lakes (from 57°27' to 57°40'N, and from 112°15' to 112°35'W). Aside from a few seismic lines, these lakes are virtually inaccessible except by air. They are relatively large (like Gregoire), but differ by being deeper and having less turbid water.

Namur Lake is located southwest of the Gardiner Lakes and north of the Rabbit Lakes and, with the exception of Richardson Lake near the Athabasca Delta, is the largest lake in the AOSERP study area (surface area of approximately 4400 ha). Its maximum length and width are 13.3 and 5.3 km, respectively, and it is a deep lake (Table 1). Located on hummocky glacial moraine with moderate relief, it drains through the Namur River into the Gardiner Lakes, and then into the Ells River drainage system. Nearly all of the east shore is bordered by the Namur Lake Indian Reserve 174B, and the lake is relatively inaccessible except by air.

2.1.2 Ground Survey Techniques

Three approaches were taken to survey aquatic macrophytes in the lakes of interest:

1. Planned Intensive Ground Survey
   Two major lakes had been chosen as described in Section 2.1.1 as showing wide diversity in aquatic macrophyte patterns and physical characteristics: Gregoire Lake and Kearl Lake. These lakes were surveyed relatively intensively from an inflatable boat using skin divers and surface observers at each location in the lake that showed a unique pattern in the FCIR photograph, or that showed aquatic plant growth from ground level (Figure 3 and 4). Several areas in each lake not showing growth in the photograph or from the water surface were also surveyed by the divers. The Rabbit Lakes, also selected initially for intensive ground survey, unfortunately were not accessible using the float plane and boat (they were too small to land on),

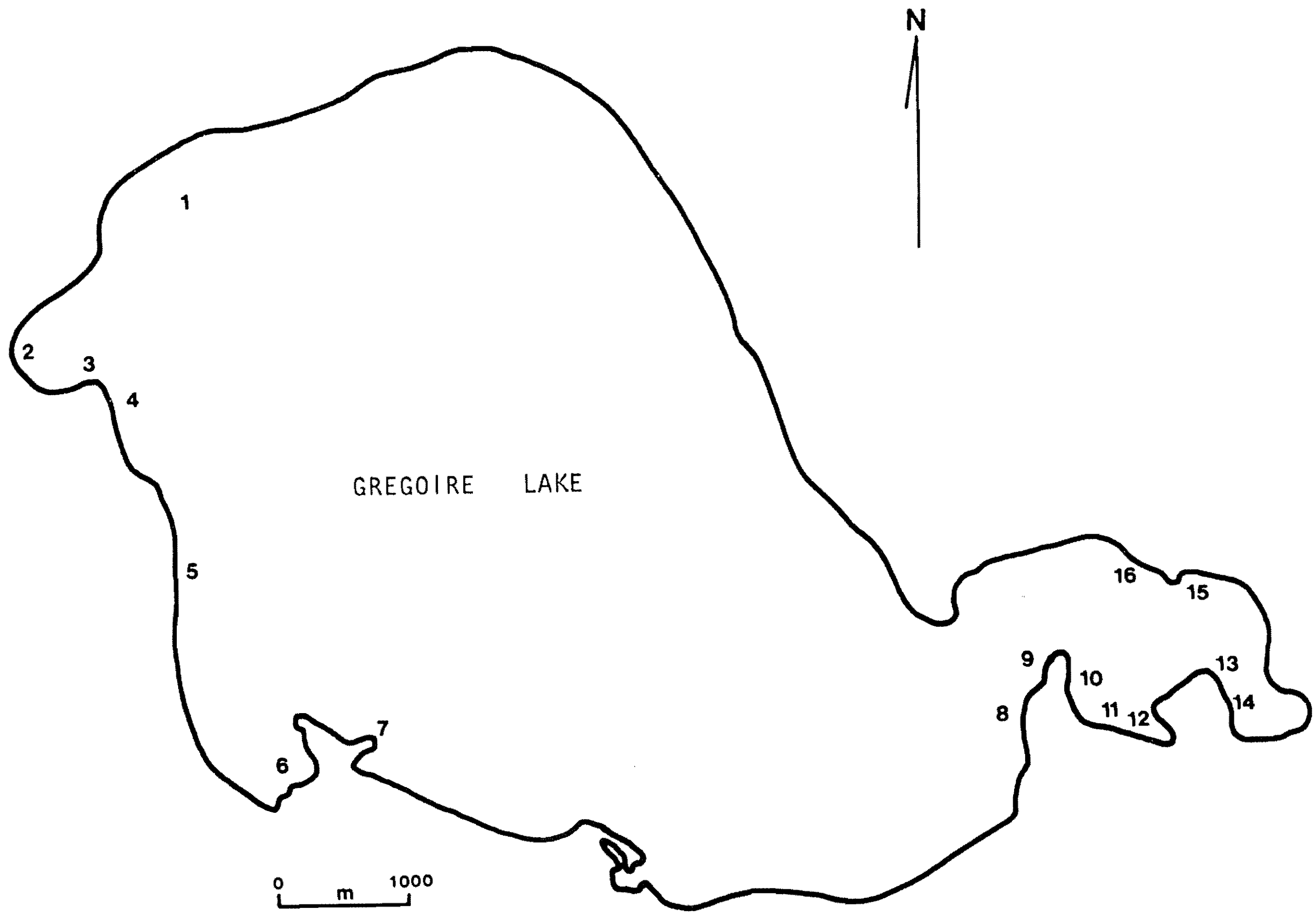

Figure 3. Gregoire Lake, aquatic macrophyte sample sites (see Table 3).

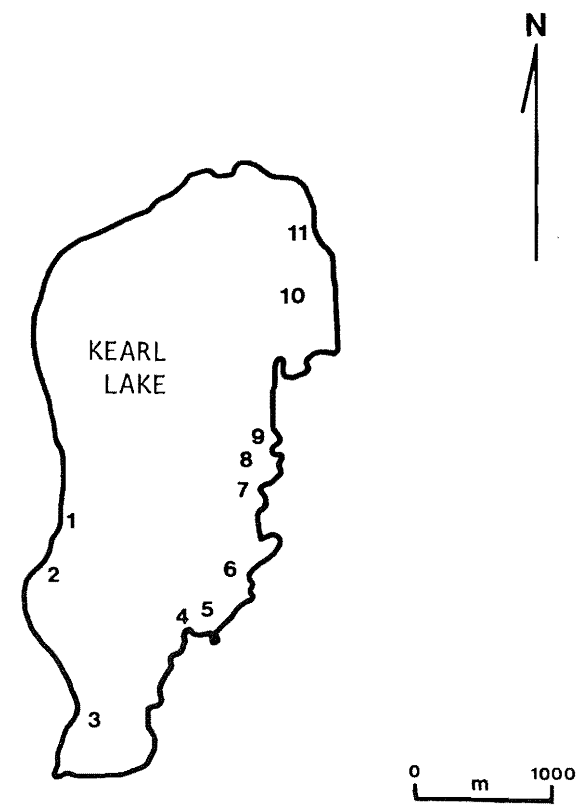

Figure 4. Kearl Lake, aquatic macrophyte sample sites (see Table 3).

so that they were surveyed as completely as possible using the other survey methods. In Gregoire and Kearl lakes, depths were measured, water samples obtained, percent cover of various species on the bottom and water surface estimated, and vegetation samples gathered. The results are presented in Section 2.2.

2. Selected Ground Survey

   Several lakes also had been selected, as described in Section 2.1.1, for consideration during the ground surveys but not for intensive data collection (these included Namur, Sandy, Gardiner, etc.). Once in the field and flying over the study area, several lakes showed more plant growth than was initially apparent in the photographs. Such lakes were circled at low elevation, a representative area of the lake chosen, and the float plane landed in this area (where the lake was large enough for landing). Observations were then made, and water and plant samples obtained from the floats of the plane and by skin diving. Lakes examined in this manner were Namur, Lower Gardiner, Sandy, Rabbit, and McClelland. The results are presented in Section 2.2.

3. Aerial Survey

   Several lakes were chosen as described in Section 2.1.1 as being of interest for various reasons but not requiring intensive survey (e.g., Richardson Tower Lakes). These, plus several of the lakes of interest (e.g., Rabbit Lakes) which were too small for landing the float plane, were flown over at low level and observations made from the air. In the majority of these, the plant species and distribution were obvious from the low-level flight over the lake, so that the observations were assumed to be reliable. Lakes surveyed in this manner included the Richardson Tower Lakes, Upper Gardiner, and the smaller Rabbit Lakes. The results are presented in Section 2.2.

2.2 PRESENTATION OF FIELD DATA

Table 2 contains a complete list of the species of aquatic macrophytes encountered in the lakes sampled, along with the abbreviations used in Table 3 to identify species. Table 3 contains a summary of the field observations of aquatic macrophytes in the lakes selected in the AOSERP study area. For each site in the lakes sampled (both intensively and from the air), species, percent cover (bottom and/or surface), and other observations are presented, plus measured depths in some cases. Figures 3 and 4 show the site locations on Gregoire and Kearl lakes, respectively. Also included in Table 3 are references to figures in the report relevant to the site described. In addition, some of the data collected in the field have already been presented in Table 1, along with relevant data from the literature. Keys used to identify plant species were those of Fasset (1957) and Moss (1974).

Three dominant species of emergent aquatic macrophytes were found in the study area--cattail (*Typha* sp.), bulrush (*Scirpus* sp.), and horsetail (*Equisetum fluviatile*). They were present to the same degree around almost every lake in which macrophytes were found, although they did not cover much of the total surface area of the lake. The major floating aquatic macrophyte species was pond lily (*Nuphar* sp.), and in the more eutrophic lakes it covered a large portion of the surface. There were many species of submergent macrophytes, with pondweeds and water milfoil the most prevalent (Table 2). Again, in the shallower eutrophic lakes, they could be found almost throughout the lake bottom, and many reached the surface of the water.

Table 2. List of aquatic macrophyte species for lakes sampled in the AOSERP study area, and corresponding abbreviations used in Table 3.

Species	Common Name	Abbreviation
EMERGENT MACROPHYTES		
Typha sp.	Cattail	Typha
Scirpus sp.	Bulrush	Scirpus
Equisetum fluviatile	Horsetail	Eqfl
FLOATING MACROPHYTES		
Nuphar sp.	Pond lily	Nuphar
Sparganium fluctuans	Bur-reed	Spfl
SUBMERGENT MACROPHYTES		
Potamogeton filiformis	Pondweed	Pfi
P. gramineus	"	Pgr
P. praelongus	"	Ppr
P. richardsonii	"	Pri
P. vaginatus	"	Pva
P. zosteriformis	"	Pz
Myriophyllum sp.	Water milfoil	Myr
Sagittaria sp.	Arrowhead	Sag
Callitricha sp.	Starwort	Call
Alisma plantago-aquatica	Broad-leaved water Plantain	Ap-a
Najas sp.	Naiad	Najas
Utricularia vulgaris	Bladderwort	Utvu
Ceratophyllum demersum	Coontail	Cede
Chara sp.	Muskgrass	Chara

Table 3. Summary of field observations of aquatic macrophytes in selected lakes in AOSERP study area.

