PRELIMINARY RECOMMENDATIONS FOR MAPPING OF AQUATIC HABITAT PARAMETERS FOR THE AOSERP STUDY AREA

by

A. BROWN, M.J. KENT, J.O. PARK, AND R.D. ROBARTS
Schultz International Limited
Edmonton, Alberta

for

ALBERTA OIL SANDS
ENVIRONMENTAL RESEARCH PROGRAM

AF 4.4.1

July 1978

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ABSTRACT

Three aspects of aquatic habitat assessment and mapping have been considered.

The first aspect was the review of the parameters which characterize aquatic habitats in the AOSERP study area. From an extensive list, ten parameters for each of lake habitats and river habitats were selected as being of greatest significance. Those in common to lakes and rivers include: dominant fish species, dominant invertebrate groups, maximum temperature, minimum oxygen, substrate codominants, and turbidity. Those characteristics of rivers only are rooted width, gradient, and velocity, while those characteristic of lakes only are maximum depth, percent littoral area, and percent surface area occupied by aquatic macrophytes. An efficient procedure for collecting the data pertaining to these parameters over a large area is recommended. This procedure includes: a watershed coding system, remote sensing analysis, preliminary mapping, helicopter surveys, and ground sampling programs. Finally, a key was developed for mapping the aquatic habitat parameters at a scale of 1:50,000.

The second aspect was the review of the application of remote sensing data to the interpretation and assessment of aquatic habitats. The applicability of several sensors, such as black and white panchromatic, colour, colour IR, black and white IR, thermal IR, SLAR, multispectral sensors, and LANDSAT sensors, to the assessment of aquatic habitat parameters is presented. The properties which are most readily distinguished are illustrated with representative photographs. The technical considerations which must be made when planning a remote sensing data gathering mission are discussed. These factors include film and filter combinations, altitudes, time of day, time of year, and other considerations.

The third aspect was the review of the state of the art in computerized mapping techniques. This review includes levels of data processing and their application, the data encoding

processes, map creation and presentation, and user competence requirements. It is recommended that a detailed comparative review of three of the most advanced computerized mapping systems be undertaken. The application of computerized mapping to AOSERP must be carefully assessed, and should be undertaken only if all resource and land management data for the study are to be included in the project.

ACKNOWLEDGEMENTS

Schultz International Limited would like to thank Mr. T. Chamberlin and his staff of the Resource Analysis Branch of the British Columbia Ministry of Environment for an informative and stimulating discussion in the areas of aquatic habitat mapping, data collection and reconnaissance. We would also like to thank Dr. P. Buttuls of the University of Alberta, Computer Services and Mr. M. Boyd of the Alberta Department of Recreation, Parks and Wildlife for their assistance in the procurement of the reports required to review the state of the art in computerized mapping.

This research project AF 4.4.1 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 north-eastern Alberta.

1. MAPPING PARAMETERS AND MAP KEY DEVELOPMENT

1.1 INTRODUCTION

This section describes the data gathering methods and map preparation procedures recommended for aquatic habitat mapping of the Alberta Oil Sands Environmental Research Program (AOSERP) study area at a scale of 1:50,000. Recommendations and requirements for mapping at larger scales are included for completeness. Our studies have concentrated on those parameters which provide the most critical determinants of aquatic habitat for rivers, streams, and lakes. These parameters were selected on the basis of extensive studies of the major fish species, benthos, and macrophytes for the study area. We have also relied heavily on the classification system currently being used by the Resource Analysis Branch of the British Columbia Ministry of Environment. In this regard, marshes, fens, bogs, and muskeg compose a major fraction of the study area. Classification systems for this type of area are currently being considered by the National Wetlands Group and its provincial affiliates. A workshop of this Group is scheduled for April 1979 where it is hoped that a national classification system can be adopted. We have not presented any recommendations for these areas in our report, but we strongly recommend that AOSERP adopt the classification system proposed by the workshop. The accompanying bibliography of reports and citations from the open literature dealing with aquatic habitats in the AOSERP study area is as complete as possible. A glossary of terms is also provided.

1.1.1 Scale Limitations and Applications

The map scale selected for data presentation must be directly related to the eventual uses to be made of the data. Levels of interpretation and quantities and detail of data to be mapped are also determined by the map scale. Similarly, the level of data gathering should be matched to the scale of map eventually produced. While resource management problems cannot be standardized, we recommend mapping and data collection be directed towards two levels of detail for aquatic habitats. The scales, levels of data collection, and the eventual management applications are:

1. 1:50,000 (Standard reconnaissance). Some point sampling within the basic map unit (reaches). Species present noted and average biophysical properties described. Areas requiring additional detailed work are identified. Used to identify generalized, and possibly sensitive, areas for development (e.g., townsites, industry, etc.). Mapping distribution of aquatic fauna and flora and their habitat limitations. Management decisions requiring regional consideration.
2. 1:20,000 (Detailed inventory). Extensive sub-sampling of mapping units. Distribution of species and biophysical properties measured. Management application at the local level. Used to identify specific site locations and their capabilities for development.

It should be emphasized that the following discussion refers only to mapping at a scale of 1:50,000.

1.1.2 Data Quality Versus Interpretation

Habitat data collected today may be used in resource management decisions in 5, 10 or 20 years. However, it is possible that resource management philosophy will change over the same time period. We wish to stress, therefore, that only data, and not interpretations, be mapped. The mapping of interpretations imposes a relatively short-term usefulness for the maps.

1.1.3 Data Organization

The identification of each field location is best accomplished using a coding system. We have chosen to use a hierarchical coding system beginning with the major component, the Athabasca River watershed. This watershed is composed of several sub-watersheds, defined by the major tributaries. Within the sub-watersheds we find rivers, streams and lakes which contain reaches and points. Reaches and points will be defined more precisely below.

In addition to providing a code for identifying each field location on a map we have developed two coding systems for defining aquatic habitats on maps at a scale of 1:50,000. The first code is designed to identify the dominant and/or co-dominant fish species and benthos and at the same time describe some of the physical and chemical properties of the habitat. The second code is designed for use in conjunction with computerized storage of data. In this system, those parameters for which data are available are indicated by code on the map. The data are stored in a data file which is obtained from a computer. The details of the two systems and their development follow.

1.2 DATA COLLECTION

We recommend that data collection be broken down into three basic steps: (1) definition of basic aquatic units with an identification coding system; (2) analysis of remote sensing data and historical field data to plan strategy for data collection; and (3) data collection, cataloguing and mapping. The choice of scale and therefore the density of sampling is the main factor influencing the cost of data collection and should be decided upon in the initial stages of program design. Each of these steps is discussed in detail below.

1.2.1 Watershed Coding

The value of each study carried out under the Program is governed by the precision with which the data can be related to the location from which they were obtained. This is particularly true for the aquatic habitat studies in the AOSERP study area. We have developed a hierarchical coding for the Athabasca River Watershed based on a system used by the Resource Analysis Branch of the British Columbia Ministry of Environment. The major watershed, the Athabasca River system, is divided into several sub-watersheds, defined by the tributaries draining directly into the Athabasca. Some of the sub-watersheds, such as the Clearwater River, are major drainage systems and can be further subdivided into drainage basins. Others, such as the Algar River, are relatively small and self-contained (Figure 1). The hierarchical coding system works equally well for both classes of sub-watersheds. The hierarchical coding system is also designed to reflect the dependence of downstream system properties on upstream characteristics and facilitates data aggregation on a stream basis. The following example will serve to illustrate how the system works.

As noted above, the Athabasca River system forms the major watershed for the AOSERP study area and is assigned the code 00. Froelich and Lee (1978) have classified the tributaries of the Athabasca into drainage basins, called sub-watersheds in our nomenclature. These have been assigned numerical codes, beginning at the mouth of the Athabasca. The codes are listed in Table 1. Taking the Muskeg River as an example, the mainstem would be identified by the code 00-13. The tributaries of the Muskeg River can then be identified by a two-digit numerical code, again beginning at the confluence of the Athabasca and Muskeg Rivers. Thus, Hartley Creek is the sixth tributary along the mainstem of the Muskeg River and would be identified by the code 00-13-06. The nine tributaries along the mainstem of Hartley Creek will be identified by four doublets, such as 00-13-06-02. A fifth doublet in the code identifies any tributaries of streams identified by the fourth doublet in the code. No more than five doublets should be used to identify rivers and streams when mapping at a scale of 1:50,000.

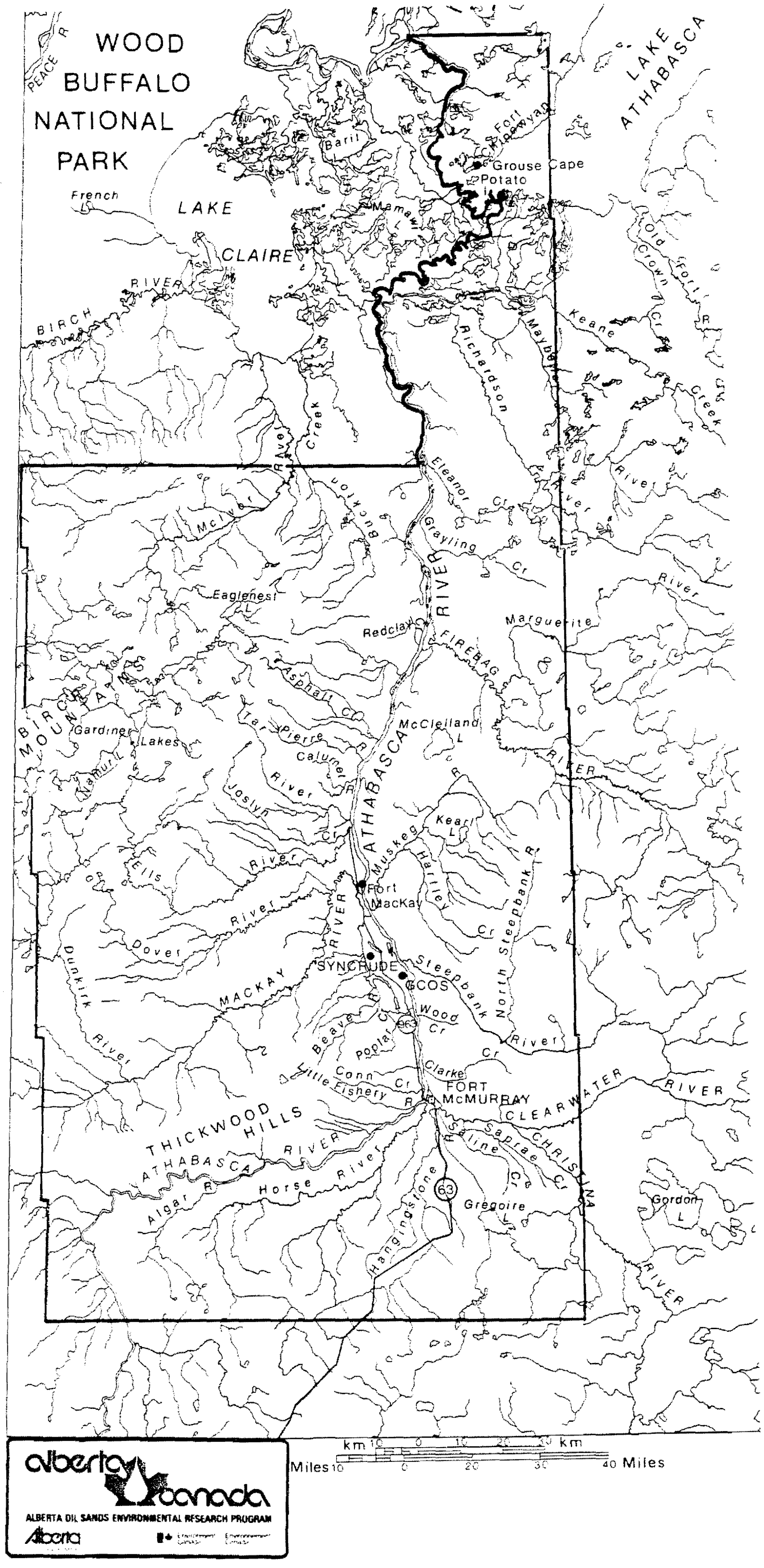


Figure 1. Streams in the AOSERP study area.

Table 1. Watershed coding for the Athabasca River and its tributaries.[a]

	Athabasca River 00		
Keane Creek	00-01	Steepbank River	00-15
Maybelle River	00-02	Poplar Creek	00-16
Richardson River	00-03	Wood Creek	00-17
Eleanor Creek	00-04	Clarke Creek	00-18
Firebag River	00-05	Conn Creek	00-19
Redclay Creek	00-06	Clearwater River	00-20
Eymundson Creek	00-07	Horse River	00-21
Pierre River	00-08	Little Fishery Creek	00-22
Calumet River	00-09		
Tar River	00-10	Algar River	00-23
Ells River	00-11	Buffalo Creek	00-24
MacKay River	00-12	Livock Creek	00-25
Muskeg River	00-13	Loon Creek	00-26
Beaver River	00-14	Deadman Creek	00-27

[a]The Buckton Creek and McIvor River drainage basins in Froelich and Lee's (1978) report do not belong to the Athabasca River watershed.