Lake & Date sampled	Site	Depth	Species	Percent cover[a]	Observations	Reference Figures
Gregoire Lake August 23, 1978	1	-	NA	0	no weeds obvious but turbid water reduced visibility - shore bare	3,10
	2a	15	Ppr[b]	B01	some reaching to surface, bottom 99% bare	3,5,10
	2b	1.5	Pz	B10,S50		3,5,10
			Ch	B40,	0.3m tall	
			Pgr	B01		
			Myr	B01		
			Cede	B01		
			Call	B01		
	2c	1.3	Nuphar	S50	-	3,5,10
			Pz	B01	-	
			Myr	B01		
			Ap-a	B01		
	3	-	Pgr	S50	-	3,10
	4	-	Scirpus	-	-	3,6,10
			Egfl		dense patches	
	5	-	Scirpus	-	in band to the west of beach clearing	3,10
	6	-	Eqfl	-	dense patches on either side of stream outlet	3,10
			Spfl		sparsely in the middle	
	7	-	-	-	dry sand spit around outlet of creed - water levels much lower in August 1978 than in 1977	3,10
	8	2.0	Pgr, Pfi	S05	-	3,10
	9	-	Scirpus	-	in dense and extensive stands	3,10
	10	-	Nuphar	S80	-	3,10
			Typha	-	dense along shore	
			Myr	S80	in dense patches in bay	
	11	-	Nuphar	S05	-	3,10
			Scirpus	S05	-	
	12	-	Nuphar	S60	-	3,10
	13	-	Nuphar	-	dense bed in bay	3,10

continued ...

Table 3. Continued.

Lake & Date sampled	Site	Depth	Species	Percent cover[a]	Observations	Reference Figures
Gregoire Lake August 23, 1978	14	-	Nuphar	-	-	3,10
	15	-	Nuphar	-	sparse	3,10
	16	-	Scirpus	-	dense stand	3,10
Kearl Lake August 24, 1978	1	-	Typha	-	dense stand to shore	4,9
			Pri, Pz, Myr, Utvu, Ap-a	S100	100% cover is to near surface, between Typha & Nuphar	
			Nuphar	S40	moderately dense band continuing but sparser across bay	
			Chara	S50	moderately dense in areas not covered by Nuphar, in patches between Nuphar, to surface	
	2	-	similar to Site 1	-	-	4,7,8,9
	3	-	similar to Site 1	-	-	4,9
	4	-	Typha	-	dense border on either side of stream	4,9
	5	-	Typha	-	dense border on either side of stream	4,9
			Myr	S100	to surface in stream and extending into lake at the mouth	
		-	Eqfl	-	dense stands in lake	
	6	-	Typha	-	dense stand near water edge in band 3m wide. Towards shore is possibly <u>Carex</u> spp. but inaccessible from water	4,9
			Myr	S100	dense, complete cover on surface	
			Pri	-	between Typha and Nuphar	
			Nuphar	-	moderate stand and cover at surface	
	7	-	Typha	-	major component	4,9
			Scirpus, Eqfl	-	towards lake centre from Typha	
	8	-	Scirpus	-	relatively dense stand	4,9
			Chara	B10-15	underlying Scirpus	
	9	-	Scirpus, Nuphar	-	dense	4,9
	10	-	Ppr	B05	reaches surface in patches	4,9
			Myr	B04		

continued...

Table 3. Concluded.

Lake & Date sampled	Site	Depth	Species	Percent cover[a]	Observations	Reference Figures
Kearl Lake	10		Nuphar	S05		
August 24, 1978			Chara	B01		
	11	-	Typha	-	dense border	4,9
			Nuphar	-	dense area near Typha	
			Najas	B05	-	
			Pva	B01	-	
			Pri	B01	-	
			Ap-a	B01	-	
Sandy Lake	west					
August 25, 1978	shore	-	filamentous green algae	S100	unidentified green algae in 8 m band	-
			Ppr	B10	these submergents found in 20 m band at surface	
			Pri	B02		
			Pgr	B02		
			Myr	B02		
			Sag	B01		
			Chara	B80	these submergents also in 20 m band	
			Pfi	B01		
			Call	B01		
			Myr	B01		
Lower Gardiner	north	-	Pri	B80	dense patches at water surface	-
August 25, 1978	shore		Algae bloom	-	unidentified bloom of algae 0.3 m below surface near shore	
			NA		shore is white sand	
Namur Lake	west	-	NA	-	near south end of lake (by fishing camp) - white sand beach with patches of floating and washed up wood detritus	-
August 25, 1978	shore					
McClelland Lake	-	-	NA	-	extremely clear water, white lake bottom obvious	-
August 24, 1978						
			Chara	B100	patches to 100% density	
			Ppr	-	patches reaching to surface	
Rabbit Lake	-	-	Ppr	-	small patches growing to the surface of the water	-
Other Lakes near Rabbit	-	-	Nuphar	-	dominant, of varying densities on water surface	-
			Scirpus	-	patches	

[a]S = surface
B = bottom
[b] = for explanation of symbols, see Table 2.

Figures 5 to 8 present some examples of the aquatic macrophytes seen during the field surveys. Figure 5 shows a moderate density of pond lilies on the water surface at Site 2 in Gregoire Lake (see Figure 3 for location). Some submergent species were associated with the floating vegetation, and reached close to the water surface. At this particular location, the shore is rocky and there is no cattail community present. Figure 6 was also taken at Gregoire Lake, at Site 4 (see Figure 3), and shows typical emergent vegetation stands of bulrush (left foreground) and horsetail (right background). It was noted that these stands do not appear on the 1:60 000 scale photographs.

Figure 7 illustrates the high productivity of Kearl Lake, seen near Site 2 (see Figure 4). In the left background are seen dense stands of cattail, which clearly appear on the photographs at all scales. In the foreground are pond lilies, in moderate density on the water surface. Also appearing at the water surface are submergents--water milfoil and pondweeds. All may be seen on the 1:60 000 scale photographs. Figure 8 presents a closer view of the submergent/floating aquatic macrophyte communities in Kearl Lake, near Site 2. Seen here are pondweeds, water milfoil, and pond lilies (the latter in the right foreground).

Examination of Tables 1 and 3 show that there is indeed a wide variation in the lakes selected with respect to depth, turbidity, and species and abundance of macrophyte growth. Broad classification of these lakes may be carried out on these bases, as described in the following section.

2.3 CLASSIFICATION OF LAKES IN THE AOSERP STUDY AREA

Based on preliminary interpretation of aquatic macrophytes using the FCIR photography and, following that, the field study data, lakes within the AOSERP study area were classified into three types. This classification is based on the productivity of the lake, in terms of aquatic macrophyte growth (abundance and species), as seen on the aerial photographs and sampled on the ground. The macrophytic

Figure 5. Pond lilies (*Nuphar* sp.) at Site 2 in Gregoire Lake.

Figure 6. Emergent aquatic macrophytes (bulrushes in left foreground, horsetail in right background) at Site 4 in Gregoire Lake.

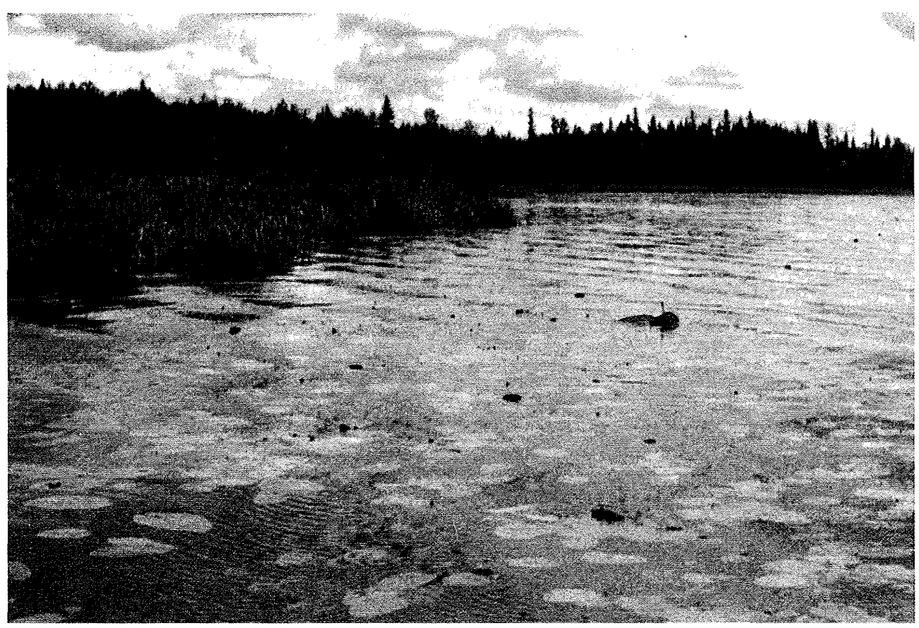

Figure 7. Dense stands of cattail, moderate density pond lilies, and submergent species being examined by skin diver near Site 2 in Kearl Lake.

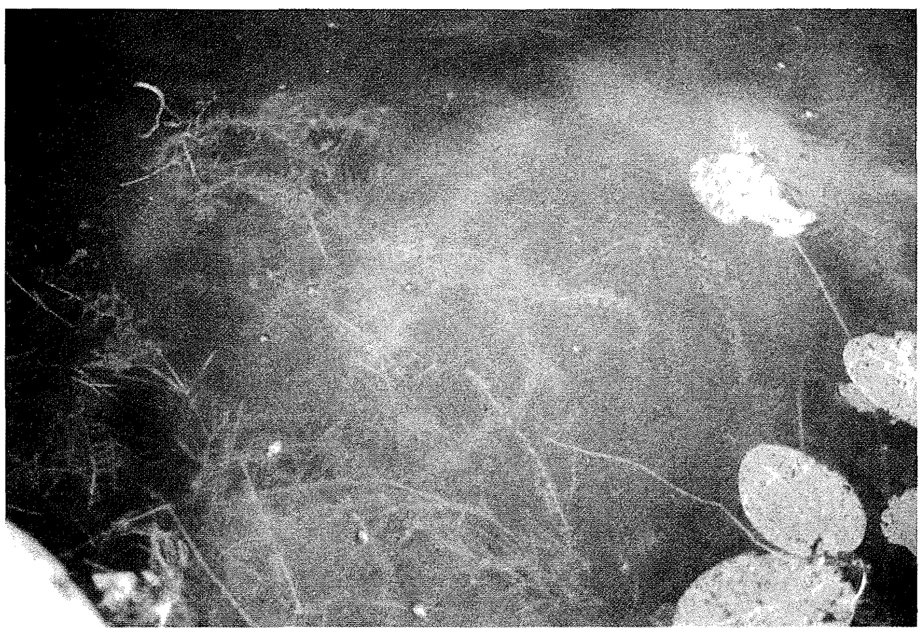

Figure 8. Closer view of submergent/floating aquatic macrophyte communities near Site 2 in Kearl Lake. Seen are *Potamogeton richardsonii*, *Myriophyllum* sp., and in the right foreground, *Nuphar* sp.

growth is then related to the overall productivity of the lake where possible. The standard description of the evolutionary ontogeny of lake systems, which emphasizes differences in inputs of organic matter (Odum 1971; Wetzel 1975), is similarly based; the terms "eutrophic" and "oligotrophic" are used to describe productive and non-productive lakes, respectively. The lake classification derived for the AOSERP study area is based on these concepts.

The typical oligotrophic lake is large and deep, has low primary productivity, scarce littoral plants, and low plankton density. Input of nutrients from external sources is low. Oligotrophic lakes are often limited by phosphorus and contain an excess of nitrogen (Wetzel 1975). As they become more productive, the primary agent is increased loading of phosphorus. Eutrophic lakes, on the other hand, are generally smaller and shallower, with high primary productivity, abundant littoral vegetation, dense plankton populations, and frequent plankton blooms. Coldwater fish are often excluded due to summer stagnation and winterkill. Levels of phosphorus and nitrogen, as well as other nutrients, are relatively high. As the rates of photosynthetic energy fixation and productivity increase, the interactions of inorganic nutrients and organic compounds increase (Wetzel 1975). Between these two extremes, there is a continuum of different stages of eutrophication, since lake systems generally move from the oligotrophic to the eutrophic state as they "age" (Odum 1971).

Lakes in the AOSERP study area were classified as follows:

1. Class 1 (Eutrophic). These lakes are very productive, usually shallow with boggy shore zones and very heavy vegetation growth on the shores and in the littoral zone. In fact, in many of these lakes, the growth of aquatic macrophytes is prevalent throughout the entire lake bottom. Such lakes are often found on relatively level terrain, often where there are fluvial or lacustrine deposits over the glacial ground moraine, such as in a glacial lake basin. This eutrophic lake

type is very common in the AOSERP study area and is typified by Kearl Lake (Figures 7, 8). Although Kearl Lake is relatively large, as is McClelland Lake, another of this type, many of the Class 1 lakes are small, such as several in the Rabbit Lake area.

2. Class 2 (Limited Growth). These lakes are neither very eutrophic, nor totally non-productive. They contain a limited amount of macrophyte growth, often only in a relatively narrow littoral zone, and there is some limiting factor to further growth in the lake. This may be the depth of the lake, type of sediment on the lake bottom, sediment load in the water (reducing the light available for submergents), chemical composition, or some other factor. Emergent vegetation may be found along the gently sloping littoral zone of a portion of the lakeshore (Figure 6), and some floating macrophytes in sheltered shallower areas (Figure 5). Submergent vegetation may be found near the shore, particularly in shallow and sheltered areas, and extending a short distance out into the lake within the littoral zone. Gregoire Lake is typical of this Class 2 type, where its size, moderate depth, and turbidity deter aquatic macrophyte growth except in limited areas.

3. Class 3 (Oligotrophic). These non-productive lakes have no or very few aquatic macrophytes. Within the AOSERP study area, there are two sub-types within this class. First, there is the large, deep, cold lake, like Namur, in which depth and wave action prevent growth of aquatic macrophytes throughout the littoral zone, although some growth is apparent in small areas of sheltered bays. The second is typified by the Richardson Tower Lakes where, although the water is extremely clear and the lake relatively shallow, the

sandy littoral zone does not provide a good rooting medium for aquatic macrophyte growth. Such lakes provide excellent locations for water-based recreation, as previously noted, and are found only in the north-east corner of the study area, where a sandy eolian veneer covers the hummocky glacial morainic material.

Table 4 presents the classification of selected lakes within the AOSERP study area, according to the above three-part classification system. Thus, Kearl, McClelland, and several small lakes in the Rabbit Lakes area are classed as euthrophic; Sandy, Lower Gardiner, Gregoire, and Rabbit lakes are classed as limited growth lakes; and Namur and the Richardson Tower lakes are classed as oligotrophic, all for reasons previously described.

The next section describes the feasibility of using remote sensing imagery for mapping the aquatic macrophytes present in lakes in the AOSERP study area.

Table 4. Classification of selected lakes within the AOSERP study area.

	Lake Classification		
Lake Sampled	Class 1 (Eutrophic)	Class 2 (Limited Growth)	Class 3 (Oligotrophic)
Kearl	X		
McClelland	X		
Gregoire		X	
Sandy		X	
Lower Gardiner		X	
Namur			X
Rabbit		X	
Richardson Tower			X

3. AQUATIC MACROPHYTE MAPPING WITH REMOTE SENSING IMAGERY

3.1 LEGEND DEVELOPMENT

As described in Section 2.1, all the July and August 1977 false colour infrared photography of the AOSERP study area was examined prior to the field surveys in August 1978. This included full coverage at a scale of 1:60 000 and coverage of seven transects of approximately 32 km in length at scales of 1:30 000 and 1:15 000. Following the field surveys, the remote sensing imagery was again examined using the field data as a check. Emphasis was placed on the lakes for which field data have been collected, but other lakes were also examined. Because complete coverage exists only at the 1:60 000 scale, and because the purpose is to evaluate the mapping of aquatic macrophytes for the entire study area at this scale, a legend was devised for aquatic macrophyte mapping at the 1:60 000 scale. As was the case for Ecological Habitat Mapping (AOSERP Projects VE 2.3 and LS 2.3.1) of terrestrial vegetation and surficial geology (Thompson et al. 1978), the legend was designed to be hierarchical in nature and thus expandable for larger scale mapping. An example of larger scale mapping from the seven transects is thus included as an illustration of this capability.

Three major categories of aquatic vegetation based on growth characteristics (Table 5) were used in the mapping legend:

1. Emergent;
2. Floating; and
3. Submergent.

The legend (Table 5) is thus divided into these three major classes of aquatic macrophytes, numbered from one to three. The prefix "Q" has been added to each class to distinguish the aquatic macrophytes from the terrestrial vegetation on the Ecological Habitat maps (should they eventually be included on the same working maps). Within the emergent and floating classes (Q1 and Q2), further subdivisions have been made on the basis of species which can be mapped at a scale of 1:60 000. Thus, in the Q1-Emergent Class, cattail, bulrush,and horsetail have been

Table 5. Aquatic macrophyte legend.

Q1	EMERGENT	
	Undifferentiated	Cattail, Bulrush, Horsetail
	T Cattail (*Typha* sp.) S Bulrush (*Scirpus* sp.) E Horsetail (*Equisetum* sp.)	
	Q1T (where too narrow to outline)	
Q2	FLOATING	
	Undifferentiated	Pond lily, Bur-reed, etc.
	N Pond lily (*Nuphar* sp.)	
Q3	SUBMERGENT	
	Undifferentiated	Water Milfoil (*Myriophyllum* sp.) Pondweed (*Potamogeton* sp.), Muskgrass (*Chara* sp.)
	M Water Milfoil P Pondweed	
(Q3)	Classification in parentheses indicates probable location of submerged macrophytes, inferred from presence of other vegetation and habitat characteristics, although not seen on the photographs.	
DENSITY CLASS[a]		
A	open	
B	medium	Example
C	dense	Q2NC Floating aquatic vegetation is yellow pond lily, with dense cover on water surface

[a]usually only for Q2 category, as Q1 almost always dense (C) and Q3 unknown.

included as major subdivisions and in the Q2-Floating Class, yellow pond-lily has been delineated. In the Q3-Submergent, Class, designations for water milfoil and pondweed have been included. Even though these are not identifiable on the FCIR photographs, this additional information may be added to the maps where known from ground surveys.

A density class rating has been included in the legend, mainly for use with the "floating" class, to roughly identify open, medium, and dense vegetation on the water surface. Also included is a symbol for use in mapping very narrow bands of cattail, to indicate its presence where it is too narrow to outline and label on the map.

The following discussion of the legend, in conjunction with Table 6 (a key for photo interpretation), provides a description of the type of aquatic macrophyte mapping which is feasible using the 1:60 000 scale FCIR photographs.

3.2 DESCRIPTION OF VEGETATION TYPES TO BE MAPPED FROM 1:60 000 SCALE FCIR PHOTOGRAPHS

The following is a description of the aquatic vegetation included in the mapping legend. The criteria for photo interpretation are summarized in Table 6.

3.2.1 Q1--Emergent Aquatic Macrophytes

3.2.1.1 Q1T cattail. This species is found in virtually monodominant stands around many of the lakes and ponds in the study area (Figure 6). The stands are typically very narrow and often difficult to map at 1:60 000 because of this characteristic. For this contingency a symbol has been added to the legend to aid in mapping. The cattail stands are easily recognizable because of their pink-brown colour, linear pattern, and "plush" texture. In some cases, the colour varies to a darker brown where stands are less dense and more widely distributed over a shallow area, or to grey-white where local clumps have died. This is one of the most reliably identified species.

Table 6. Aquatic macrophyte photo interpretation key for 1:60 000 scale FCIR photographs.

Class	Symbol	Type	Components	Situation	Pattern	Texture	Colour	Reliability of identification on 1:60 000 FCIR Photographs
EMERGENT	Q1T	Cattail	-	found in shallow water (up to 1.5 m) on pond & lake edges, usually in monodominant and dense stands	uniform, sometimes broken or mottled	fine "velvet" or "plush"	red/pink to pink/ brown	high
	Q1S	Bulrush	-	slightly deeper water than cattail off shore, in mo-nodominant, sparse and areally res-tricted bands	uniform-broken	fine-med.	very dark red/black	low
	Q1E	Horsetail	-					low
	Undifferentiated	-	cattail, bulrush and/ or horsetail	as above	-	-	-	-
FLOATING	Q2N	Pond lily	-	shallow less than 2 m and/or shel-tered areas of lake, ponds, in very dense clumps, moderately dispersed, or very sparse distribution over the water surface	usually broken	coarse	mauve/light pink to dark pink	high
	Undifferentiated	-	pond lily, bur-reed etc.	-	-	-	-	- -
SUBMERGENT	Q3		water mil-foil, pond-weeds, muskgrass	relatively shallow 1.5-4m ponds, lakes relatively sheltered best seen where they reach the surface in slightly turbid water	broken	medium	pinkish/blue or darker cyan/black in water (dark blue/black), often noted simply as a change in tone & pattern in the water	moderate

3.2.1.2 Q1S Bulrush. Bulrush stands are usually found farther out into the water than the cattail stands and are extremely difficult to detect even on the largest scale FCIR photography. These plants are tall, vertical, very slender, occasionally have small fruiting bodies (infloresence) at or near their tips, and are found in relatively open stands (Figure 5). Thus, they present very little surface area to a downward-looking camera and in most cases are not resolved on the resulting photography. This class thus has low detection reliability. However, it has been included in the legend because bulrushes are an important component of the emergent aquatic macrophytes and may be mapped at very large photo scales or with oblique photographs.

3.2.1.3 Q1E Horsetail. The same problem applies to horsetail as described for bulrushes above. Their very small surface area ("crown cover") makes this species very difficult to detect, although it is present in many of the lakes and ponds within the area, usually in conjunction with the cattail and bulrush communities (Figure 5).

3.2.1.4 Undifferentiated. This class is not used often, since if emergent vegetation can be seen, it can usually be recognized as cattail. However, in cases where the species or community type cannot be distinguished, the undifferentiated class is used. This may also indicate a combination of species or communities too small to be broken into individual units.

3.2.2 Q2--Floating Aquatic Macrophytes

3.2.2.1 Q2N Pond lily. This is by far the dominant type of floating aquatic vegetation in the study area, and certainly the most easily recognized and mapped due to its relatively large horizontal leaf surface area. The pond lilies appear in characteristic patches in shallow bays (less than 2 m deep) and in protected areas of ponds and lakes, often covering most of the water surface of smaller water bodies (Figures 5, 6). They appear light pink on the dark blue to black water surface, and vary widely in density, so that a density classification (open, medium, dense) has in most cases been added to the Q2N subclass. It has also been noted that there is usually a band of clear water between the floating vegetation and the shore or emergent vegetation (Figure 6). Ground surveys have shown that this band is often occupied by dense submerged vegetation which usually is not seen on the aerial photographs.