The code described above enables the researcher to identify the water system very quickly and precisely, but does not necessarily define a specific location. For example, the Athabasca River extends throughout the AOSERP study area, but its entire length is designated by the code 00. In addition, the aquatic habitat properties will vary from location to location over the length of the river. For these reasons, the major units must be divided into smaller units called reaches. A reach is defined as a variable length of a river or stream which has relatively homogeneous properties over its length. A lake is considered to compose a single reach. Thus, a reach is the basic biophysical mapping unit to be used in the AOSERP study area. The size of a reach should be directly related to the mapping scale. Ground truthing and field sampling programs which are carried out within each reach should be located as precisely as possible, using landmarks and distances along the watercourse. The reach and sample points within the reach can be identified by an extension of the above codes. A reach is designated by a two or three digit number which follows the river system designation and colon. Using the above example, the seventh reach on Hartley Creek would be designated by 00-13-06:07. Each sample point will be indicated as a subscript to the reach number, e.g. $00\text{-}13\text{-}06\text{:}07_3$ is sample point number three on the seventh reach of Hartley Creek. These code designations should be placed on all data sheets, field samples, and analyses to be used in the preparation of maps, ensuring identification of all data with a specific location.

1.2.2 Remote Sensing

The application of remote sensing to analyzing aquatic habitats in the AOSERP study area is discussed in detail in Section 2. Here we describe the application of remote sensing to the preliminary stages of the data gathering process.

Air photos and topographic maps at a scale of 1:50,000 can be used to define the locations of reach boundaries. Thus, reach boundaries will be located in regions where the topography changes drastically, or significant changes in water quality, channel form, and/or flow character are indicated by the photos. Careful examination of the photos can also indicate specific sites and/or reaches which require detailed field study. Careful study and preparation at this stage can save much time and money in the subsequent field studies.

1.2.3 Preliminary Mapping

Prior to entering the field, each crew should be as familiar as possible with the study area. To facilitate this process any historical data (previous field studies) should be reviewed and the pertinent data placed on a field map. This map should also indicate the reach boundaries, sample areas, physical features, water quality, shore vegetation, and sampling and data requirements recommended by the analysis of air photos. These maps should be taken into the field to assist in planning the daily work and to refresh the memory of the study team. The cost of the preliminary mapping will be more than recovered by the greater efficiency in the field and the greater awareness of the study area by the team members.

1.2.4 Ground Truthing and Field Surveys

Field surveys serve to verify the initial analysis of the air photos, topographic maps, and historical data. In addition, they provide quantitative measurements of the physical, chemical, and biological parameters of the water system. The field surveys should be carried out using a combination of helicopter reconnaissance and ground sampling techniques, which are discussed in more detail below.

1.2.4.1 <u>Helicopter surveys</u>. Each reach within the watershed system under investigation will have many characteristics which will be presented as averages of these parameters over the length of the reach. These characteristics include velocity of the stream, substrate of the stream bed, terrestrial vegetation on the bank areas, turbidity estimates, obstructions, etc. These properties which are averages over the length of the reach can generally be assessed more accurately, and much more quickly, using a helicopter. Each stream reach can be flown fairly rapidly and the observer can record his observations using a portable tape recorder or by filling in the data card illustrated in Figure 2. Considerable skill is necessary to ensure that all of the data which should be collected are obtained on a single pass over the reach. In this regard, review of the preliminary mapping data can be very useful, so that areas of rapid increases in elevation, stream blockages, or areas of particular interest will have been noted previously on the Reach Tally Card as requiring special attention. It is essential that the pilot keep the craft on one side of the stream at all times, and follow the exact course so that the observer can see all the essential details from one side of the craft. The Resource Analysis Branch of the British Columbia Ministry of Environment has used this technique for several years and found that a skilled pilot/observer team can traverse the stream reach at approximately 65 to 100 km/h (40 to 60 mph), with the advantage that areas requiring further observation can be studied in detail while hovering. The helicopter reconnaissance can also serve to locate these points along the reach which should be studied further by a ground study team.

The Reach Tally Card in Figure 2 requires some further discussion and justification. This card must be filled out for each reach that is studied. Those parameters that serve to characterize aquatic habitat over the entire length of the reach have been collected on this card. A justification for these

Reach Tally

Abbreviations	Substrate %		Terrestrial Vegetation %		System	
Velocity	Silt		Coniferous		System No.	
P Placid	Sand		Deciduous		Reach No.	
M Moderate	Gravel		Shrub		Air Photo No.	
F Fast	Boulders		Grasses		Reach Length (km)	
VF Very Fast	Bedrock		Barren		Channel Width (m)	
			Muskeg		Tally Completion Date	

Abbreviations		
Fish Use	Flow Character	P M F VF
S Spawn	Turbidity	L M H
R Rear		algal inorganic
M Migration	Form	S I M
Obstruction Type	Gradient (%)	
R Rock	Water Temp. (°C)	
L Logs	Dissolved O_2	
B Blocks	Rooted width	
D Man-made	Lake Surface Area	
Bd Beaver dam	Aquatic Macrophytes	
C Cascade/chute		
U Unknown		
Turbidity		
L Low		
M Medium		
H High	% surface area	

OBSTRUCTIONS

Dist. (km)	Height (m)	Type

Fish	Species	Use

Comments:

Benthic Invertebrates	Species

Figure 2. Proposed Reach Tally Card. One of these cards should be completed for each reach studied.

parameters and those associated with the point sampling data, discussed below, is given in Section 1.2.4.3. The left column of the Reach Tally Card has the abbreviations which can be used in completing the card. At the top of the second column is a section for the identification of the substrate composition of the reach, to be estimated percent of the major components. Immediately below this block is a section where the average velocity, the estimated turbidity, as well as several other important parameters are to be recorded. Aquatic macrophytes by species should be identified, if possible, and the surface area occupied by these plants should also be noted. The third column of the Reach Tally Card is provided to describe surrounding terrestrial vegetation and bank cover in very general classifications. The final column is used to identify the reach and water system using the code described in Section 1.2.1 and by common name as well as several other pertinent pieces of information. The final items on the card are: a section for identifying any obstructions; a section for identifying fish; a section for identifying benthos; and a section for any comments which the observer may have. The presence of fish species may be implied from the stream properties and documented evidence of the presence of the species at some other point or reach on the system being studied. The presence of fish may only be confirmed from ground sampling. This is true for benthos, dissolved oxygen, and temperature as well. These cards will serve as the primary record of the data for each reach and as such can be microfilmed for more efficient storage.

1.2.4.2 Ground sampling. It should be obvious that any study of aquatic habitat cannot be based solely on analysis of aerial photo data, historical data and helicopter surveys. At some point, the parameters of interest must be sampled and analyzed in the traditional ways. It may not be necessary to obtain samples from every reach on a given system, but a sufficient number of ground sampling stations must be established to provide a reliable confirmation of the analyses alluded to above. The points for ground truthing should be chosen carefully, possibly as a result of the helicopter survey and analysis of air photos. Some of the criteria for selecting sampling points include regions where obvious changes in stream properties such as velocity, substrate, or terrestrial vegetation occur. Other reasons may be the discovery of a major obstruction on the river system, or the river may be downstream from a lake, and the properties of the two waterbodies will differ significantly. With experience, the number of sampling points required to confirm and supplement the data collected using the techniques described above will be easily determined.

Once the sites to be studied by the ground truthing methods outlined below have been selected, several crews can be used in conjunction with the helicopter survey crew. These crews can be working in areas close to those being surveyed by the helicopter crew; thus, transporting the ground crews from site to site can be done easily and rapidly, using the helicopter which is in the area. The data which we have deemed essential for the ground sampling crew to obtain are summarized in Figure 3. Figure 3 is a proposed Point Sample Tally Card and must be completed for each point selected for ground truthing. The completion of this card will require the collection and preservation of some samples for later analysis in the laboratory and the direct measurement of some parameters such as dissolved oxygen, temperature, pH, and turbidity. Those samples which are collected for later analysis in the laboratory should be preserved using accepted procedures (Seidner in prep; Scott and Crossman 1973). The Point Sample Tally Card is very similar to that proposed for the Reach Tally Card and is self-explanatory. The Fish Sample Card in Figure 4 should be used in conjunction with the Point Sample Tally Card; each fish taken at the sample point should be characterized by completing the form shown in Figure 4.

Point Sample

Channel	
Gradient (%)	
Rooted Width (m)	
Velocity (m s^{-1})	
Depth	
Turbidity (F.T.U.)	
Lake Surface Area (km^2)	
Temperature air:	water:
pH	
D.O. (mg/l)	
Conductivity	
Substrate Sample No.	
Nutrients	mg/l
% Littoral (< 6 m)	
Phytoplankton	
species	biomass
zooplankton	
species	biomass

Terr. Vegetation (%)
Coniferous
Deciduous
Shrubs
Grasses
Muskeg
Benthic Invertebrates
Aquatic Macrophytes
% Surface Area
Aquatic Mammals
Watershed Activities

System				
System No.				
Reach No.				
Point No.				
Air Photo No.				
Date	yr	mo	day	time
Investigator				
Point Location				
Fish				
Method	Catch No.	No.	Species	Size Range
Shocking Time (sec)		Length Sampled		
Catch No.				
Comments:				

Figure 3. Proposed Point Sample Tally Card. One of these cards should be completed for each location sampled.

Fish Sample Card No. ____________________ System Name ____________________

System No. ________ ________ ________ ________ ________ : ________

Date ____________________ Point No. ________ of ________

Pictures ____________________ Distance from mouth (km) ________

Actual Location ______________________________________

Species[a]	Sex	Maturity	Length	Weight	Scales	Otoliths	Age	Sample Preserved and No.	Sampling Method

[a]Key

SPECIES: code (see Table 3)

SEX: M - male F - female U - undetermined

MATURITY: I - immature; A - adult; R - ripe; PreS - prespawning; PostS - post spawning

LENGTH: cm to nearest 1/10

WEIGHT: grams to nearest gram

SCALES: V + scale sample taken

OTOLITH: V - otoliths taken

AGE: 0+ to 10+

SAMPLE PRESERVED + NO. WHOLE FISH WF STOMACH - S OTHER (specify)

SAMPLING METHOD: SHOCK GILL NET EXPLOSIVES
ANGLE TRAP
SEINE POISON

Figure 4. Fish Sample Card used by Resource Analysis Branch, B.C. Ministry of Environment.

The combination of analysis of remote sensing data, historical data, topographic maps, helicopter surveys, and field sampling and data collection using the above procedure will prove cost effective. The approach has proven to be a method of rapid accumulation of data, while at the same time providing accurate, site-specific descriptions of the aquatic habitat capabilities in the extensive program undertaken in British Columbia (Chamberlin and Humphries 1977). The quality of data is such that regional management decisions can be made with confidence.

1.2.4.3 Justification for the aquatic habitat parameters recommended. The aquatic habitat parameters recommended above and listed in Figures 2 and 3 and Tables 2 and 3, have been carefully selected from a much larger number based on the critical requirements for the fish species, benthos, and aquatic macrophytes found in the AOSERP study area. Our reasons for selecting these parameters are summarized below.

The presence or absence of any particular fish species, benthic invertebrate, aquatic macrophyte, or other biotic component in an aquatic environment is the result of a large number of physical, chemical and biological factors. A single parameter may be the dominant factor, limiting the distribution of a single species or even several species. Conversely, a particular species distribution may be regulated by the interaction of two or more parameters. The number of aquatic habitat parameters which can be mapped using the coding system proposed below is limited by the map size and scale, but within reason, should not be considered finite.

The aquatic habitat parameters presented in Tables 1 and 2 were selected from an extensive list of possible mapping parameters because they appeared to provide an adequate physical description of an aquatic environment and because they have been most frequently cited as major factors in regulating fish and benthos distribution.

Table 2. Example of a river reach code on a 1:50,000 map.

Habitat characteristics:

1) dominant fish species
2) dominant invertebrate groups
3) rooted width (m)
4) gradient given as a percentage (± 0.1%)
5) velocity (m/s)
6) depth (m)
7) turbidity (F.T.U.)
8) maximum temperature (± 1°C)
9) minimum dissolved oxygen (mg/l)
10) substrate codominants to nearest 10%

    Silt = A, Sand = B, Gravel = C, Boulders = D, Bedrock = F

Format:[a]

1	2
3, 4, 5, 6	7, 8, 9, 10

---

[a]Example:

WA, GO↑, (FC)	OL, PL, EP
100, 0.5, 0.3, 4	40, 17, 8, A_6B_3

Explanation: Dominant fish are walleye, goldeye (which uses the river for migration only) and possibly flathead chub. The dominant benthic invertebrates are oligochaetes, plecopterans and ephemeropterans. The rooted width of the river is 100 m, it has a gradient of 0.5%, a moderate velocity of 0.3 m/s and a maximum depth of 4 m. The river is turbid with a value of 40 F.T.U.'s, a maximum temperature of 17°C and a minimum oxygen concentration of 8 mg/l. The substrate was composed mainly of silt (60%) and sand (30%).

Table 3. Example of a lake reach code on a 1:50,000 map.

Habitat characteristics:

1) dominant fish species
2) dominant invertebrate groups
3) surface area (km^2)
4) maximum depth (m)
5) turbidity (F.T.U.)
6) maximum temperature ($\pm$ 1°C)
7) minimum dissolved oxygen (mg/l)
8) littoral substrate codominants to nearest 10%. Silt = A, Sand = B, Gravel = C, Boulders = D, Bedrock = F
9) % littoral (depth < 6 m)
10) % surface area occupied by aquatic macrophytes

Format:[a]

$$\frac{1}{3,\ 4,\ 5,\ 6}\ \Big|\ \frac{2}{7,\ 8,\ 9,\ 10}$$

[a]Example:

$$\frac{\text{BS, FM}}{1.5,\ 3,\ 0.9,\ 22}\ \Big|\ \frac{\text{CH, EP, AP}}{0,\ A_{90}B_{10},\ 100,\ 44}$$

Explanation: The fish species found in this lake were brook stickleback and fathead minnows. The benthic invertebrate population was dominated by chironomids, ephemeropterans, and amphipods. The lake has a surface area of 1.5 km^2, a maximum depth of 3 m and a turbidity of 0.9 F.T.U.'s. The maximum temperature was 22°C and dissolved oxygen reached a value of 0 mg/l indicating a major restraint to water fauna. The substrate is composed of 90% silt and 10% sand. The lake is 100% littoral by definition and contains a large macrophyte population which covers 44% of the surface area.