3.2.2.2 Undifferentiated. There are other species and communities of floating aquatic vegetation within the study area, not reliably distinguished from each other at the 1:60 000 scale, and often not at other larger scales either. When floating vegetation is seen and not identified by species, this classification is used in the mapping.

3.2.3 Q3--Submergent Aquatic Macrophytes

Many lakes and ponds in the study area are replete with submergent aquatic macrophytes, but these cannot be detected or identified on the FCIR photography with a high degree of reliability. Typical species noted in the ground surveys include water milfoil and various pondweeds; they are generally found in sheltered, shallow waters (generally to 1.5 to 4 m deep), often associated with the floating and emergent macrophytes (Figure 5, 6, 7). Water milfoil can be mapped only where growth is dense and reaching near the surface (within about 10 cm). The other most apparent submergent species were two pondweeds, *Potamogeton praelongus* and *P. richardsonii*. These were most easily identified on the photographs where growth occurred up to the water surface and where the water was slightly turbid (e.g., Rabbit Lake). Other submergents (e.g., muskgrass) do not grow close enough to the surface to the water to be identified in the photographs. On rare occasions they could be seen in low level flight in bright sunlight if the water was exceptionally clear (e.g., McClelland Lake).

In some cases it is possible to predict the abundance of submerged macrophytes even if not apparent on the photographs. For example, in lakes bordered by cattail and with pond lilies near the centre of the lake, any apparently bare area between the cattail and pond lilies is likely to support dense submergent growth (e.g., Kearl Lake, Figure 6). In lakes bordered by a clean white sand beach, the presence of macrophytes is unlikely (e.g., Richardson Tower Lakes). If a lake is known to be deep (i.e., deeper than 5 m), macrophytes will be found only in shallow bays, and then only if the substrate is soft (indicated by vegetation to water's edge or a border of cattail) and the area is sheltered from severe wave action (e.g., bays in Namur Lake).

However, predictions based on these criteria cannot be regarded as highly reliable. They only provide an indication of possible conditions of the vegetation in a lake and assist in delineation of areas for more intensive investigations if required.

3.2.4 Other Considerations for Photo Interpretation

It should be noted that, for interpretation of aquatic macrophytes, some characteristics of the existing aerial photographs are prohibitive. For example, much of the FCIR photography was carried out at a high sun angle, as recommended for terrestrial vegetation studies. However, this often causes specular reflection (sun glare) from the lakes, masking the signatures of aquatic vegetation where present. The photography of Gregoire Lake at 1:60 000 is a good example of this phenomenon: one frame of the lake is glarefree, while in the other frame, the entire lake surface is obliterated by glare. Thus aquatic macrophytes may be seen monocularly, but not in stereo as required. Future remote sensing surveys for the purpose of mapping aquatic vegetation, water quality, or other parameters associated with the water surface should take this into account in the planning stage.

3.3 EXAMPLES OF AQUATIC MACROPHYTE MAPPING

This section includes examples of the mapping which may be carried out for the various types of lakes with aquatic macrophyte growth, using the legend described in Sections 3.1 and 3.2 and the 1:60 000 scale FCIR photographs. Also included is an FCIR photograph of oligotrophic lakes with no macrophyte growth, and an example of mapping from the 1:15 000 scale FCIR photographs, to illustrate the increase in detail which is possible at such a scale.

1. Class 1 (Eutrophic Lake). Figure 9 is an FCIR photograph (1:60 000 scale) of Kearl Lake, obtained in July 1977, with an overlay showing aquatic vegetation in the lake mapped according to the previously described legend. The entire lake is bordered by a band of cattail of varying width, and much of the lake is covered by medium to sparse density pond lilies. The entire lake bottom appears to be covered by submergent vegetation. In this shallow, relatively clear lake, it is felt that nearly all of the aquatic macrophytes may be mapped with moderate to high reliability.
2. Class 2 (Limited Growth Lake). Figure 10 is an FCIR photograph (1:60 000 scale) of Gregoire Lake, obtained in July 1977, with an overlay showing aquatic vegetation in the lake mapped according to the legend described. It can be seen that the growth has occurred only in the shallow bays and sheltered areas, and does not extend very far out into this deeper, more turbid lake.
3. Class 3 (Oligotrophic Lake). Figure 11 is an FCIR Photograph (1:60 000 scale) of some of the Richardson Tower Lakes, obtained in July 1977. It is obvious from this photograph that no aquatic macrophytes are growing in the sand-bordered, clear lakes, as compared to Kearl Lake in Figure 9 for example.

In order to provide an illustration of the increased mapping detail which is possible using larger scale photography, Figure 12 presents a 1:15 000 scale FCIR photograph of a portion of the east

Figure 9. Aquatic macrophytes in Kearl Lake (Class 1), mapped over 1:60 000 scale FCIR photograph (July 1977) according to legend in Table 5.

Figure 10. Aquatic macrophytes in Gregoire Lake (Class 2), mapped over 1:60 000 scale FCIR photograph (July 1977) according to legend in Table 5.

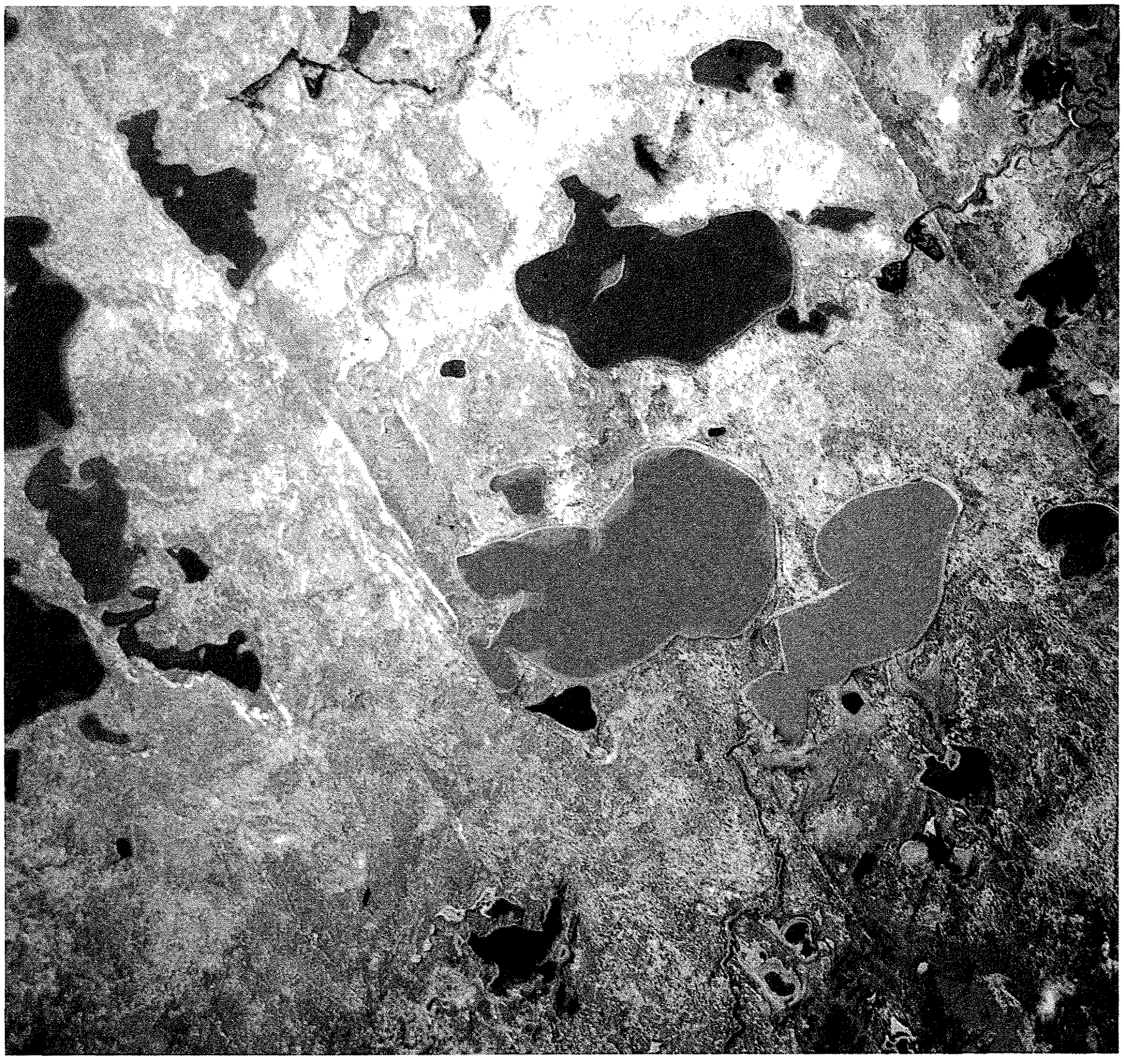

Figure 11. FCIR photograph of Class 3 lakes near the Richardson Tower. These relatively shallow, clear lakes on sandy eolian material show no macrophyte growth.

Figure 12. Aquatic macrophytes in a portion of Kearl Lake (outlined in Figure 9), mapped over 1:15 000 scale FCIR photograph (August 1977) according to legend in Table 5.

shore of Kearl Lake and an overlay showing aquatic vegetation (the exact location is outlined in Figure 9). This photograph was obtained in August 1977, four weeks later in the season than the 1:60 000 scale photograph seen in Figure 9, so that conditions may be noted to be slightly different. However, these two figures may be compared for the detail of mapping, the application of the legend for both small and large scale mapping, and thus an evaluation derived of the need for either type of mapping in a particular application.

3.4 SUMMARY

This investigation has shown that it is possible to roughly categorize the lakes within the AOSERP study area into three major trophic classes reflecting their overall productivity in relative terms, using the 1:60 000 scale FCIR photographs. Emergent, floating, and submergent aquatic macrophytes present within the first two classes of lakes (there are none or very few in the third class, oligotrophic) may be mapped with varying levels of reliability. Most reliably identified and mapped are the cattail and pond lily communities. Next are some of the submergent species where they grow close to the water surface and are in slightly turbid water. Least reliably mapped are bulrush and horsetail communities and submergent species not growing close to the water surface. However, it has been shown how the presence of submergents may occasionally be inferred from the habitat characteristics and presence of emergent and floating species.

4. AQUATIC MACROPHYTE HABITAT IN THE AOSERP STUDY AREA AND IMPLICATIONS FOR MANAGEMENT

4.1 RELATIONSHIP BETWEEN AQUATIC MACROPHYTE GROWTH AND HABITAT FACTORS

As seen from examination of the literature on aquatic macrophytes and limnological factors affecting growth in the AOSERP study area and similar areas (Section 7.1), as well as from the field surveys described in Section 2 and the remote sensing mapping in Section 3, the productivity and community composition of aquatic macrophytes are determined by a complex interaction of a multitude of factors. Any one of these factors could be limiting to a single species or to growth of aquatic macrophytes in general. However, in the majority of habitats like those in the AOSERP study area, the factors which have the greatest influence on aquatic macrophyte growth are the following:

1. Light availability, as determined by water depth and water clarity; and
2. Type of bottom sediment, as it influences nutrient availability for plant growth and rooting stability.

From the limited chemical and physical data available for selected lakes in the AOSERP study area (see Table 1), it is apparent that this is in fact the case.

Table 7 summarizes the data for six lakes in the study area and indicates the effect of light availability. Availability of light for aquatic macrophyte growth has been indicated in terms of water depth and of turbidity. When the six lakes are ranked by the relative abundance of macrophytes present, and the light availability for growth of aquatic plants compared to this ranking, a strong correlation is apparent.

Kearl Lake, which is shallow and has clear water, has the most abundant macrophyte growth. McClelland Lake with clearer water than Kearl, but greater mean depth, has less abundant growth. Gregoire Lake, deeper and more turbid, has correspondingly fewer macrophytes, and Lower Gardiner which is as clear as Kearl Lake

Table 7. Relationship between aquatic macrophyte abundance, lake depth, and turbidity for six AOSERP study area lakes.

Relative Abundance of Macrophytes	Lake	Mean Depth (m)	Turbidity (JTU)	Comments
Abundant	Kearl	1.8	1.4	Shallow, clear water
	McClelland	3.1	1.0	moderately deep, slightly turbid
	Gregoire	4.2	2.2	moderately deep, but exceptionally clear
	Lower Gardiner	6.1	1.5	clear but deep
	Rabbit	2.0	8.7	shallow, very turbid
Scarce	Namur	13.1	-	clear, very deep

but much deeper has fewer still. Rabbit Lake is relatively shallow, but is very turbid and thus growth is restricted. Finally, Namur Lake has the least macrophyte growth because of its great depth.

All of the above lakes are found on somewhat similar material--usually glacial moraine, in some cases with fine lacustrine deposite overlying the moraine. The effect of sediment type on growth of aquatic macrophytes may be seen when contrasting them with the lakes northeast of Richardson Tower. These are located on a sandy eolian veneer, and virtually no macrophytes grow in the white sand of these lakes, despite the shallow depths and exceptionally clear water.

From the data presented in Table 1, it is seen that the more eutrophic lakes have higher pH values than oligotrophic lakes in the area. McClelland Lake, a Class 1 or Eutrophic lake, has an average pH of 8.4., while Gregoire Lake, a Class 2 (Limited Growth) lake has a pH of 7.6 to 7.8, and Namur Lake (Class 3, Oligotrophic) a pH of 6.0 to 7.1. This same situation is reflected in the values for total alkalinity, where McClelland, Gregoire, and Namur lakes have values of 117, 50 to 55, and 20 to 30 ppm respectively.

Thus, a preliminary examination of the limnological habitat factors affecting growth of aquatic macrophytes in lakes in the AOSERP study area has shown that several factors are important and that they interact with one another to affect growth. It may be said, however, that the most abundant growth of macrophytes will be found in lakes which are shallow, have clear water, nutrient rich bottom sediments, and non-acidic waters. It should also be noted that relatively sheltered areas of a lake will support more macrophyte growth. The least abundant macrophyte growth will be found in deep, turbid lakes with nutrient-poor bottom sediments, acidic waters, and heavy or frequent wave action (such as found in larger lakes).

4.2 IMPLICATIONS FOR MANAGEMENT AND RECLAMATION

Identification and mapping of the presence or absence, species, abundance, and spatial distribution of aquatic macrophytes have relevance for many of the studies conducted at present or in the future within the AOSERP study area. Aquatic macrophytes provide important habitats for fish, waterfowl, and semi-aquatic mammals, in addition to insect and other life. Researchers involved in environmental studies, including waterfowl and semi-aquatic mammals, fish, limnology, water quality and hydrology, should benefit by inventory and monitoring of aquatic macrophytes.

The implications for change in aquatic macrophytes during and after oil sands development are great. This study has shown that the distribution and abundance of aquatic macrophytes in the AOSERP study area are related to a number of factors, the major ones being water depth, water clarity, and type of sediment. When any of these factors are altered, there will be a corresponding change in the distribution and abundance of aquatic macrophytes in the water body.

The future development of the oil sands is likely to affect one or more of these factors in any water body. When water levels are raised or lowered, the littoral zone is increased or decreased depending on the morphology of the lake bottom and edges, and macrophytes requiring certain depths for growth must adjust. When effluents or sediments of any type are added to the lake or pond, the clarity of the water is affected, and thus light availability for plant growth. Submergent macrophytes would likely be affected first by such a change. The bottom sediment type can be changed due to deposits of silt or clay washed in from nearby or upstream developments. Of course, if a water body is completely drained, the aquatic macrophytes will be eliminated.

This study has shown that 1:60 000 scale FCIR photography can be used, in conjunction with judicious ground surveys, to inventory certain types of aquatic macrophytes in the AOSERP study area. Most reliably mapped are emergent species (cattail, in particular) and floating species (pond lily). The distribution and abundance of these species can be very reliably mapped. It has also been shown that the presence of other communities of aquatic macrophytes (especially submergents) may be either identified in some cases, or inferred in others, according to the proximity of other mapped communities and various habitat characteristics. From this information, the general trophic levels of lakes and smaller water bodies are indicated.

This information may then be mapped for the entire AOSERP study area, to provide a set of baseline data on aquatic habitats against which future oil sands developments and their effects on aquatic macrophytes may be measured. Such baseline data would thus include the distribution of cattail and pond lily in water bodies in the study area, and less reliably the presence of submergent communities. This could be mapped directly onto the vegetation overlay of the Ecological Habitat Maps at 1:50 000 scale (Thompson et al. 1978) and thus be made available for use as a working map.

When interest for management or reclamation of a particular water body is important, then remote sensing imagery (likely FCIR plus colour photography) could be obtained at a larger scale for more detailed mapping. It will always be necessary to include ground surveys as part of the data collection, unless only a gross overview of aquatic macrophyte growth is desired. The photography may also be obtained sequentially, so that monitoring of changes in aquatic macrophytes may be carried out.

Once the distribution and abundance of aquatic macrophyte growth are known by the above inventory method then, based on actual or anticipated changes in the above-mentioned schemes (e.g., harvesting, restoring water levels, herbiciding, reducing chemical effluent) may be carried out. Finally, the effects of such measures may be monitored and their effectiveness evaluated using the same techniques.

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSIONS

This study has evaluated the growth of aquatic macrophytes in selected lakes within the AOSERP study area in terms of lake type, and the feasibility of mapping such aquatic macrophytes using the existing FCIR photography of the study area.

First, the field surveys which were carried out in August 1978 and the preliminary classification of lakes within the study area were described. The methodology for initial selection of lakes for the field study and for the ground surveys was presented, followed by the data collected in the field and from the literature for selected lakes. Intensive ground surveys were carried out on Kearl and Gregoire lakes, less intensive work done on Namur, Lower Gardiner, Sandy, Rabbit and McClelland lakes, and aerial surveys carried out on the Richardson Tower Lakes, Upper Gardiner Lake and the smaller Rabbit Lakes. The field data were summarized in tabular form and a list of aquatic macrophyte species from the selected lakes presented. Finally, the three major lake classes encountered within the study area were detailed: Class 1 (Eutrophic); Class 2 (Limited Growth); and Class 3 (Oligotrophic).

Section 3 discussed the feasibility of mapping the aquatic macrophytes present in lakes in the study area using the existing FCIR photography of the study area (1:60 000 scale). A legend for such mapping was presented which divided aquatic macrophytes into their three major classes (emergent, floating, and submergent) and allowed species identification where possible. A density identifier was included for the floating vegetation class, as well as a symbol for mapping narrow emergent vegetation units.

Each vegetation type included in the legend was then described based on the field and literature surveys, plus the information on spatial distribution obtained on a sample basis for the FCIR photographs. A key for the interpretation of the aquatic vegetation types in the AOSERP study area was included in tabular form. Finally, examples of the mapping of aquatic macrophytes using the FCIR photography were presented. For each of the three lake types (Class 1, 2 and 3), an FCIR photograph was included, the first two with an overlay showing mapped aquatic macrophytes using the legend described above, at the 1:60 000 scale. One example of mapping at the 1:15 000 scale was also included, to illustrate the additional detail possible with larger scale photography, plus the expandability of the legend.

This evaluation showed that the 1:60 000 scale FCIR photography may be used to map the emergent, floating, and submergent aquatic macrophytes present within the first two classes of lakes at varying levels of reliability. Most reliably identified and mapped were the cattail and pond lily communities, representing the most common emergent species found within the AOSERP study area and the most common floating vegetation (pond lily). Next reliably mapped were some of the submergent communities, where they grow close to the water surface in slightly turbid water. Least reliably mapped are bulrush and horsetail communities and submergent communities not growing close to the water surface. However, it was shown that the presence of submergents could occasionally be inferred from the habitat characteristics and presence of emergent and floating species.

Section 4 described the relationship between aquatic macrophyte growth and habitat factors as encountered within the AOSERP study area, and outlined briefly some of the implications of aquatic macrophyte inventory for management and reclamation of such vegetation. It was noted that several factors influenced the growth of aquatic macrophytes and interacted with one another to restrict or encourage growth. Most important were light availability, as determined by water depth and water clarity, and type of bottom sediment. Also important were acidity of the water and physical location (sheltered or open).

Aquatic macrophytes provide important habitat for fish, waterfowl, and semi-aquatic mammals, in addition to smaller insects and other life. The implications for management and reclamation of aquatic macrophytes during and after oil sands developments are great. Changes in water levels, water quality, and other factors which may be expected during such development will affect the growth and distribution of aquatic macrophytes within the AOSERP study area. Much of the aquatic macrophyte growth and distribution may be mapped using the existing 1:60 000 scale FCIR photographs, and the general trophic levels of lakes evaluated. This baseline information would then serve as a management and reclamation tool, as well as providing a basis for future monitoring of aquatic macrophyte growth, distribution, and change.

An annotated bibliography in two parts has been included in Section 7. The first part includes relevant literature on the growth, species, and habitat of aquatic macrophytes in the AOSERP study area and other similar areas. The second part contains literature on the use of remote sensing for identification and mapping of aquatic vegetation, also within the AOSERP study area and in similar areas.

5.2 RECOMMENDATIONS

Based on the data collected from the literature and in the field and on the mapping of selected lakes using the 1:60 000 scale FCIR photography, it is recommended that mapping of aquatic macrophytes at this reconnaissance scale be carried out. The mapping should be done using the legend developed for this purpose in Section 3, and will thus include identification and spatial distribution of emergent (cattail) communities and floating (pond lily) communities, in addition to some of the submergent vegetation (either seen on the photographs, known to be present from the field work, or determined as "probably present" from habitat characteristics). From this information, it should be possible for researchers to initially evaluate aquatic habitat for waterfowl, fish, and semi-aquatic mammals, the general trophic level of a lake, and so on.

It is recommended that this mapping be carried out at once, adding the mapped information to the terrestrial vegetation overlay of the Ecological Habitat Maps (1:50 000 scale) now being finished under AOSERP Project LS 2.3.1. The legend for the aquatic macrophytes mapping has been designed to be compatible with the terrestrial vegetation mapping and will fit well onto those overlays, particularly if done before the final maps are produced.

Where more detailed studies are required on specifically important lakes in the AOSERP study area in future, larger scale FCIR photographs, and possibly colour photographs as well, should be obtained and mapping carried out in addition to ground surveys. Such data acquisition should be done during the peak growth period (July, August), at a time of day other than high sun angle (to eliminate specular reflectance from the water surface). Photographs for such detailed studies could be obtained at scales ranging from 1:5000 to 1:30 000 depending on the nature of the research.

6. REFERENCES CITED

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Fassett, N.C. 1757. A manual of aquatic plants. The University of Wisconsin Press. 405 pp.

Griffiths, W.H., and B.D. Walton. 1978. The effects of sedimentation on the aquatic biota. Prep. for the Alberta Oil Sands Environmental Research Program by Renewable Resources Consulting Services Ltd. AOSERP Report 35. 86 pp.