1. Oxygen: Dissolved oxygen is an obvious choice for aquatic habitat, since most species require well-oxygenated waters. If waters become anaerobic at some time during the year, a major barrier to the survival of most fish and invertebrates will be presented. Some species of oligochaete worms can tolerate extremely low oxygen concentrations, however.

2. Temperature: Maximum temperature was chosen as a limiting factor because fish species can be separated generally into cold water and warm water fishes. Arctic grayling, longnose suckers, and lake whitefish prefer cooler waters while northern pike are generally found in warm waters. Water temperature is also an important factor determining spawning season.

3. Rooted Width: Many fish species tend to be found in larger rivers. Goldeye, flathead chub and walleye prefer large rivers (McCart et al. 1977). Hawkes (1975) notes that grayling, for example, are rarely found in streams less than 5 m wide, even when the gradient is suitable.

4. Gradient and Velocity: These two habitat parameters are important in regulating the distribution of fish and benthos species. Several authors have attempted to describe the distribution of fish and invertebrate species on the basis of these parameters (Hawkes 1975). For example, a river which is 15 m wide with a 4% gradient would be a grayling zone, but with an 8% gradient would be a trout zone. Trout-perch prefer slow streams (McCart et al. 1977).

5. Depth: Depth appears to be a parameter which influences the distribution of fish species in lakes and benthic invertebrates in rivers. Depth is also important in the selection of spawning grounds for many fish in rivers. Trout-perch, for example, typically inhabit deep lakes (McCart et al. 1977). Davies et al. (1978) have noted that the depth of the water column can be related to food availability since the deeper the sample area, the less light which penetrates, and hence, the less algae and oxygen. These factors have been shown to be related to

benthic organism distribution.

6. Turbidity: Turbidity due to algal populations indicates eutrophic, or nutrient rich waters. These waters are probably excellent habitat for many benthic invertebrate and fish species (with the exception of advanced eutrophication which produces anaerobic lake bottoms). Large algal populations usually indicate large invertebrate and fish populations. On the other hand, turbidity due to inorganic particles may indicate low productivity systems. The stream or lake bottom may be unsuitable for benthic invertebrates and benthic algae due to poor light penetration and/or silting. These systems would be unsuitable for many fish species. Goldeye, flathead chub, trout-perch and walleye prefer turbid waters while northern pike and longnose suckers prefer clear waters (McCart et al. 1977).

7. Substrate: The composition of the substrate of either lakes or rivers is an important parameter limiting the species composition and sizes of benthic invertebrate populations, hence fish species distribution. Substrate is also an important factor in determining good spawning grounds. For example, lake trout spawn over large boulders or rubble bottoms, Arctic grayling over gravelly to rocky bottoms (but sometimes in mud-bottomed vegetated pools below rapids, as observed in Alaska), spottail shiners over sandy shoals, white suckers over gravel bottoms, and burbot over sand or gravel or on gravel shoals, depending on water depth (Scott and Crossman 1973).

8. Surface Area: Surface area is intended to be used as a simple means of ranking lakes in the mapping code for comparative purposes. McCart et al. (1977) note that walleye prefer large lakes while goldeye prefer the turbid waters of small lakes and the muddy shallows of larger lakes.

9. Percent Littoral Area and Percent Surface Area Occupied by Aquatic Macrophytes: The littoral area is an extremely important zone in a lake and the size of this zone has many important ramifications to lake chemistry and biology. The littoral

zone of a lake is the area in which fish spawn and therefore the size of the littoral zone is important in assessing the importance of a lake as a spawning ground. The littoral zone is also the area in which rooted aquatic macrophytes flourish (both emergent and submerged). "Weed beds" provide a good habitat for young game fish and small forage species. "Weed beds" also provide some fish with protection from predators during the reproductive season. Rooted aquatic plants shelter a rich assortment of invertebrate animals which are a major food source for fish. Some of the fish species found in the AOSERP study area which spawn in the littoral zone of lakes are the burbot, brook stickleback, yellow perch, walleye, Iowa darter, and slimy sculpin. Lake whitefish usually spawn in water less than 8 m deep and lake trout usually spawn in water less than 12 m deep and sometimes as shallow as 0.3 m (Scott and Crossman 1973). Aquatic macrophytes, in terms of both percent cover of lake surface and species, are important in regulating waterfowl distributions in the AOSERP study area lakes (Sharp et al. 1975).

1.3 MAP PREPARATION

We have prepared, from an extensive review of the literature, a list of biophysical parameters which adequately define the aquatic habitat capability for the AOSERP study area. This list includes those parameters employed by several authorities (Ryder 1965; Griffiths 1969; Hawkes 1975) to classify rivers and lakes for fisheries potential. Suggestions for expanding this list are included. In the following discussion, we present a key to the above parameters and two methods for presenting the data on maps using this key. The work of Chamberlin and Humphries (1977) has influenced our recommendations substantially.

1.3.1 Development of the Key

The map key and codes for the aquatic habitat parameters listed in Tables 4, 5, and 6 were developed for mapping at a scale

Table 4. Fish species found in the AOSERP study area and their code symbols for mapping at 1:50,000.

Family	Common Name	Scientific Name	Code
Salmonidae	lake trout	*Salvelinus namayeush*	LT
Hiodontidae	goldeye	*Hiodon alosoides*	GO
Coregonidae	lake whitefish	*Coregonus clupeaformis*	LW
	mountain whitefish	*Prosopium williamsoni*	MW
Thymallidae	Arctic grayling	*Thymallus arcticus*	AG
Esocidae	northern pike	*Esox lucius*	NP
Cyprinidae	flathead chub	*Platygobio gracilis*	FC
	lake chub	*Couesius plumbeus*	LC
	finescale dace	*Chrosomus neogaes*	FD
	longnose dace	*Rhinichthys cataractae*	LD
	pearl dace	*Semotilus margarita*	PD
	emerald shiner	*Notropis atherinoides*	ES
	spottail shiner	*Notropis hudsonius*	SS
	brassy minnow	*Hyboganthus hankinsoni*	BM
	fathead minnow	*Pimephales promelas*	FM
Catostomidae	white sucker	*Catostomus commersoni*	WS
	longnose sucker	*Catostomus catostomus*	LS

continued...

Table 4. Concluded.

Family	Common Name	Scientific Name	Code
Percopsidae	trout-perch	*Percopsis omiscomaycus*	TP
Gadidae	burbot	*Lota lota*	BB
Gasterosteidae	brook stickleback	*Culaea inconstans*	BS
	ninespine stickleback	*Pungitius pungitius*	NS
Cottidae	spoonhead sculpin	*Cottus ricei*	SH
	slimy sculpin	*Cottus cognatus*	SC
Percidae	yellow perch	*Perca fluviatilis*	YP
	walleye	*Stizostedion vitreum*	WA
	Iowa darter	*Etheastoma exile*	ID
	Fish present; species undetermined		SP
	Fish undetected		Ø
	Species known but other than those listed		OS
	Probable but unconfirmed species		()
	Used by fish for migration only		↑

Table 5. Major benthic invertebrates--broad classification for coding, on a 1:50,000 map. Classified by order.

Invertebrate	Code
Chironomidae	CH
Other diptera	OD
Plecoptera	PL
Ephemeroptera	EP
Tricoptera	TR
Coleoptera	CO
Oligochaeta	OL
Amphipoda	AP
Gastropoda	GA

Table 6. Major aquatic habitat parameter codes for mapping as indicators of data available in computer files.

Parameter	Code
reach	>—<
point sampling station	▷<
substrate	S
oxygen	O_2
temperature	T
nutrients (e.g. N & P)	N
conductivity	μ
turbidity	÷
velocity	V
gradient	Σ
rooted width	W
depth--river	Z
aquatic macrophytes	M
fish	F
benthic invertebrates	Ƭ
zooplankton	Z_o
phytoplankton	P
aquatic mammals	AM
terrestrial vegetation	Λ
lake morphometry	α
watershed activities	WC

of 1:50,000. The symbols selected for fish species and benthic invertebrates are based on a two letter code related to the common names. Wherever possible the two letter code is derived from the first two letters of single word names, e.g. GO for goldeye, and the first letter of each word in two word names, e.g., NP for northern pike. In addition to the codes for fish and benthos we have developed a key for the remaining parameters for which data will be collected and recorded of the Reach and Point Sample Tally Cards (Figures 2 and 3). The symbols were selected for their compatibility with computerized graphics as well as for their neumonic properties. These latter symbols or codes are listed in Table 6.

We have recommended data collection and assessment be carried out at two levels: a helicopter survey which will generate average value parameters over an entire reach, and ground survey samples which will generate site-specific values associated with the time of sampling. In order to reflect this difference in quality of data we have developed two coding systems for the preparation of an aquatic habitat capability map. The first code was developed to reflect the average parameters for a reach. Each reach has its upper and lower boundaries indicated by the appropriate symbol. The reach number is indicated on the downstream boundary using the coding system described in Section 1.2.1. The habitat parameters for the reach are presented as a four quadrant symbol illustrated in Tables 2 and 3 for a river reach and a lake respectively. The tables are self-explanatory. The second code was developed to present field sampling data and as such are site-specific parameters. The site specific data must be placed on the map at the point they were obtained, indicated by the point sample symbol, ⋈. The sample point is identified according to the code developed in Section 1.2.1. The sample point identification is followed by a linear string of symbols which indicate that data pertaining to those symbols are available in a data storage file, perhaps a computerized data base. The actual data will be obtained from the data file associated with the sample point. Since the data will also be time specific, each time data are collected at a sample point they will be stored as a separate entry for that point, providing for a time profile to be built into the data system. Since the data is a specific point, computerized mapping techniques drawing on the data base may be employed, providing an opportunity to incorporate the co-ordinates of the sample point into the data base. An example of the format suggested is given in Table 7. When the second coding system is interfaced to data processing facilities, it provides the researcher and cartographer with an unlimited variety of possibilities. Some of these possibilities are discussed in greater detail in Section 3.

In addition to the reach and sample point codes discussed above, a number of symbols indicating specific areas or sites whose properties are of interest are indicated in Figure 5. The symbols and definitions of Figure 5 are intended to represent the type and location of features in stream channels and to provide habitat information in addition to that presented in the map code.

1.3.2 Map Printing Specifications

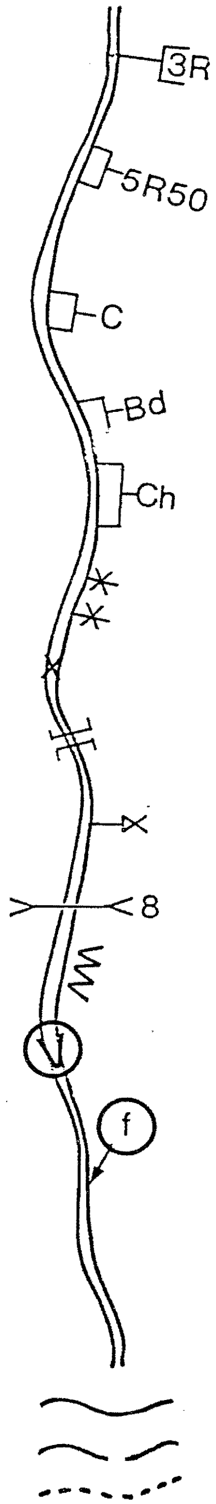
This section describes the production of maps at a scale of 1:50,000 for the presentation of aquatic habitat data.

National Topographic Series (NTS) maps at 1:50,000 scale of the AOSERP study area will form the working and final draft base maps. Drainage basin and stream-reach information can be plotted on these maps. A mylar overlay on the base map will allow for detailed drafting of the information. A negative of the base map can be produced by photography, with details to be emphasized by screening (streams 80%, lakes 10%, and topography 60%). The mylar overlay, containing the habitat data, can be photographed and combined with the base map negatives. An auto-positive can be produced containing a base map incorporating emphasized and labeled aquatic habitat data with a legend included on the side.

Table 7. Example of a point sampling station code to computer files on aquatic habitat data.

Format:[a]	$\bowtie\!<25_3$, S, O_2, T, μ, ÷, V, Σ, F, Ͳ, Z_o, WC

[a]Explanation: The above symbols, which would appear on a map, indicate that for reach 25, point sampling station 3, data have been collected on the following parameters: substrate, oxygen, temperature, conductivity, turbidity, water velocity, gradient, fish, benthic invertebrates, zooplankton and human activities in the watershed. The data may be extensive, e.g., fish species and other biological data such as length, weight, sex, etc., or superficial, e.g., list of fish species recorded at the point sampling station.



An obstruction 3 m high of the following types: R (Rock), L (Logs), B (Blocks), D (Man-made), Bd (Beaver dam), O (Culvert), U (Type unknown), V (Velocity), C (Cascade or Chute).

A chute or cascade 5 m high and 50 m long of the above types.

A chute or cascade with details unknown; obstruction type symbols used when possible.

A sequence of beaver dams.

Clear evidence (e.g.: persistent redds or observed spawning adults) of spawning by the indicated species.

A general zone of flood and side channels.

A bridge (Chan = a man-made channel or a culvert).

A site point sampling station marker with biophysical data available.

A reach boundary. Reach number on downstream reach boundary.

A major bank or valley side wall slump zone.

An alluvial sink hole without surface effluent.

Spring f fresh
t thermal
s saline

Major watershed boundary)
Sub-watershed boundary)
Minor watershed boundary)
) indicates watershed system code number

Figure 5. Site specific stream symbols.

The auto-positive allows the production of inexpensive blue line prints. These can be used as working maps when conducting field verification checks.

To update the base map, the draftsperson overlays a mylar sheet on the base map and re-drafts the various key symbols. These sheets are photographed, negatives made and a new auto-positive is prepared. Blue line prints are made from the auto-positive.

2. REMOTE SENSING PROCEDURES

2.1 INTRODUCTION

Until the mid 1960's very little had been done to apply remote sensing techniques to the analysis of aquatic habitat systems. Although aerial photography had been used previously, the real advances came with the development and improvement of the multi-spectral system and with the launching of the Earth Resources Technology Satellite (ERTS), on 23 July 1972. ERTS provided the user with complete coverage of Canada at a scale of 1:1,000,000, with each location being imaged every 18 days. Although ERTS-1 has ceased to function properly, a second satellite, LANDSAT-2 has been in a sun-synchronous orbit since 21 January 1975, providing excellent imagery. The results have been so good that interpretive technology has been struggling to meet the demands for increased application of the imagery to a variety of fields, such as hydrology and aquatic systems.

Advances have been made recently in camera systems, photographic films, and scanner systems for ultraviolet, thermal infrared and multispectral reflectance. Also, the Side-looking Airborne Radar (SLAR) system is being increasingly investigated for its application to ecological studies.

Imagery from some of these remote sensing devices is extremely useful in the analysis of aquatic habitats. The following is a description of that imagery and a discussion of its uses and limitations, along with diagnostic examples. Finally, requirements for future studies are outlined and suggestions made for technical approaches for particular problem areas.

2.2 IMAGERY

2.2.1 Panchromatic Black and White

The least expensive imagery available for the study of aquatic habitats is Black and White Panchromatic (B&W Pan), with a spectral range of 0.4-0.7 μm, or the entire visible spectrum.

Since the spectral response recorded on the film is the same as that recorded by the human eye, minus the colour, the photo-interpreter does not have to be as concerned about variations in response to electromagnetic energy of physical features as he does with image parameters such as tone, texture, shape, size, pattern, site and time of photography. For example, if beaver habitat is being studied, the proximity of deciduous tree species such as aspen, balsam poplar, birch, and willow to a waterbody is an important factor. Identification of these species on Black and White Panchromatic photographs is relatively simple if the interpreter is trained in recognizing the characteristic crown shape, growth pattern, grey tone of the leaves, and drainage requirements of the particular species, or if the photographs were taken in the fall when separation of deciduous and coniferous species is facilitated by the lighter tones, or lack of leaves, of the former. Although coniferous species are usually distinguishable from deciduous ones during the summer due to a darker tone and different crown shape, difficulty may be encountered in separating birch from pine in areas where they are intermixed. In this situation a better film to use would be photographic infrared.

Probably the best use for B&W Pan imagery in studying aquatic habitats is in recognizing differences between turbid and clear water in streams and lakes. A muddy river will appear much lighter in tone than a clear lake, as is illustrated in Figures 6 and 7. This results from the scattering of light by the particulate matter in the river and the reception of this light by the film, producing a light tone on the image. Clear water absorbs most of the solar radiation incident upon it and gives a poor return, or dark tone, on the film. A quick survey of B&W Pan photographs of an area can produce an initial separation of clear and turbid waterbodies and degrees of the latter can be determined. Caution must be used, however, in assigning the quality of turbidity to all light-coloured waterbodies. It must be remembered that the absolute brightness of a given waterbody is also dependent on

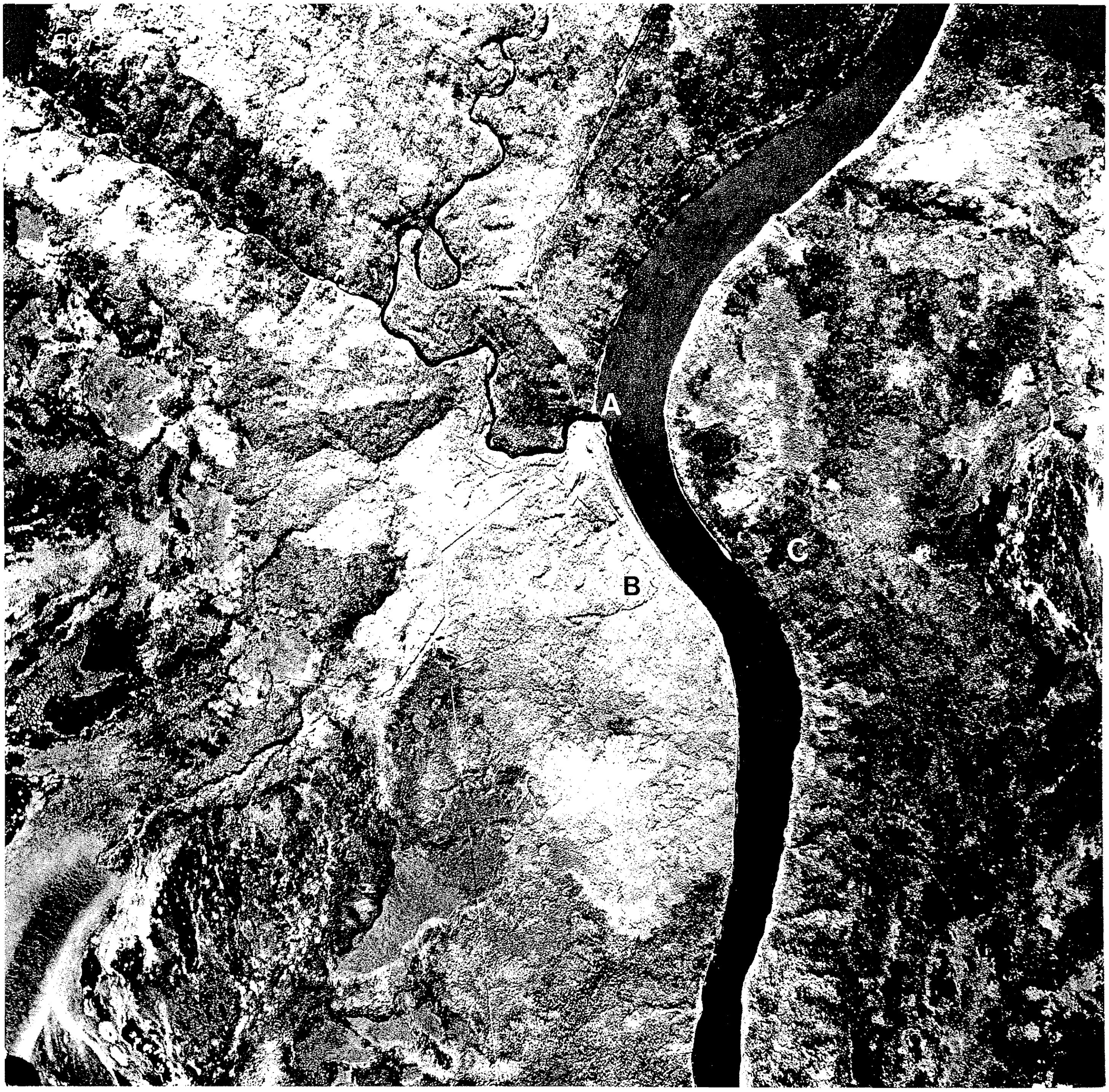


Figure 6. Black and white panchromatic photo at a scale of 1" = 2,640' showing relatively clear stream entering turbid river at A. Turbidity is caused by suspended sediment. Also compare difference in grey tone of aspen stand at B and spruce at C.

Figure 7. Black and white panchromatic photo at a scale of 1" = 1,320' illustrating turbidity conditions. Note river at A with a high degree of suspended sediment and numerous sandy point bars and shoals. Compare with the relatively clear water in the oxbow lakes at B and C. The oxbow lakes at D and E show a grey tone half-way between the previous examples and is probably due to an algal bloom. The lake at F exhibits a very light tone, mostly due to specular reflection.

the amount of energy reflected by the atmosphere, the water surface, and the bottom if the water is clear and shallow. But the effects of these factors can be easily confirmed or denied by noting if there are dark and light-toned waterbodies on the same photo in the case of atmospheric causes, and comparing the appearance of the same waterbody on adjacent photos in the case of surface specular reflection.

A limitation of this film is that the cause of the turbidity cannot be ascertained except by inference. The two main causes of turbid conditions in waterbodies are suspended solids and organic material. If a river gives a light tone on B&W Pan photography indicating turbidity, the interpreter can infer that it is due to suspended clay and/or silt particles in the moving water. If a small lake without any appreciable inflow which would agitate the water is found to give a light tone, the interpreter could conclude that the cause was most probably due to a subsurface algal bloom. But these would only be inferences. Some of the imagery to be discussed later can provide the interpreter with not only a definitive separation of organic and inorganic causes of turbidity, but accurate estimates of the exact diameter of the particulate matter of the suspended solids.

Depending on the scale of the photography, differences in depth can often be interpreted in relatively clear waterbodies. But other sensors must be used if reliable estimates of water depth are to be made.

The benefits of B&W Pan photography for analyzing aquatic systems are that it is relatively inexpensive and from it the interpreter can distinguish the presence and comparative degree of turbidity in waterbodies, species type and distribution of shoreline vegetation, the presence of floating aquatic vegetation, and relative water depth (see Figures 8 and 9).

2.2.2 Colour

The drawback of colour photography is that it is expensive to take and to reproduce. Its main advantage is that the user

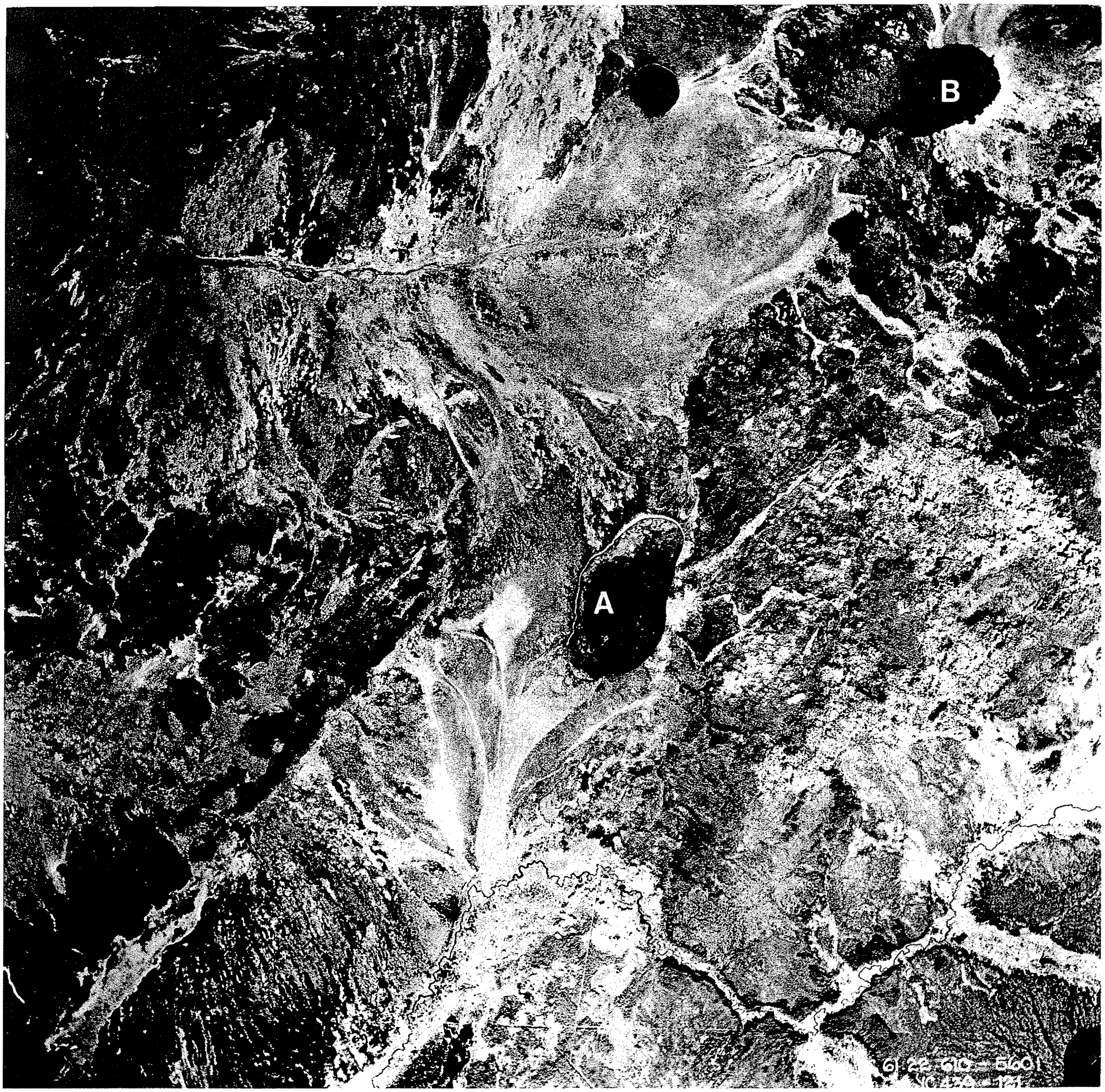


Figure 8. Black and white panchromatic photo at a scale of 1" = 2,640'; the lake at A shows a 90% or greater coverage of floating aquatic vegetation. Compare with the clear lake at B.