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Jantzie, T.D. 1977. A synopsis of information relating to aquatic ecosystems toxicology within the Alberta oil sands area. Prep. for Alberta Oil Sands Environmental Research Program by Renewable Resources Consulting Services Ltd. AOSERP Project AF 3.1.2. 70 pp.

Lutz, Andrew. 1976. Survey of baseline levels of contaminants in aquatic biota of the Alberta Oil Sands Environmental Research Program study area. Prep. for AOSERP by Fisheries and Environment Canada. AOSERP Report 17. 51 pp.

Machniak, K. 1976. The impact of saline waters upon freshwater biota (A literature review and bibliography). Prep. for Alberta Oil Sands Environmental Research Program by Aquatic Environments Ltd. AOSERP Report 8. 258 pp.

Mills, D.H. 1972. An introduction to freshwater ecology. Oliver and Boyd. Edinburgh. 101 pp.

Moss, E.H. 1974. Flora of Alberta. University of Toronto Press, Toronto. 546 pp.

Noton, L.R., and N.R. Chymko. 1978. Water quality and aquatic resources of the Beaver Creek Diversion System, 1977. Report prepared by Chemical and Geological Laboratories Ltd. for Syncrude Canada Ltd. 1978-3. 341 pp.

Odum, E.P. 1971. Fundamentals of ecology, 3rd ed. W. B. Saunders Co., Toronto. 574 pp.

Renewable Resources Consulting Services Ltd. 1975a. Baseline environmental studies of Ruth Lake and Poplar Creek. Report to Syncrude Canada Ltd. 148 pp.

Renewable Resources Consulting Services Ltd. 1975b. Northwest Alberta Regional Plan Project. Fishery resources, Volume II. Technical appendices. Prep. for Ekistic Design Consultants Ltd. 389 pp.

Renewable Resources Consulting Services Ltd. 1976. Northeast Alberta Regional Plan Project. Phase I. Fisheries. Prep. for Ekistic Design Consultants Ltd. 32 pp.

Renewable Resources Consulting Services. 1977. Aquatic studies of Upper Beaver Creek, Ruth Lake and Poplar Creek, 1975. Report prepared for Syncrude Canada Ltd. 203 pp.

Stringer, P.W. 1976. A preliminary vegetation survey of the Alberta Oil Sands Environmental Research Program study area. Vegetation Technical Research Committee, AOSERP. Sub Project VE 2.2. November, 1976. 108 pp.

Thompson, M.D., M.C. Wride, and M.E. Kirby. 1978. Ecological habitat mapping of the AOSERP study area: phase I. Prep. for the Alberta Oil Sands Environmental Research Program by INTERA Environmental Consultants Ltd. AOSERP Report 31. 176 pp.

Thompson, M.D. 1979. Ecological habitat mapping of the AOSERP study area: phase I aquatic macrophytes. Prep. for the Alberta Oil Sands Environmental Research Program by INTERA Environmental Consultants Ltd. AOSERP Report 57. 45 pp.

Turner, W.R. 1968. A preliminary biological survey of waters in the Birch Mountains, Alberta. Alta. Dept. of Lands and For., Fish and Wildlife Div., Edmonton. 138 pp.

Wetzel, R.G. 1975. Limnology. Saunders. Philadephia. 743 pp.

7. AQUATIC MACROPHYTE COMMUNITIES IN THE AOSERP STUDY AREA AND REMOTE SENSING OF AQUATIC MACROPHYTES: AN ANNOTATED BIBLIOGRAPHY

7.1 ANNOTATED BIBLIOGRAPHY ON AQUATIC MACROPHYTE COMMUNITIES, AOSERP AND RELATED STUDY AREAS

Allen, E.D. 1973. An ecophysiological study of the effects of thermal discharges on the submerged macrophytes of Lake Wabamun. M.Sc. Thesis. University of Alberta. 88 pp.

M.Sc. dissertation documenting the growth of aquatic macrophytes in Lake Wabamun, Alberta. Laboratory studies were conducted on the biophysical responses of a number of macrophytes to varying environmental conditions.

Allen, E.D., and P.R. Gorham. 1973. Changes in the submerged macrophytes of Lake Wabamun as a result of thermal discharges. Proc. Symp. on the Lakes of Western Canada, University of Alberta: 313-324.

An investigation into nuisance growth of aquatic macrophytes in Lake Wabamun, Alberta. Emphasis is placed on the role of thermal effluent discharge into the lake and the growth of *Elodea canadensis*.

Beak Consultants Limited. 1975. The first year of investigation into the effect of thermal effluent on the biota of Wabamun Lake, 1974 Interim Report. Prepared for Calgary Power Limited. 200 pp. + tables and figures.

Beak Consultants Limited. 1976. The second year of investigation into the effect of thermal effluent on the biota of Wabamun Lake, 1975 Interim Report. Prepared for Calgary Power Limited. 115 pp. + tables and figures.

Beak Consultants Limited. 1977. The third year of investigation into the effect of thermal effluent on the biota of Wabamun Lake, 1976 Interim Report. Prepared for Calgary Power Limited. 95 pp. + tables and figures.

Beak Consultants Limited. 1978. The fourth year of investigation into the effect of thermal effluent on the biota of Wabamun Lake, 1977 Interim Report. Prepared for Calgary Power Limited. 69 pp. + tables and figures.

A long-term study on the aquatic macrophytes in a lake receiving thermal effluent. Changes in the distribution and community composition of macrophytes are documented, concentrating on the growth of *Elodea canadensis* to nuisance proportions. A final report is anticipated in 1979. An extensive bibliography dealing with macrophyte ecology, temperature effects, herbiciding and other control mechanisms is included in the above interim reports.

Blackburn, R.D., J.M. Lawrence, and D.E. Davies. 1961. Effects of light intensity and quality on the growth of *Elodea densa* and *Heteranthera dubia*. Weeds 9(2):251-257.

Laboratory studies to determine the optimum light intensity and spectral range for *Elodea densa* and *Heteranthera dubia*. The latter was found to have a higher light intensity requirement with rather better growth response to green light. Red light produced fastest growth in both species.

Bond, W.A., and K. Machniak. 1977. Interim report on an intensive study of the fish fauna of the Muskeg River watershed in northeastern Alberta. Prep. for Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Fisheries and Marine Service. AOSERP Report 26. 137 pp.

This report deals with the Muskeg River drainage and evaluation of fish species and abundance, plus other water quality characteristics. Aquatic plants are not mentioned specifically.

Buscemi, P.A. 1958. Littoral oxygen depletion produced by a cover of *Elodea canadensis*. Oikos 9(2):239-245.

A massive standing crop of *Elodea canadensis* was observed to produce substantial oxygen depletion near the sediment in the inlet bay of Parvin Lake, Colorado. Inhibition of photosynthesis by self-shading and the reduction of vertical water circulation were chiefly responsible for this situation. Implication of the impact of dense macrophytes on fish and invertebrates is implied.

Dale, H.M., and T.J. Gillespie. 1977. The influence of submersed aquatic plants on temperature gradients in shallow waterbodies. Can. J. Bot. 55:2216-2225.

Temperature gradients through aquatic plant populations were investigated both in the field and laboratory. Both algae and macrophytes exert a discernable influence on the thermal regime of shallow waterbodies. Effects on invertebrates and fish can be inferred.

Davies, G. 1970. Productivity of macrophytes in Marion Lake, British Columbia. J. Fish Res. Board Can. 27(1):78-81.

Measurements of primary productivity of both phytoplankton and macrophytes in Marion Lake, British Columbia indicates the latter to be the more important component of lake productivity.

Edwards, D. 1969. Some effects of siltation upon aquatic macrophyte vegetation in rivers. Hydrobiol. 34:29-36.

A review of the changes included in aquatic macrophyte communities by high silt loads. Although specifically concerned with southern African rivers, the general principles involved in siltation effects have worldwide application.

Fassett, N.C. 1957. A manual of aquatic plants. The University of Wisconsin Press, Madison, Wisconsin. 405 pp.

An excellent taxonomic key for aquatic plants. North American distribution is presented for each species.

Forsberg, C. 1960. Subaquatic macrovegetation in Osbysjon, Djursholm. Oikos 11:183-199.

Data on the productivity of *Nitella mucronata* Miq., *Chara fragilis* Desv., *Ceratophyllum demersum* L. and *Myriophyllum verticillatum* L. indicates that these species have lower production rates than heliophytes or marine algae. Of the above species, *Ceratophyllum* showed the greatest production of organic matter.

Fuller, W.A., and G.H. LaRoi. 1971. Historical review of biological resources of the Peace-Athabasca Delta. Proc. Peace-Athabasca Delta Symposium, Edmonton, January 1971. Water Resources Center, University of Alberta. 153-173.

Following a historical review of the biology of the area, a description of the vegetation and fauna on the delta prior to 1968 is given. Three habitat types are identified: aquatic, wetland and terrestrial. Each is divided into units. Those pertinent to this study are Aquatic (standing water-lake): (1) deep (submerged macrophytes), (2) shallow (floating macrophytes); Wetland (on alluvium and muck): (1) marsh - shallow (sedges), or seep (rushes). Standing water is the most productive and extensive unit, supporting rapid growth of submerged and floating pondweeds, etc. The deep marsh is dominated by emergent bulrushes, spikerush, manna grass, cattail and pondweed. In the shallow marsh, tall sedges are the dominant cover, with other grasses and sedges. This paper provides a relatively good overview of ecological habitat types present in the delta area, including aquatic macrophyte types, and an excellent diagram of these habitat types.

Griffiths, W.H., and B.D. Walton. 1978. The effects of sedimentation on the aquatic biota. Prep. for the Alberta Oil Sands Environmental Research Program by Renewable Resources Consulting Services Ltd. AOSERP Report 35. 86 pp.

The effect of sedimentation on fishes, benthic invertebrates and aquatic flora is reviewed. Levels of 80 to 100 mg/L^{-1} of suspended solids for fish and 10 to 15 mg^{-1} for benthic invertebrates are quoted as upper tolerance limits. The recovery of aquatic systems from sedimentation is discussed from the literature. Biomonitoring and remote sensing techniques are reviewed. of note is a compilation of data on the sedimentation characteristics of rivers and streams within the AOSERP study area and a subsequent section specifically relating AOSERP developmental activities to sedimentation as it affects the aquatic biota.

Hutchinson, G.E. 1975. A treaties on limnology, Vol. III - Limnological botany. John Wiley and Sons, Toronto. 660 pp.

In this third volume in Hutchinson's comprehensive series, extensive chapters are presented on the chemical ecology of aquatic macrophytes and their distribution in lakes. This volume has an excellent bibliography.

Intercontinental Engineering of Alberta Ltd. 1973. An environmental study of the Athabasca Tar Sands. Report prepared for Alberta Environment. 112 pp.

General coverage of the Athabasca Tar Sands area with sections on the physical and biological environment. A limited amount of chemical data is included for lakes in the study area. Namur, Gardiner and Gregoire Lakes are given alkalinity and pH values. No mention is made of aquatic vegetation.

Jantzie, T.D. 1976. A synopsis of the physical and biological limnology and fishery programs within the Alberta oil sands area. Prep. for Alberta Oil Sands Environmental Research Program by Renewable Resources Consulting Services Ltd. AOSERP Report 7. 73 pp.