Figure 9. Black and white panchromatic photo at a scale of 1" = 1,320' showing turbidity conditions. Lake at A is lighter-toned than that at B, indicating organic turbidity and eutrophic status. Lake inflow to the turbid river at C adds relatively clear water which makes the river less turbid downstream than above the inflow.

who is interpreting the photography sees objects in their natural colour--the same colour that he or she is used to seeing them. Some investigators have found it second only to colour infrared imagery in its value to the study of aquatic habitat studies.

The two most important characteristics of colour imagery to this type of study are depth penetration through water and the ease of identification of water indicators such as vegetation. The electromagnetic wavelength range of colour film is the same as B&W Pan, 0.4-0.7 μm. Thus, the advantages of Panchromatic film noted above are augmented by the substitution of colour for grey tone. The human eye can discern approximately two hundred shades of grey but over five million colour hues. The wavelength range in which it is most sensitive is 0.5-0.6 μm, or the colour green, because it is in the center of the visible spectrum. Thus the photo-interpreter can possibly distinguish between two types of green vegetation on colour photos while those types may appear the same grey tone on B&W Pan film.

The presence of colour resolves the difficulty of distinguishing causes of turbidity in waterbodies encountered in B&W Pan: muddy water appears brownish and algae images yellow to yellow-green. Floating aquatic vegetation will usually give a different colour than the water on which it is floating. Submerged shoreline vegetation can be located, if the water is not turbid, and identified, if the scale of photography is sufficiently large. An important consideration to remember is that light penetration through water is wavelength dependent. The same submerged vegetation species will appear as different shades of colour at different depths, depending on the unabsorbed wavelengths of light available to be reflected back to the camera at a particular depth. Thus if it is known that only one species of bottom vegetation grows in a particular lake, the colour change in that vegetation is an indication of water depth and this can be mapped.

While colour photographs are excellent for interpretation of shallow water areas, they are not considered propitious for wetland plant communities. Colour films are highly susceptible to haze conditions of the atmosphere. Haze affects the shorter wavelengths, i.e. blue and possibly some of the green. Although lens filters are available for eliminating some of the scattering and thus facilitating the penetration of the haze, they are far from being perfected. The use of filters to control atmospheric scattering necessitates deletion of some of the wavelengths which contribute to the colours with which we are familiar. The result is that differences in vegetation hues tend to be reduced and green tones tend to blend with one another, creating difficulties in species differentiation.

Despite this fact, colour photography is far superior to B&W Pan. The interpreter does not have to be extensively trained to identify objects on colour photographs, except for the unique aerial perspective which air photographs afford the viewer, because these objects are seen in their natural colours.

2.2.3 Colour Infrared

Colour infrared (IR) film is probably the single most valuable type of imagery available for the study of aquatic habitats. This is a remarkable statement in view of the fact that IR wavelengths are readily absorbed by pure water and there is little or no depth penetration. But its superiority for vegetation analysis, delimitation of land/water boundaries and detection of turbidity make it almost a necessity for accurate aquatic habitat analysis.

The IR wavelengths, from approximately 0.7-1,000 μm, begin just beyond the visible range on the electromagnetic spectrum. They can be divided into two distinct groups: those which are reflected from objects on the earth and are found between 0.7 and 3.0 μm, and those which are emitted by objects are are situated between 3.0 and 1,000 μm in the spectrum. The latter group are called Thermal IR and will be discussed later. Some of the IR wavelengths in the first group, because they are reflected energy, are capable of being photographed and are often referred to as Photographic IR or Near IR. Infrared photographs, then, normally consist of small portions of the IR range plus the entire visible spectrum, or a wavelength range from 0.4-0.9 μm. The maximum IR wavelength which can be imaged on photographs is approximately 1.0 μm. All of these wavelengths are imaged on B&W IR photos. However, the production of colour IR photography requires some adjustment to be made.

Because near IR wavelengths are located just outside the visible spectrum, our eyes cannot detect their presence, i.e. they have no colour. To view IR reflectance the colour spectrum is shifted upward; the colour red is assigned to IR wavelengths, red wavelengths appear green, green wavelengths are blue, and the blue wavelength region is eliminated entirely by filtering. Because the resultant imagery does not show objects in their natural colour, it is often referred to as false colour photography.

The interpreter must be familiar with the reflectance characteristics of objects to understand their representative shade of colour on this imagery. For example, healthy green vegetation will appear red because green vegetation reflects much more IR radiation than any other wavelength. If we could naturally see IR energy, a forest would be so bright that we would have to shield our eyes. The shade and brilliance of the red is dependent upon the internal leaf structure of the particular species and the orientation of the leaves with regard to the incident radiation. The internal structure of conifer needles and their arrangement on the tree is such that less IR radiation is reflected back to the film than is the case with broadleaved deciduous species. Thus a deciduous stand will appear very red in colour IR photographs indicating maximum IR reflectance, while a coniferous stand will give a purple to brown hue, signifying reduced IR reflectance, and consequently, more green reflectance. Since IR is represented by the colour red, and green wavelengths are blue, the mixture of the two colours will give brownish purple, the shade depending on the percent of each component. Figures 10 and 11 illustrate this example.

Once the interpreter masters the reflectance variables of physical objects it is just a matter of deducing why an object appears as a particular colour on colour IR photography. Vegetation species in wetland communities can often be separated by their characteristic differences in red tone on this photograph, while the same communities would not exhibit enough difference in green tone to be separated on regular colour imagery (Figures 10 and 11).

Another important use of colour IR is in the early detection of vegetation stress. If a beaver has dammed a small stream in a heavily forested area in which the overhanging trees obscure the photo interpreter's view, the resultant beaver pond might be overlooked on B&W Pan or colour photography. On colour IR imagery, however, the probability of its discovery are much better. A rising watertable can kill those tree species unable to cope with it. Long before a tree visibly appears to be dying, the internal structure of its leaves, mainly in the spongy mesophyll area, begins to break down, decreasing the IR reflectance from it. Species which the interpreter expects to see a particular shade of red will instead give a pink or purple shade as the IR reflectance diminishes. Once vegetation under stress is located cause of the stress can be investigated.

The fact that IR wavelengths are readily absorbed within the first few inches of water render this imagery undesirable for detection of underwater phenomena. Colour photography would be the best imagery to use if depth penetration is required. However, the attenuation of IR wavelengths by water makes it extremely valuable for detection and mapping of floating aquatic vegetation. The appearance of anything on or just below the water surface will be accentuated by the opacity of the water. Even tonal anomalies on water surfaces are enhanced, allowing recognition and delimitation of current and dispersion patterns.

Figure 10. Colour photo of a muddy, turbid river adjacent to a shallow eutrophic lake which is populated by aquatic macrophytes, shown at A, and algae, at B. Compare with Figure 11.

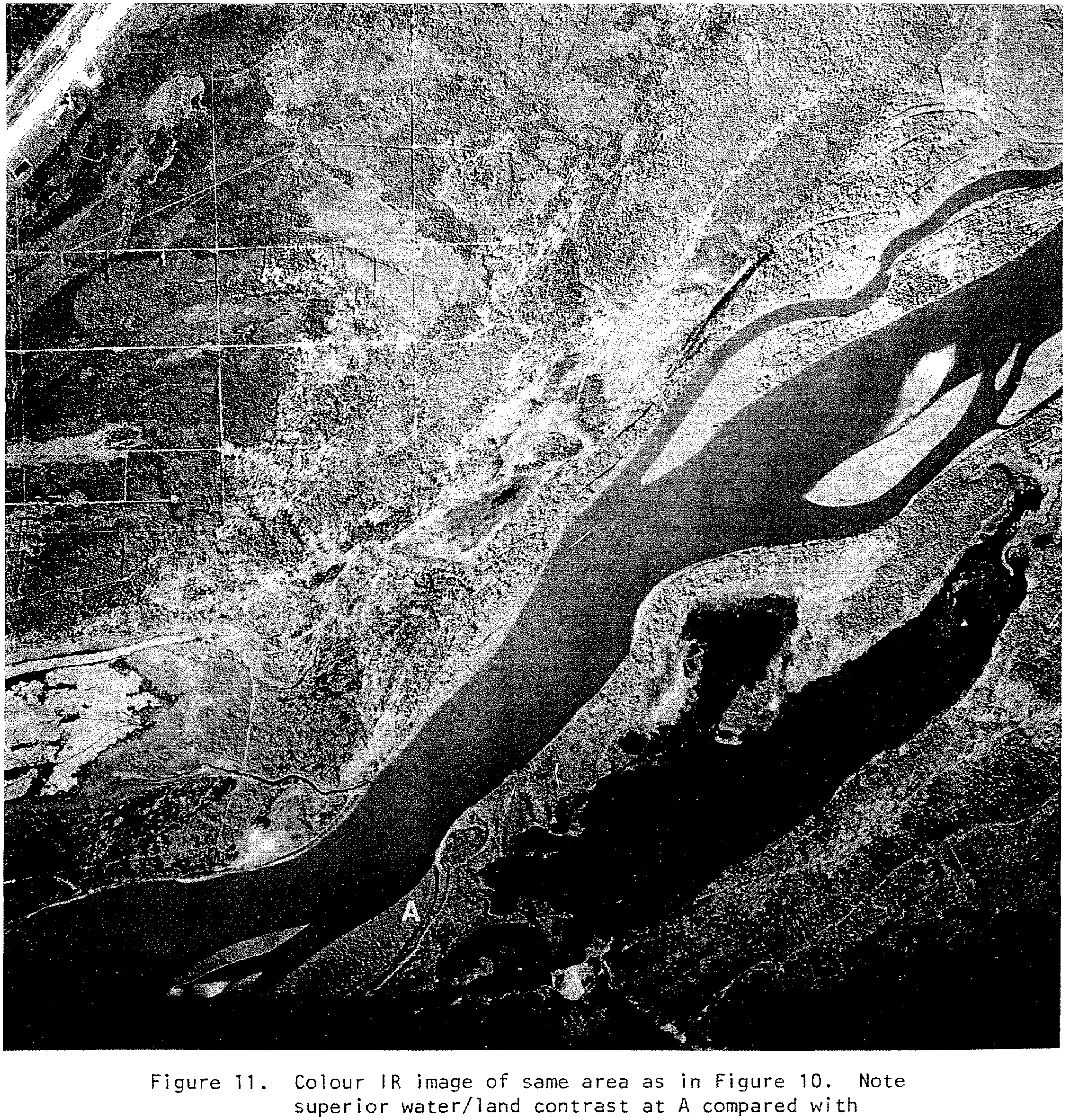


Figure 11. Colour IR image of same area as in Figure 10. Note superior water/land contrast at A compared with Figure 10. Also notice the greenish-brown coniferous trees at B compared to the red deciduous species at C, and their better differentiation than in Figure 10.

Eutrophic waterbodies cannot necessarily be differentiated from nutrient-poor waterbodies by their increased nutrient level per se, but they can be interpreted by the resulting high phytoplankton population.

Concentrations of algae or algal blooms in a waterbody can occur when the nutrient level is high enough and sufficient quantities of sunlight are available. Colour IR film is an excellent detector of these conditions for two reasons. First, algae has a high chlorophyll content and when the surface component of the bloom is dense enough, the IR reflectance from it becomes visible as a red tone on the water. If the algae is just below the surface, a bright pink swirl pattern is observed, indicating some attenuation of the IR wavelengths by the water. Secondly, as with floating aquatic vegetation, the algae is further enhanced by the dark tone of the water, facilitating its delimitation. Often white lines appear on the surface of a waterbody experiencing an algal bloom. These are created by floating dead algae and are called spume.

Turbidity conditions are easily discernable on this film because any particulate matter in the water will increase the reflectance of certain wavelengths of energy depending on the size of the particles. The rule is that a particle will scatter any energy with wavelengths equal to or less than the diameter of that particle. The reason that glacier-fed lakes, for example, naturally appear turquoise in colour is because the clay and silt particles from the melting glacier in suspension in the water have diameters which are equal to or greater than both blue and green wavelengths, thus the scattering of blue and green light gives turquoise.

On colour IR photos these same lakes would image blue because blue wavelengths have been deleted and the green wavelengths are represented by blue. Muddy water in a river or lake may give a variety of hues depending on the particle sizes but it will not appear black, indicative of clear water conditions and it will not appear any shade of red which would attest to the presence of algae (see Figures 10, 11, and 12).

Figure 12. Colour IR photo showing silty Athabasca River at A and adjoining relatively clear Firebag River at B. Note that the influence of the clearer water can still be seen along the shore at C.

The final two advantages of colour IR photography for aquatic habitat studies are its excellent land/water boundary delimitation and its atmospheric haze penetration ability. On regular colour photography, the interpreter frequently encounters difficulty in accurately defining the exact shoreline of a lake or river, especially if emergent vegetation along the shore confuses the effort. Colour IR photography gives the user a precise boundary as a result of a combination of the opacity of the water to IR reflectance and the high return of IR energy from vegetation and land surfaces (see Figures 10 and 11).

The elimination of interpretation problems resulting from bothersome atmospheric haze conditions increases the favorability of this imagery. Haze affects the shorter wavelengths of light, the blue portion of the visible spectrum, due to the diameter of haze particles. The fact that blue wavelengths are not imaged on colour IR photographs reduces the possibility of poor imagery due to these conditions. This superior haze-cutting ability provides clarity of detail even at the high camera altitude of 18,000 m. Very little wetland data is lost with increased altitude.

Most researchers have found that in comparison with colour photography colour IR was definitely superior for delimitation of wetlands and shallow water emergent plant species. Colour IR imagery has great potential for wetland and aquatic habitat studies and could greatly reduce time and expense.

It should be noted that B&W IR photography can also be used in lieu of colour IR. The same relationship exists between these two imagery types as between B&W Pan and colour. B&W IR photographs cost much less to obtain and show basically the same electromagnetic energy response as does colour IR. The addition of colour increases the interpretability of the images so greatly that colour IR should be used if economically feasible.

2.2.4 Thermal IR

Infrared wavelengths in the photographic portion of the spectrum detect reflected energy originated by the sun but are insensitive to radiation emitted from warm bodies. Energy corresponding to 0.003-1.0 mm in wavelength is thermal IR energy and is emitted by any object which has a temperature greater than absolute zero, which qualifies all natural objects in the environment. Due to atmospheric absorption of most IR wavelengths by water vapor and carbon dioxide, there are only two areas of relatively free passage, or windows, in this portion of the spectrum: 0.003-0.0055 mm and 0.008-0.014 mm. Of these wavelength bands, the latter is the most extensively used for delineating temperature differences in aquatic and terrestrial ecosystems.

Since thermal IR energy cannot be sensed on film emulsions, the scanner system is employed. A scanner senses a continuous strip of terrain beneath the aircraft. The strip is composed of contiguous scan lines repeatedly taken transverse to the direction of flight. As the instrument scans, commonly 120 to 130 scans per second, the responses are amplified and recorded at a rate proportional to the speed of the aircraft. They are then projected onto a cathode-ray tube and may be photographed to produce "imagery" which looks like a direct aerial photograph. In the case of thermal scanners, the detector which transforms the impinging IR radiation to electrical signals has to be cooled to a given temperature to sense the thermal differences of the landscape.

A thermal scanner records relative temperature differences and must be used with a temperature reference source and with actual measured temperatures of the surface over which the scanner passes. The measurement of these surface temperatures should be carried out at the same time as the scanner overpass.

The use of thermal IR imagery for detecting differences of temperature in aquatic ecosystems has been extensive, mainly due to the recent interest in thermal pollution from power plants.

Location of groundwater inflow to waterbodies, and current patterns have also been studied using thermal imagery. Little has been done, however, to apply thermally-sensed data to studies of wetlands and shallow water systems because only water surface temperatures are recorded. Any thermal energy emitted at depth in the water is absorbed before it can reach the surface and escape. Surface temperatures can be up to 3°C warmer than those below in shallow, quiet water bodies. That could be a critical difference in aquatic habitat studies.

There are several positive uses of thermal IR imagery in these types of studies. Algae growth can be monitored since definite temperature changes are associated with its proliferation. The identification of possible source regions for the warmer water and prediction of potential algal blooms could be made.

In streams and rivers where turbulence causes mixing of the water, the surface temperature often corresponds to that below. Deeper channels will tend to have cooler temperatures than will quieter, shallow areas, the surface of which may be warmed by solar radiation. Since certain fish species prefer the deeper, cooler water, locating and mapping these areas on thermal images can simplify and concentrate the ground work.

2.2.5 SLAR

SLAR, or Side-looking Airborne Radar systems, have not been used extensively in aquatic habitat studies. They are better suited for geological and geomorphological research. However, some aquatic studies have made use of them. Several types of aquatic vegetation can be differentiated on SLAR imagery by using indications of their relative heights, densities and surface roughness. There has not been enough research completed in this area for the production of a key to identification of specific vegetation species by their radar "signatures". SLAR imagery has proven to be a better indicator of relative vegetation heights than any of the sensors discussed above. SLAR systems may prove useful in regional survey of emergent and floating aquatic plants because of their relative roughness compared to the normally smoother water surfaces. For specifics on the use of SLAR imagery in water resource and aquatic vegetation studies already completed see, for example, Drake (1974).

2.2.6 Multispectral

Every object on the earth reflects electromagnetic energy according to its particular physical and chemical characteristics. This reflectance can be recorded and plotted on a spectral analysis chart, the particular signature or "fingerprint" being unique to that type of object only. Multispectral sensing involves the division of electromagnetic wavelength regions into narrowly-defined bands in which objects can be recognized and differentiated by their spectral signatures. For example, suppose that two species of aquatic vegetation gave the same grey tone response on B&W Pan photos, appeared basically the same shade of green on colour photographs and imaged the same red tone on colour IR photos. If it were necessary to differentiate these two species, none of the above imagery could be used. But if their spectral signatures were examined closely, a particular wavelength in which the response of the two species differed would probably be found somewhere in the visible and IR wavelength region. If only that narrow region were sensed, a separation of the two could easily be made on the imagery. This is the rationale for the use of multispectral sensing.

Multispectral sensors can be either camera systems or scanners depending on the wavelengths to be sensed. In the case of a camera system the lenses are all bore-sighted to focus on the same area, and filters are used on each lens to ensure that only the specific wavelength range is able to be photographed. The film used is either B&W Pan or B&W IR. Any number of lenses or cameras can be used. All shutters operate at the same time so that a particular area is photographed in all bands simultaneously. The result is that differences in response or grey tone are due strictly to wavelength differentiation and not atmospheric conditions. Spectral signatures of each object in the area photographed do not have to be known. The interpreter can determine if separation of two or more objects can be made in any of the bands by comparing all of the images of the same area. If it is found that the two aquatic vegetation species in the previous example can indeed be separated in a particular band, such as 0.73-0.79 µm, and this is the purpose of the study, the entire study area can be flown using only that band at a large savings of time and money.

A comparison of spectral reflectance curves of most aquatic vegetation species studied in various aquatic habitat research indicates that the best spectral range to use for their differentiation is the IR band of 0.9 - 1.1 µm. As was noted previously, the reflected IR portion of the spectrum is the best area for land and water differentiation because of the high absorption of IR wavelengths by water. Within this zone the relatively narrow band of 1.5-1.8 µm has been found to be the most effective in detecting surface water areas.

If the image interpreter is interested in submerged phenomena, the change in spectral composition of light reflected from underwater objects should be understood. In pure water, maximum absorption of light is in the infrared wavelengths and the minimum is in the blue-violet (0.48 µm). In river water which has a tendency to be turbid, the maximum absorption is in the blue-violet while the minimum is in the yellow-orange (0.576-0.609 µm). Depending on whether the study is in turbid or clear water, the proper wavelength region can be chosen to produce maximum depth penetration.

The use of multispectral scanners for measurements of suspended sediment has been found to be more valuable than the use of multispectral camera systems because the ever-present problems of possible variations in films and development techniques are eliminated. Also the compatibility of scanner systems to digital conversion and automatic data processing make them advantageous. Selection of a narrow wavelength band centered around 0.57 µm and one near 0.69 µm would permit measurement of low concentrations of sediment while simultaneously detecting the presence of algae growth.

2.2.7 LANDSAT

Satellite imagery from LANDSAT-2 is available for the study area at a fraction of the cost of conventional imagery, considering that most of the Athabasca Oil Sands region can be included in four images. The small scale of the LANDSAT images, 1:1,000,000, may seem to be a drawback but there are distinct advantages other than the low cost. Images of a particular location are available every 18 days, and for the past several years until recently when a malfunction placed it out of order, LANDSAT-1, formerly ERTS-1, was also sending back image signals, so that the study area was imaged every nine days. All of these images are on file in Ottawa and are rated as to image quality and percent cloud cover. They can be viewed on microfilm at facilities such as the Alberta Remote Sensing Center in Edmonton before ordering.

LANDSAT is equipped with a multispectral scanner system which records energy in four wavelength regions: MSS-4 images green (0.5-0.6 μm), MSS-5 is red (0.6-0.7 μm), MSS-6 is near IR (0.7-0.8 μm), and MSS-7 also in the near IR (0.8-1.1 μm). The blue wavelengths are not included due to their high susceptibility to atmospheric scattering. In addition to each of these separate images of a particular scene, colour composites of any two or three are available. The most common combinations are MSS-457, in which 4 is colour-coded blue, 5 is green, and 7 is red; and MSS-567, where 5 is red, 6 is green and 7 is blue.

For limnologists LANDSAT imagery provides the most detail in MSS-4 and MSS-5 for such parameters as circulation, biomass and turbidity conditions. In optically pure water, fifty percent light transmission will occur to a depth of 10 m by MSS-4, 2.5 m by MSS-5, 0.5 m by MSS-6, and 0.2 m by MSS-7. The four LANDSAT bands detect increasing sediment with decreasing band number. In a waterbody with a high sediment content the turbidity will image best on MSS-4 and least on MSS-7. However, due to the possible presence of atmospheric haze which would affect MSS-4, sediment patterns are usually interpreted best on MSS-5. Of the two most common colour combinations, MSS-567 is considered best for sediment patterns because of the much better visual contrast between the gold and red colour of sediment-laden water and the black of relatively clear water. The contrast on colour combinations MSS-457 is between blue and black (see Figures 13 and 14).

When the suspended matter causing the turbidity is algae, MSS-6 is best suited to surface algae detection. Infrared reflectance from living plants increases rapidly between 0.7 and 0.75 μm. This wavelength region is also characterized by decreased reflectance from water, thus providing a highly contrasting background for the algae. If the algal bloom is intense enough to cause the biomass to emerge slightly above the water surface and to dry, the reflectance from the algae will be intense enough to be observed in MSS-7. The fact that most algal blooms take place over just a few days makes LANDSAT a poor vehicle with which to monitor their progress.

2.3 REQUIREMENTS AND SUGGESTIONS

When a study of aquatic habitats is being planned and a choice of imagery has been decided upon which will be the most beneficial for the parameters to be studied, there still remains the task of having the imagery flown. If the user does not know what specifications to ask for, especially with photographic missions, the imagery obtained can be almost useless for his particular research. Types of cameras, films and filters, flying heights, scale, time of day and time of year are only some of the considerations which must be made. The more the researcher knows about what he requires regarding these factors the more useful the resultant imagery will be to his research. Following is a description of some of the factors which should be known by the research planner.

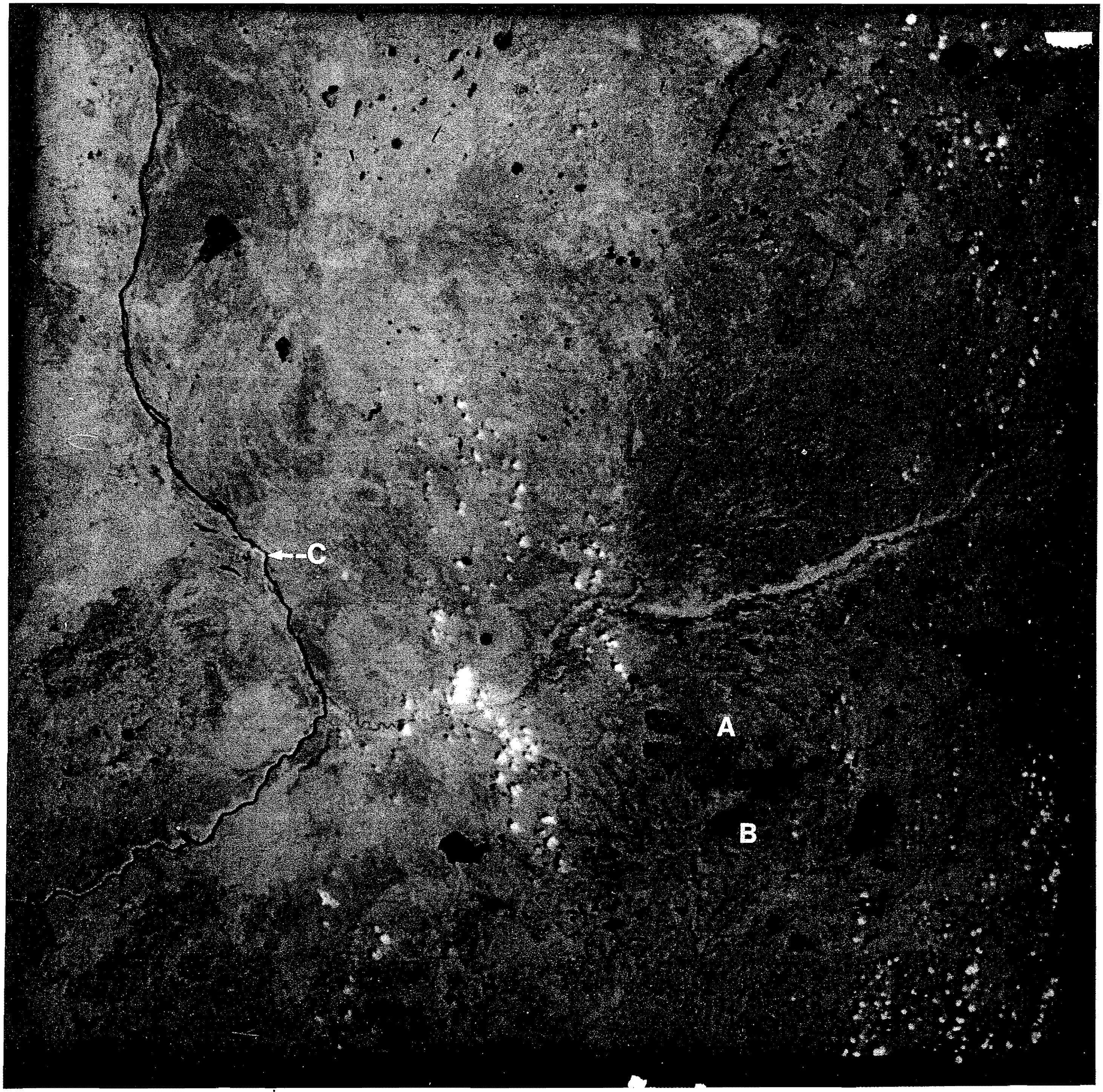


Figure 13. LANDSAT image of a portion of the AOSERP study area using MSS-567 at a scale of 1:1,000,000. Compare the gold colour of the turbid lake at A with the black water tone of the clear lake at B. Also note the highly turbid tailings pond at the Syncrude site at C. Contrast with Figure 14.