This report provides a comprehensive overview of research conducted and data available on lakes and rivers in the AOSERP area. A brief classification of lakes is given, based on physiographic regions, plus other characteristics. General physical and chemical limnology, fishery resources and relative importance of the larger lakes is discussed. In Appendix II, a listing of reports dealing with aquatic macrophytes (species composition, relative abundance, distribution) is provided. Only three lakes, Mildred, Ruth and Unnamed (Horseshoe) have been studied in this manner, with the aquatic macrophytes at Ruth Lake studied more intensively. A extensive bibliography is included, and the appendices summarizing work on lakes and streams in the AOSERP area are very useful.

Jantzie, T.D. 1977. A synopsis of information relating to aquatic ecosystems toxicology within the Alberta oil sands area. Prep. for Alberta Oil Sands Environmental Research Program by Renewable Resources Consulting Services Ltd. AOSERP Project AF 3.1.2. 70 pp.

This report contains no discussion of aquatic macrophytes. However, Table 10 includes a summary of water quality characteristics of aquatic systems in the area of active oil sand developments including Ruth, Mildred and McClelland lakes.

Lutz, A., and M. Hendzel. 1976. Survey of baseline levels of contaminants in aquatic biota of the AOSERP study area. Prep. for Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada. AOSERP Report 17. 51 pp.

This study evaluates background levels of contaminants in fish, water, sediments, and invertebrates, as measured at 15 sites along or near the Athabasca River within the AOSERP study area. Aquatic macrophytes are not discussed. However, some data are provided for Richardson Lake.

Machniak, K. 1976. The impact of saline waters upon freshwater biota (A literature review and bibliography). Prep. for Alberta Oil Sands Environmental Research Program by Aquatic Environments Ltd. AOSERP Report 8. 258 pp.

This report discusses aquatic macrophytes in general and in relation to the effects of salinity upon them, but does not cover specific aquatic macrophytes within the AOSERP area or similar areas. It contains an extensive bibliography.

McCombie, A.M., and I. Wile. 1971. Ecology of aquatic vascular plants in Southern Ontario impoundments. Weed Sci. 19(3):225-228.

Data on macrophyte species and physical-chemical conditions was compiled from 19 ponds and lakes. From the above, habitat preferences were inferred for a number of species including *Elodea canadensis*, *Potamogeton amplifolius* and *Chara* spp.

Meeks, R.L. 1969. The effect of drawdown date on wetland plant succession. J. Wildl. Mgmt. 33:817-821.

The effect of drawdown timing on plant succession was investigated over a seven year period. Implications regarding wildlife utilization of the area are discussed.

Millar, J.B. 1976. Wetland classification in western Canada. Can. Wildlife Service Report Series No. 37, Ottawa. 38 pp.

In this study, Millar has divided wetland vegetation into seven categories according to species composition, stability and gross appearance: Wet Meadow, Shallow Marsh, Emergent Deep Marsh, Transitional Open Water, Shallow Open Water, Open Alkali, and Disturbed. Aquatic macrophyte communities are described under three of the classes.

Newroth, P.R. 1974a. Studies on aquatic macrophytes, Part IV: A review of the ecology and control of some aquatic macrophytes (unpublished). Water Investigations Branch, B.C. Water Resources Service, Victoria, B.C. File 0316533. 64 pp.

A review of the literature on the ecology and control of *Myriophyllum* spp., *Elodea canadensis*, *Potamogeton* spp. and *Ceratophyllum demersum*. The literature pertaining to the control of aquatic macrophytes using a variety of herbicides is summarized in the second part of this work.

Newroth, P.R. 1974b. A discussion of some aspects of aquatic weed growth in Okanagan Lake (unpublished). Water Investigations Branch, B.C. Water Resources Services, Victoria, B.C. File: 0316533. 42 pp.

Factors which influence nuisance growth of aquatic macrophytes are discussed with emphasis on Okanagan Lake in B.C. A summary of work conducted by the Water Investigations Branch, B.C., in this lake is presented.

Nichols, S.A. 1974. Mechanical and habitat manipulation for aquatic plant management. A review of techniques. Technical Bulletin #77. Department of Natural Resources, Madison, Wis. 34 pp.

A review of methods for the management of aquatic vascular plants including both harvesting and habitat manipulation techniques. Regarding the latter, methods discussed include shading with dyes and black plastic sheeting, dredging, drawdown, nutrient limitation and sand or gravel blanketing.

Noton, L.R., and N.R. Chymko. 1978. Water quality and aquatic resources of the Beaver Creek Diversion System, 1977. Report prepared by Chemical and Geological Laboratories Ltd. for Syncrude Canada Ltd. 1978-3. 341 pp.

This study examines post-diversion conditions in Beaver Creek, Beaver Creek Reservoir, Ruth Lake, Poplar Creek Reservoir, Poplar Creek and a number of diversion canals. Physical and chemical characteristics of the waterbodies are presented with data on the major biotic groups, i.e., aquatic macrophytes, zooplankton, macroinvertebrates and fish. In Beaver Creek Reservoir and Poplar Creek Reservoir the macrophyte communities reflected the colonization of a new habitat, with a few species being locally abundant. Fluctuating water levels and increased turbidity in Ruth Lake appeared to have greatest effect on the aquatic macrophytes.

Peace-Athabasca Delta Project Group. 1972. The Peace-Athabasca Delta: A Canadian resource. A report on low water levels in Lake Athabasca and their effects on the Peace-Athabasca delta. Peace-Athabasca Delta Project Group, Summary Report. Information Canada, Ottawa. 144 pp.

This summary report provides an overview of the work of the Delta Project Group. Brief descriptions are provided of the aquatic vegetation native to the delta, and some figures on relative abundance given. A diagrammatic representation of the process of succession of emergent and wetland species is included.

Peltier, W.H., and E.B. Welch. 1970. Factors affecting growth of rooted aquatic plants in a reservoir. Weed Sci. 18:7-9.

Nuisance growth of aquatic macrophytes in Pickwicky Reservoir, north Alabama was investigated. The major limiting factor was apparently light penetration through the water column, in turn controlled by rainfall. Nutrient levels showed no relationship to variations in plant growth.

Renewable Resources Consulting Services Ltd. 1975a. Baseline environmental studies of Ruth Lake and Poplar Creek. Report to Syncrude Canada Ltd. 148 pp.

Comprehensive investigation of Ruth Lake and Poplar Creek in terms of physical and chemical characteristics and floral and faunal groups. Contains documentation of aquatic macrophytes in the two waterbodies with estimates of areal cover.

Renewable Resources Consulting Services Ltd. 1975b. Northwest Alberta Regional Plan Project. Fishery resources, Volume II. Technical Appendices. Prep. for Ekistic Design Consultants Ltd. 389 pp.

This volume is a compendium of fisheries information on lakes and rivers in Northwest Alberta. Sport and commercial fisheries utilization and potential are noted where applicable. Stream gradients and profiles are also given. Water chemistry data, gathered in September 1974 for a number of lakes and streams, are presented.

Renewable Resources Consulting Services Ltd. 1976. Northeast Alberta Regional Plan Project. Phase I. Fisheries. Prep. for Ekistic Design Consultants Ltd. 32 pp.

The sport fishery resources of the Fort McMurray Tar Sands Area is reviewed, relying heavily on Griffiths 1973. The disadvantages of Griffiths' stream classification system are discussed. Water chemistry data are presented for a number of rivers and lakes in the study area.

Renewable Resources Consulting Services. 1977. Aquatic studies of Upper Beaver Creek, Ruth Lake and Poplar Creek, 1975. Report prepared for Syncrude Canada Ltd. 203 pp.

A report presenting the findings of two years sampling. Baseline data on the physical, chemical and biotic components of the Upper Beaver Creek, Ruth Lake and Poplar Creek system are given with discussion. The macrophyte vegetation of Ruth Lake is listed with estimates of percentage cover of the substrate.

Robel, R.J. 1962. Changes in submersed vegetation following a change in water level. J. Wildl. Mgmt. 26(2):221-223.

Changes in production of submerged vegetation are presented following an increase in water depth of 3 inches in a Utah marsh. A 32% increase in production occurred in the shallower area of the marsh while in the deeper parts, a 35% decrease was noted.

Ryan, J.B., D.N. Reimer, and S.U. Toth. 1971. Effects of fertilization on aquatic plants, water and bottom sediments. Weed Sci. 29(5):482-486.

Following the fertilization of experimental ponds with ammonium nitrate, sulfur phosphate and muriate of potash, *Elodea canadensis* and *Myriophyllum spicatum* displayed no increase in growth over control ponds. *Potamogeton pulcher* produced significantly greater yields only in the second year of the program. The major effect of fertilization appeared to be enhanced algal growth.

Sawyer, C.N. 1962. Causes, effects and control of aquatic growths. J. Water Poll. Control Fed. 34:279-288.

A review of the major factors influencing the nuisance growth of both algae and aquatic macrophytes. The control of such growths is discussed from the point of view of both chemical and ecological treatments. The latter is recommended as the more effective and lasting solution.

Sculthorpe, C.D. 1967. The biology of aquatic vascular plants. Edward Arnold (Publishers) Ltd. London. 610 pp.

A comprehensive treatment of the physiology and ecological requirements of aquatic macrophytes. Contains an extensive bibliography.

Titus, J., R.A. Goldstein, M.S. Adams, J.D. Mankin, R.V. O'Neill, P.R. Weiler, Jr., H.H. Shugart, and R.S. Booth. 1975. A production model for *Myriophyllum spicatum* L. Ecology 56:1129-1138.

A mathematical model is presented for *Myriophyllum spicatum* which evaluates growth form, areal cover, biomass, and photosynthetic assimilation with depth and the contribution of the macrophyte to nutrient fluxes in the water column. The model was tested against field data from Lake Wingra, Madison, Wisconsin. The simulation of macrophyte growth responses to changes in environmental conditions is possible with this model.

Turner, W.R. 1968. A preliminary biological survey of waters in the Birch Mountains, Alberta. Alta. Dept. of Lands and Forests, Fish and Wildlife Div., Edmonton. 138 pp.

A preliminary survey of the physical and chemical limnology and fisheries potential of a series of lakes and streams is reported. Morphometry, water chemistry, plankton, benthic invertebrates and fish species are discussed for most lakes. Good sport fishery potential is attributed to Namur Lake, Gardiner Lake and Unnamed Lake (99-16-W4), particularly the former two. It is recommended that these be reserved for a sport fishery, with the possible inclusion of Unnamed Lake (99-16-W4) at a later date.

7.2 ANNOTATED BIBLIOGRAPHY ON REMOTE SENSING OF AQUATIC MACROPHYTES

Anderson, R.R. 1971. Multispectral analysis of aquatic ecosystems in Chesapeake Bay. Proc. 7th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan. 2217-2227.

This comparison contains a very good comparison of remote sensing techniques for mapping, classifying and monitoring wetland, emergent and submerged vegetation in the Chesapeake Bay area. Spectral characteristics of ten marsh plant species are discussed and one graph provided. Colour infrared photography provided the best results.

Anderson, R.R., and F.J. Wobber. 1973. Wetlands mapping in New Jersey. Photogrammetric Engineering 39(4):353-358.

Coastal wetlands mapping carried out over smaller areas and with larger scale colour and FCIR photography than that in Delaware. With 1:12 000 scale photos, upper wetlands boundary, mean high water level, and major species associations or species were mapped. Field checks used helicopters and black and white enlargements of FCIR photos for annotation. Produced 21 maps at 1:2400 scale in 105 days.