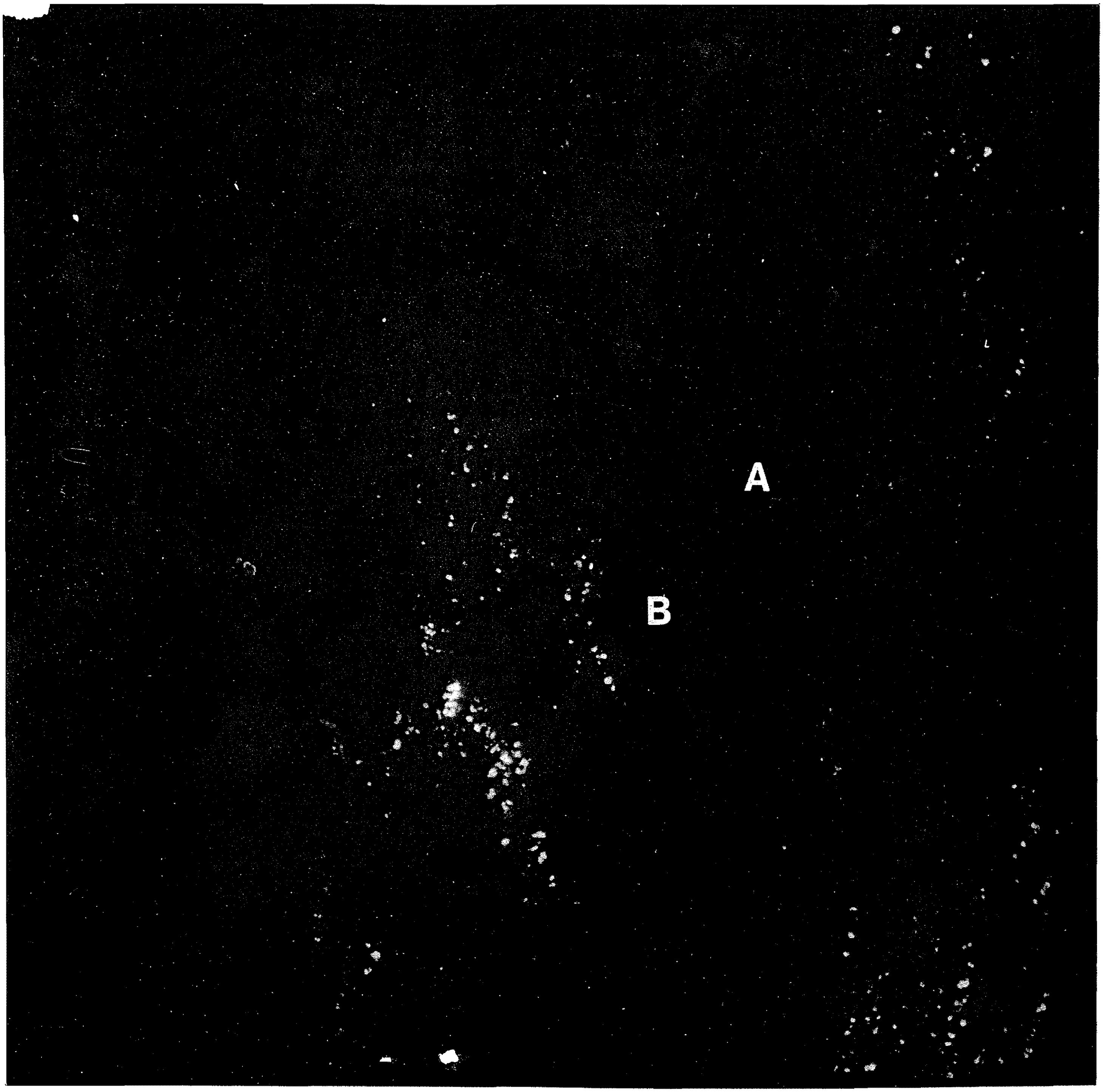


Figure 14. LANDSAT image using MSS-457 of same area as in Figure 13. Notice how wet muskeg areas (darker tones) contrast nicely with the more vigorous vegetation growth (red tones) surrounding them. Compare with same area in Figure 13.

Table 8. Generalized guide to the value of various remote sensors to aquatic habitat parameters.

Aquatic Habitat Parameters	Remote Sensors[a]							
	B&W PAN	B&W IR	COLOUR	COLOUR IR	THERMAL IR	SLAR	MSS[b]	LANDSAT
Terrestrial Vegetation	G	G	G-E	E	P	P	E	G
Aquatic Vegetation	G	G	G-E	E	P	F-G	E	G
Turbidity: Suspended Solids	G	G	G-E	E	P	P	E	G
Turbidity: Organic	G	G	G-E	E	F	P	E	G
Water Temperature	P	P	P	P	E	P	P	P
Land/Water Interface	F	G	F	E	G	F	E	E
Underwater Phenomena	G	P	E	P	P	P	E	G

[a]Symbols: E = Excellent, G = Good, F = Fair, P = Poor.

[b]MSS values are based on the fact that most phenomena can be differentiated in a given narrow wavelength band. In actual practice, the user may be limited to available multispectral imagery that may not divide the spectrum enough for his particular purpose. In this case the E rating would be downgraded to G, F, or even P.

Table 9. Selected aquatic habitat parameters and their detection on LANDSAT MSS wave bands.

Parameter	Wave Band			
	4 GREEN	5 RED	6 IR	7 IR
Chlorophyll (Land)		X		
Chlorophyll (Water)			X	
Cloud Penetration				X
Eddies		X		X
Flood Plains				X
Haze	X			
Lakes				X
Lake Eutrophication	X			
Marshes			X	
Rivers			X	X
Shallow Waters	X			
Shoals	X			
Shores			X	X
Small Lakes				X
Stream Channels			X	
Stress (Vegetation)		X		
Surface Water			X	X
Turbidity	X	X		
Water Boundaries			X	X
Water Depth	X	X		
Water Pollution	X	X		
Water Sedimentation	X	X		
Wetlands			X	X

Table 10. Values for uses of each LANDSAT MSS wave band.

Parameter	Wave Band[a]					
	MSS-4	MSS-5	MSS-6	MSS-7	C-1 MSS-456	C-2 MSS-567
Wetlands	P	F	G	E	G	E
Turbidity	G	E	F	P	G	F
Water Penetration	E	F	P	P	F	P
Vegetation & Stress	F	G	G	G	E	G
Atmospheric Transmission	P	F	G	E	F	G
Rivers & Streams	P	F	G	E	G	G

[a]Symbols: E = Excellent, G = Good, F = Fair, P = Poor.

2.3.1 Camera Systems

An inherent problem with aerial cameras is that since the image of an area must pass through a lens to reach the film, it is focussed in the centre of that lens and diminishing light intensity can occur on the final image, with minimum intensities at the outer extremities of the lens. Nine-inch format cameras employ a between-the-lens shutter so that this falloff factor is consistent and can be corrected for, which is not the case with many smaller format focal plane shutters. Also the lenses associated with nine-inch format cameras tend to have high resolution qualities. But there are disadvantages associated with these cameras too. If B&W Pan or B&W IR film is to be used, the final cost of a photograph is nominal. But if colour or colour IR film is required, the cost is between $5 and $13 a print and increasing. Another problem occurs when simultaneous colour and colour IR imagery is required, because few aircraft are equipped with the necessary hardware to accomplish this.

Seventy millimetre format cameras provide good resolution and many have between-the-lens shutters which provide adequate correction for lens falloff. However, the nine-inch format camera is superior. Film must be viewed on a light table.

Thirty-five millimetre cameras have been used both mounted and hand held. The film is easy to obtain and the results can be viewed on a large format microfilm viewer. The economy of using this film is a great advantage. Disadvantages include a relatively poor resolution, one-fourth that of 70 mm format cameras, and unpredicatable light intensity distribution on the film.

2.3.2 Film/Filter Combinations

B&W Pan films (Kodak type 2402 and 2405) are still the most commonly used today for interpretation and mapping. They provide good tonal contrast, wide exposure latitude, reasonably good resolving power and low graininess. They also have a higher than normal sensitivity to red wavelengths which makes them very useful for multispectral camera systems recording in the red and green regions of the spectrum.

Several filters are available for these and other film types. The Wratten #58 filter (0.5-0.6 µm) is useful for differentiating a variety of wetland and aquatic plant communities, especially Juncus spp. Another filter which has proven quite valuable for marsh species and suspended sediment patterns is the Wratten #25-A (0.6-0.7 µm). Its best differentiating ability is toward the upper limit of its range.

The use of polarizing filters in vertical aerial photography has been relatively unexplored. The reason is that polarization is effective only when the angle of reflection is approximately 35^{o}; thus a polarizing filter will have no effect when the sun is directly above the aircraft. If a mission is being flown with a low sun angle, however, a polarizing filter may be used in conjunction with all film types. It will improve the image contrast by reducing the amount of radiation from the ground by a factor of three. It must be remembered that less radiation reaching the film means that a longer exposure time is required. Also, due to the nature of polarized light, under no circumstances should the resultant image be used for exacting measurements.

Two widely used colour films are Types 2445 and 2448. The former provides the researcher with a variety of end products from which to choose. Depending on his needs, he can have the negative of this film processed to B&W or colour prints, diapositives, or transparencies. Type 2445 is very good for detection of underwater objects such as submerged aquatic plants. Manipulation during processing and reproduction can be used to enhance various features in the landscape. The disadvantages of this film are that it has a narrow exposure range and is extremely sensitive to haze. Type 2448 is also good for water penetration but has a narrow exposure latitude compared to Pan film.

If the budget allows for a large expenditure on photography, we recommend that simultaneous colour and colour IR images be obtained. For water quality investigations, Wratten #12 or #15 filters are best.

Kodak Aerographic IR Type 2443 (estar-base) and 3443 (thin-base) are best all purpose films for interpreting wetland plant communities and production zones. Colour IR is a high-contrast film with a limited exposure range of 0.5 f-stop. The addition of a CC10B colour-compensating filter will enhance algal blooms better than just the #12 or #15 alone. If this additional filter is used the exposure settings will have to be adjusted. The interpretation of shallow water environments may be augmented by a one-step over exposure of the film either during the photography or later in the processing. If the exposure setting is in doubt, it is always better to overexpose than underexpose this film. Exposure settings for colour and colour IR film are very critical as 0.5 f-stop off the optimum can adversely affect image quality. Suggested exposures for colour IR film with a Wratten #12 filter are as follows:

Altitude (AGL)	f-stop	Shutter Speed
2,400 m	8	1/500 second
1,200 m	5.6	1/500 second
600 m	4/5.6	1/500 second
300 m	4/5.6	1/500 second

B&W IR film (Kodak IR Type 2424) used with a Wratten #89-B filter (0.7-0.9 μm), is very good for detecting wetlands but vegetation species differentiation is poor.

2.3.3 Other

An important problem associated with aquatic habitat studies is that of wave patterns causing sun glitter on the surface of a waterbody and thus obscuring underwater phenomena as well as floating aquatic vegetation. Wind speed forecasts during flying time should be less than eight knots if the sun angle is above 34°. It is not advisable to fly imagery when the sun altitude is less than 25°. Sun altitudes can be found in solar altitude tables.

The best time of the year for flying a photographic mission for aquatic habitat studies in the Athabasca Oil Sands region is late August or early September. The aquatic vegetation has reached its maximum extent, emergent aquatic species have changed colour and contrast well with submerged green species, the water is clearer than at any other time during the summer and there is usually less haze in the atmosphere. Of course weather conditions can turn bad quickly at that time of the year.

For thermal imagery the time of flight is especially critical. The best contrast between objects will be in the evening just as twilight is ending. A gradual reduction of image contrast continues throughout the night, the poorest being just before sunrise. The problem is increased in aquatic studies because of the common occurrences of fog over wetland areas at night, which obliterates much of the temperature contrast.

The scale of the imagery is an important consideration. Scales of 1 cm to 158.4 m (1 in. to 1320 ft.), 1 cm to 316.8 m (1 in. to 2640 ft.), and 1 cm to 400 m (1 in. to 3333 ft.) are common for photography of the study area flown in the past. A scale of 1 cm to 120 m (1 in. to 1000 ft.) may be necessary. It is difficult to suggest any particular scale until the nature of the study is known. With the rapid advancement in interpretation equipment, smaller scale photographs are becoming increasingly more interpretable. The best advice is to discuss the nature of the project with the photo-interpreter and have him suggest the smallest scale possible that he feels he can be comfortable with.