Austin, A., and R. Adams. 1978. Aerial color and color infrared survey of marine plant resources. Photogrammetric Engineering and Remote Sensing 44(4):469-480.

Colour, colour infrared and water penetration aerial photographs were assessed for identification, mapping and inventory of macroalgal vegetation along shoreline of Georgia Strait. Colour film was most useful for definition of submerged vegetation to depths of 7 m while colour infrared and colour together provided best delimitation and identification of above-water seaweed vegetation transects from the shore to a maximum depth of 10 m. Data included seaweed samples, abundance, depth and substrate type, visible differences between sites, location of nearest buoy. Phytosociological community analysis was carried out and correlated with appearance of communities on remote sensing imagery.

Brown, W.W. 1978. Wetland mapping in New Jersey and New York. Photogrammetric Engineering and Remote Sensing 44(3):303-314.

Use of 1:12 000 scale colour and colour infrared aerial photography to map dominant plant species in New Jersey and New York wetlands areas. Fresh water wetland coverage most useful around end of June and end of August, for optimum growth characteristics. Colour infrared film best for illustrating stream sedimentation, shadow areas, and assist with plant identification using colour infrared flim. Five criteria for interpretation were tone, texture, knowledge of growing environment, stereo viewing, structure of plant species, and leaf or stem orientation.

Carter, V. 1977. Coastal wetlands: the present and future role of remote sensing. Proc. 11th International Symposium on Remote Sensing of Environment, ERIM, Ann Arbor, Michigan. 301-323.

This position paper provides perspective on the use of remote sensing for wetlands, and an overview of past and present U.S. work in the coastal states. Includes discussion of the value of Landsat. Aquatic vegetation is mentioned incidentally.

Dirschl, H.J. 1972. Evaluation of ecological effects of recent low water levels in the Peace-Athabasca Delta. Can. Wildlife Service Occ. Paper No. 13. Ottawa. 28 pp.

In this paper, a study using remote sensing imagery to evaluate the effects on vegetation of lowered water levels on the delta is described. Mapping was carried out with low level photography, and several vegetation zones identified (emergent, immature fen, fen, low shrub, tall shrub, deciduous forest) by reconnaissance mapping. Detailed vegetation maps done for portions of the delta are included.

Dirschl, H.J., D.L. Dabbs, and G.C. Gentle. 1974. Landscape classification and plant successional trends. Peace-Athabasca Delta. Can. Wildlife Service Report Series No. 30. Environment Canada. Ottawa. 34 pp.

This study was carried out to evaluate vegetational patterns, successional trends, and adjustments required by altered water regime in the delta. Remote sensing imagery plus ground survey data were utilized. Three large parts of the delta were mapped at 1:37 000, using a landscape classification which included aquatic macrophytes.

Further mapping was done in a more detailed number at 1:10 000. Overall, this is a useful document for detailing this area of the AOSERP study area, although the classifications are very different from what is found in the rest of the area, where muskeg-type wetlands predominate.

Gammon, P.T., D. Malone, P.D. Brooks, and V. Carter. 1977. Three approaches to the classification and mapping of inland wetlands. Proc. 11th International Symposium on Remote Sensing of Environment, ERIM, Ann Arbor, Michigan. 1545-1555.

Three separate studies are discussed, from Florida, Tennessee and Virginia-North Carolina. The application of remote sensing for mapping wetlands, mainly forested or meadow type, is considered, with the application for aquatic plants or habitat discussed only incidentally. Remote sensing including Landsat, high altitude colour infrared photography, and black and white photography were used for these studies, and seasonal coverage was found to be of value.

Kelly, M.G., and A. Conrod. 1969. Aerial photography studies of shallow water benthic ecology. Pages 173-184 in P.L. Johnson, ed. Remote sensing in ecology. University of Georgia Press, Athens, Ga.

Purpose of this study in the Bahama Banks was to map distribution of biological communities, identify anomalous features, and examine dynamic interrelationships between biological communities and environment. They used various film/filter combinations at a wide range of scales, plus Gemini photography, for the mapping and felt they had good results. Best film/filter was not identified, but colour photography shown to be useful.

Klemas, V., F.C. Daiber, D. Bartlett, O.W. Crichton, and A.O. Fornes. 1974. Inventory of Delaware's wetland. Photogrammetric Engineering 40(4):433-439.

Coastal wetlands in Delaware were mapped using 1:60 000 scale FCIR 9 inch photographs, plus 1:120 000 scale FCIR photographs. Five categories of wetland vegetation were mapped by dominant species, and mapping ground-checked by boat and low altitude aerial photography. Used visual interpretation plus automated analysis.

Lawrence, G.R., and C.W. Graham. 1975. Remote sensing applied to algal problems in lakes. Proc. 3rd Canadian Symposium on Remote Sensing. Edmonton. 309-314.

Using Landsat imagery, colour infrared 35 mm photography, and field sampling, surface distribution of algae blooms on Lake of the Woods (Ontario) was mapped. Remote sensing imagery obtained in August, after sufficient development of the algae bloom on the lake, showed the concentrations of algae on the lake surface which could be related to total algae present and to water quality. These results were verified by a ground data collection program.

Long, K.S., and L.E. Link. 1977. Remote sensing of aquatic plants. Proc. 11th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan. 817-826.

This paper describes a study designed to rapidly assess the extent and composition of aquatic plant infestations, using computer simulation remote sensing and field surveys. The model showed that submersed and emergent aquatic plant infestations should be detectable in clear water and that species differentiation should be possible expecially if emergent or floating. Low altitude colour, colour infrared, and black and white infrared 35 mm and 70 mm aerial photographs were interpreted and results were consistent with those of the computer model. Some Landsat imagery (Band 7) was also examined and showed evidence of aquatic plant infestations, but analysis is not yet complete. This article contains relatively specific information regarding the distinction of particular species of aquatic plants, and a brief discussion of the literature in this field.

Lukens, J.E. 1968. Color aerial photography for aquatic vegetation surveys. Proc. 5th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan. 441-446.

This paper deals with colour photography only, and contains extremely basic information regarding data acquisition for such photography. However, it does contain one good table - an interpretation key for aquatic plants in New York for colour aerial photography.

McEwen, R.B., W.J. Kosco, and V. Carter. 1976. Coastal wetland mapping. Photogrammetric Engineering and Remote Sensing 42(2):221-232.

This paper takes the New Jersey wetland mapping experience, and applies similar techniques in Georgia coastal wetlands. There is discussion of accuracies in mapping, topographic contouring, mosaics, etc., as their objective was to evaluate accuracy, time and cost for such a project. Used 1:80 000 scale FCIR spring photos for preliminary mapping on the B/W orthophotos, and found that spring was poor time for data acquisition. Plan larger scale data acquisition.

Practical Applications, Technology (PAT) Report. 1976. The aerial photo-water quality link. Environmental Science and Technology 10(3):228-229.

This brief report deals with the application of colour photography from low altitude to monitor algae in lakes, through use of densitometry and processing of blue/green ratio from the film. The use of satellite imagery for similar work is discussed, but no examples given.

Practical Applications, Technology (PAT) Report. 1977. The aerial photo-eutrophication link. Environmental Science and Technology 11(8):742-743.

This brief report discusses a Cornell study which used 1:6000 scale colour aerial photographs to study the effects of eutrophication and subsequent revitalization of a lake on fish and plant life. Five types of floating or emergent vegetation (lilies, pickerelweed, bulrush, burreed and cattail) and five types of submergent vegetation (water milfoil, mud plantain, elodea, curly-leaved pondweed, muskgrasses) were identified and mapped using a stereoscope.

Reimond, R.J., J.L. Gallagher, and D.E. Thompson. 1973. Remote sensing of tidal marsh. Photogrammetric Engineering 39(5):477-488.

The authors used FCIR photography, thermal imagery and ground surveys to evaluate the spatial distribution of species and primary production in tidal marsh in Georgia. Emphasis is placed on biomass production in these ecosystems.

Schneider, W.J. and M.C. Kolipinski. 1969. Applications of colour aerial photography to water resources studies. Proc. Seminar on New Horizons in Color Aerial Photography. American Society of Photogrammetry. Falls Church, Va. 257-262.

Discussion of colour photography and its applications in water resources studies. Applicationsinclude under-water vegetation and sediment mapping, mapping offshore springs, inventory of coastal estuaries, determination of pollution, effects of urbanization, salinity studies, circulation patterns, groundwater discharge areas, mapping of aquatic and wetland vegetation. A very general treatment with some mention of specific studies.

Seher, J.S., and P.T. Tueller. 1973. Color aerial photos for marshland. Photogrammetric Engineering 39(5):489-499.

This excellent paper describes a study of marshlands in Nevada with colour and FCIR photography, with emphasis on waterfowl habitat. Found late summer best time of year, early morning best time of day, and 1:10 000 a reasonable scale for mapping and price (although much more detail could be mapped at 1:1000 of course). There is a complete description of their ground survey procedures, plus method of analysis. Vegetation keys for use with both colour and FCIR photographs are included in tables, and are very useful as examples. They recommend the use of both film types for such studies.

Vadas, R.L., and F.E. Manzer. 1971. The use of aerial colour photography for studies on rocky intertidal benthic marine algae. Proc. 3rd Biennial Workshop on Color Aerial Photography in the Plant Sciences. A.S.P., University of Fla., Gainesville. 255-266.

Deals with marine algae in Maine. They have noted the seasonal changes in IR reflectivity in a freshwater marsh. Found colour photography better for water penetration and FCIR better for identification and mapping of plants. This paper does not contain detailed information, and what is there is rather basic.

8. AOSERP RESEARCH REPORTS

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

26. AF 4.5.1 Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27. ME 1.5.1 Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28. VE 2.1 Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29. ME 2.2 An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30. ME 2.1 Ambient Air Quality in the AOSERP Study Area, 1977
31. VE 2.3 Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32. AOSERP Third Annual Report, 1977-78
33. TF 1.2 Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34. HY 2.4 Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
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36. AF 4.8.1 Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37. HE 2.2.2 Community Studies: Fort McMurray, Anzac, Fort MacKay
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45. VE 3.3 Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978
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47. TF 1.1.1 A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area
48. HG 1.1 Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49. WS 1.3.3 The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50. ME 3.6 Literature Review on Pollution Deposition Processes
51. HY 1.3 Interim Compilation of 1976 Suspended Sediment Date in the AOSERP Study Area
52. ME 2.3.2 Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53. HY 3.1.2 Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54. WS 2.3 A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta
55. HY 2.6 Microbial Populations in the Athabasca River
56. AF 3.2.1 The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates
57. LS 2.3.1 Ecological Habitat Mapping of the AOSERP Study Area (Supplement): Phase I
58. AF 2.0.2 Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
59. TF 3.1 Semi-Aquatic Mammals: Annotated Bibliography
60. WS 1.1.1 Synthesis of Surface Water Hydrology
61. AF 4.5.2 An Intensive Study of the Fish Fauna of the Steepbank River Watershed of Northeastern Alberta
62. TF 5.1 Amphibians and Reptiles in the AOSERP Study Area
63. ME 3.8.3 Analysis of AOSERP Plume Sigma Data
64. LS 21.6.1 A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65. LS 21.6.2 A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66. AS 4.3.2 An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
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84. WS 1.6.1 Investigations of the Spring Spawning Fish Populations in the Athabasca and Clearwater Rivers Upstream from Fort McMurray; Volume I.
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