Once the imagery has been flown and is available for interpretation, use should be made of such interpretive devices as the Colour Density Slicer and the Additive Colour Viewer. These machines can augment the interpretability of good imagery and possibly transform "useless" images into valuable resources for research. Both of these devices can be found at the facilities of the Alberta Remote Sensing Center in Edmonton, and are available to anyone for use.

Transparencies are the best form of imagery to use for interpretation; features are clearer, contrasts are better and possible problems associated with reproduction are eliminated. Transparencies are also much more compatible for use with the Colour Density Slicer and the Colour Additive Viewer than are prints. Disadvantages are that transparencies must be used on a light table and stereo-vision is often difficult to obtain.

Black and white LANDSAT imagery may be purchased only from:

Integrated Satellite Information Services Ltd.
P.O. Box 1630
Prince Albert, Saskatchewan S6V 5T2
Phone: (306) 764-3602

Colour LANDSAT imagery and computer compatible tapes may be purchased only from:

Canada Centre for Remote Sensing
717 Belfast Road
Ottawa, Ontario K1A 0Y7
Phone: (613) 995-1210

Photographic imagery can be obtained from:

National Air Photo Library
Surveys and Mapping Branch
615 Booth Street
Ottawa, Ontario K1A 0E9
Phone: (613) 994-5779

AND/OR

Alberta Department of Energy and Natural Resources
Air Photo Services
Petroleum Plaza Building - South Tower
9915 - 108th Street
Edmonton, Alberta T5K 2C9

3. COMPUTERIZED MAPPING: A REVIEW OF THE STATE OF THE ART AND ITS APPLICABILITY TO THE NEEDS OF THE ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

3.1 DATA PROCESSING FACILITIES READILY AVAILABLE TO AOSERP IN EDMONTON

The Alberta Oil Sands Environmental Research Program (AOSERP) is managed under the Alberta Department of the Environment, and as such has access to the Alberta Central Government Computing Facilities in Edmonton. In addition, the University of Alberta Computing Services offers their facilities to external non-profit organizations. These facilities are available to AOSERP. Commercial data processing firms will generally accept data processing at somewhat higher rates while offering limited facilities in the Edmonton area. A more detailed description of the hardware available at the University of Alberta and Alberta government facilities follow.

3.1.1 University of Alberta Computing Services

3.1.1.1 Hardware. As with most major universities, the hardware facilities available at the University of Alberta are excellent. The university's processing unit is an Amdahl 470V/6 with four million bytes of memory. Additional storage on magnetic disc provides a total accessible storage greater than two billion characters. This central processing unit is supported by batch processing facilities and a network of more than two hundred terminals throughout the campus. Card reader and printer facilities, magnetic tape drives, a digitizer, a paper tape reader/punch, an incremental plotter, interactive graphic display, calcomp plotting facility and an electrostatic plotter are among additional significant items available to users of the system. The magnetic tape handling facilities include both seven and nine track tape drives which can handle tape densities of 6250, 1600, or 800 BPI (nine-track) and 800, 556, and 200 BPI (seven-track). The interactive graphics unit is a DEC GT42 Graphics Display Processor operating with FORTRAN callable subroutines. Digitizing is done with a Graphitizer digitizer which can be used to convert analog data to digital data.

3.1.1.2 Software. The University of Alberta computing facilities operate on the Michigan Terminal System (MTS) which offers both batch and interactive processing. Language compilers available include FORTRAN, ALGOL, COBOL, PL/1 for batch processing. Interactive processing can be done using the languages APL, BASIC, IF, and three specialized languages.

Graphic software packages include the Digital Plotting System for passive graphics using FORTRAN-callable subroutines and the Integrated Graphics System for interactive graphics. Specific mapping routines which are available are SYMAP and SURFACE II used to produce contour maps. These two programs will be discussed below. New programs and routines which have wide user demand are examined by the Computing Centre staff and made available as part of the systems package.

3.1.1.3 User rates. The University Computing Services offers two rates to outside users. The rate for non-profit organizations and governmental agencies is significantly lower than the commercial rate. AOSERP qualifies for the non-profit organization rate. Arrangements could be made for consultants, researchers and others under contract to AOSERP to use these facilities, at the non-commercial rate specifically for AOSERP contracts, using an AOSERP identification. Alternatively, these agents can use the facilities at the commercial rate, using their own identification. Current rate schedules for both types of non-university user can be found in Section 5.2.

3.1.2 Alberta Central Government Computing Facilities

3.1.2.1 Hardware. The Central Government Computing Facilities operate using two IBM 370/168 machines and the accompanying facilities for batch processing and interactive data processing. Plotting facilities consist of a Calcomp plotter which is to be replaced by a new model in the near future. Electrostatic plotting facilities may be available by special arrangements with specific users such as the Department of Recreation who may have departmental capabilities in these areas.

3.1.2.2 Software. Major software capabilities include FORTRAN for batch processing and several packages for interactive, on-line processing including BASIC and APL. According to the Executive Director, Hugh Kelly, specific mapping software is not available, nor are there any interactive graphics capabilities. These capabilities may be available through specific departments and arrangements for their use may be possible. Mr. Al Schut, Manager of User Support, indicated that a program package for mapping contours and densities should be available midway through 1978, but no details regarding this package were released.

The Central Government Computing Facilities do not offer as wide a range of software capabilities as do the University Computing Services. Many departments within the government have developed their own specialized capabilities and the mapping capabilities possessed by the Departments of Transport and Recreation may be of use and interest to AOSERP.

3.1.2.3 User rates. Mr. Hugh Kelly, Executive Director of the Central Government Computing Facilities, would not release any rate schedules until he established for himself that AOSERP is an agency of the Alberta government. As a result, Schultz representatives have been unable to obtain rate schedules, despite repeated requests.

3.1.3 Commercial Facilities

Several commercial data processing facilities were contacted. In many cases the data processing capabilities were impressive and provided significant flexibility for interactive processing.

The disadvantage with commercial facilities is that the user is responsible for providing his own programs or making arrangements with other user/authors for the use of their packages. The rates for commercial facilities are higher than those offered by the University. The commercial facilities, in general, do not offer graphics systems to provide hard copies of the processed data.

3.2 WHY COMPUTER BASED MAPPING?

Data processing capabilities have become so sophisticated, it may be useful to examine the rationale for considering a computer based mapping capability: is the objective to provide maps generated using data processing techniques?; is the objective to provide for rapid and thorough analysis of large volumes of complex data?; is the objective to create a data storage bank from which rapid recall is possible? The application of data processing facilities for each of the purposes listed above will be discussed in terms of aquatic habitats of the AOSERP study area.

3.2.1 Levels of Data Processing and Their Application

As implied in Section 3.2, geographic data processing can be carried out at several levels of sophistication. The application for which the data has been collected will determine which level of sophistication should be used for processing. Some thought must also be given to the possible uses of such data in the future when designing computer mapping capabilities. In the following sections three levels of application, map production, data storage and retrieval and analysis of complex resource management problems, are reviewed and analyzed.

3.2.1.1 Map production. The hardware and software are now available for the complete production of maps at any desired scale. The sophisticated digitizing equipment currently available provides rapid location of co-ordinates for each change in contour, or direction with an average reproductibility of ± 0.05 inches. It is now possible to produce a base map of any desired complexity, including contour lines, data information and data locations using automated data processing techniques with relative ease. There is no economic advantage in producing maps in this way, however. The time required to encode such a map would be at least as great as the time required to manually draft the same map. The editing and proofing processes for computerized mapping remain manual. There are several obvious advantages to automated cartography. For example, once the data have been encoded, the scale of the map produced can be easily changed to any desired scale. Alternatively, only a portion of the map could be reproduced. The coded map can be used as an information source to assist in analysis of a problem. In yet another application, the coded base map could be used to produce many different maps, illustrating several separate data types, such as a map illustrating aquatic macrophytes, a second illustrating fish species distribution and a third illustrating spawning areas, all for a prespecified watershed base map. Finally a great saving in the work associated with the printing process can be effected using machine produced maps.

Even with the great flexibility for map production which can be realized using computerized techniques, encoding data solely for this purpose is not recommended. The amount of work required to encode the data is sufficient to demand that further application be made of these data. The demand for additional analysis of encoded data is further emphasized by the wide availability of highly sophisticated data handling techniques requiring a minimum level of training.

3.2.1.2 Data storage/retrieval system. As indicated above, data processing is a powerful and useful tool if used efficiently. In this regard, encoding of data for the creation of large data storage banks is an inefficient use of computer facilities. The data can be recorded without transcription error and stored in much less space using microfilm techniques. A more efficient use of computer techniques relating to data storage and retrieval would be to convert the data to a more useful form prior to being retrieved. Conversion of the stored data into a new format requires some recalculation, but this can be done quickly and accurately using a computer. For example, the resource manager may wish to know what the littoral area covered by a given species of aquatic macrophyte is. Following the recommendation of Section 1.2.4.3, the percent littoral area of each lake which has been studied will have been recorded and encoded. Similarly, the aquatic macrophyte cover for these lakes will have been identified by location and species and encoded. Using manual techniques, considerable time and effort would be required to answer the question posed above. Using data processing techniques the total littoral area in the study area could be rapidly determined, as could the area covered by the species of aquatic macrophyte under question. Finally, the area which is both littoral and covered by the aquatic macrophyte species in question would be readily calculated. The calculations can be performed quickly and easily using minimal computing facilities. The overlap area could also be quickly identified by map co-ordinates and a new map delineating this area readily prepared. Alternatively, the resource manager may be interested in the watershed area inhabited by Arctic grayling and the specific locations of inhabitation or probable inhabitation. These areas could be quickly determined, identified and mapped using data processing techniques. These same steps done manually would require extensive time and effort and are subject to error. The data storage/retrieval function of computer mapping is closely related to the third category, analysis of resource management problems.

3.2.1.3 <u>Analysis of resource management problems</u>. The use of computer mapping techniques to solve resource management problems is the most sophisticated and powerful use of data processing in computer mapping. The resource manager is limited only by the data base at hand and his ability to construct a valid model. A very basic and obvious question which will undoubtedly arise in the future of the AOSERP study area is: "What is the best site for an industrial facility with specified requirements for water supply, distance from raw material, and gaseous emission dispersal?" If the hydrological and meterological data have been gathered and encoded, several sites meeting the specifications may be quickly identified using data processing techniques. The suitability of these sites can then be refined by selecting only the sites with minimal impact on the aquatic habitat, for example. Continuing in this way the industrial site can be selected to minimize its overall negative environmental impact and still meet the engineering requirements. Selecting a site based on a thorough analysis of all parameters available should be preferred to the random selection of a site based on a qualitative analysis of impacts.

Although the data processing techniques are very rapid and accurate, the analyses and conclusions reached are only as valid as the model used to analyze the data. For example, it would be foolhardy to base site specific decisions on data collected as an average reach parameter. At the same time, a careful weighting for each parameter must be applied to the model selected. We emphasize again, the efficacy of any conclusions will depend on the validity of the model selected and availability of data balanced to the level of application sought.

3.3 SOFTWARE COMMONLY USED IN COMPUTER MAPPING

3.3.1 The Encoding Process

The encoding process is the most difficult and complex phase of computer mapping. The operations used in encoding depend somewhat on the method of data presentation selected. There are two methods under wide use for storage of geographic data, the polygon method and grid method. These methods of data entry correspond directly to the two main methods of map presentation, a plotter, such as a Calcomp, and a line printer or electrostatic plotter, respectively. The co-ordinates used to locate key points in either method are determined by a process referred to as digitizing.

These aspects are discussed in more detail below.

3.3.1.1 Digitizing. The process of converting data associated with a geographic location into a form which can be used in data processing requires a reduction of two dimensional areal data to a single dimension linear string. This must be done in several steps with the programs currently available. The first of these steps is common to both of the geographic data encoding techniques used routinely and is called digitizing. Digitizing is the process of determining the co-ordinates of significant parameters from a source map. The important points whose co-ordinates are determined include polygon vertices in the polygon method, or the grid cell of a data point for the grid system.

At the University of Alberta, electronic digitizing facilities and accompanying software are available for rapidly digitizing a source map. This unit consists of a workboard, cursor, keyboard, tape unit, display console, and electronic unit. The co-ordinates of each selected point on the source map to be digitized are encoded relative to a preselected origin and stored on a seven track tape. For example, the boundary locations for each reach and point sample locations within a drainage basin may be located with the cursor and stored on the seven track tape for future use. The data on the seven track tape can then be converted to a form used more conveniently by higher level languages using the program *DIGICONV. This program converts the data to a binary encoded format, performs any conversion, scaling and compensation for position on the workboard which may be necessary and stores the data on a nine track tape. Following this procedure, a complete watercourse could be encoded, including reach boundaries, point sample locations, barriers and obstructions, and then plotted with the Calcomp plotter to produce a map.

One copy of the user handbook, "GRAPHITIZER, the Digitizer" (Perry and Butler 1974), has been presented to AOSERP. Additional details regarding the capabilities and use of this unit can be found in this handbook.

Less sophisticated versions of the digitizing unit are available, or can be assembled from the basic units of cursor, workboard, small programable computer equipped with the capability of producing a permanent copy. If AOSERP decides to proceed with computer mapping capabilities, we highly recommend the purchase of digitizing facilities for the Program.

3.3.1.2 Polygon and grid techniques. Geographic data are generally classified as point, line or area data. Applying these classifications to the mapping of aquatic habitats, a point would correspond to a specific sample location, line representations would be used to indicate rivers, streams and reaches, and area representations would correspond to watersheds, sub-watersheds and drainage basins.

Each of the data storage and encoding processes, the polygon method or the grid method, has advantages and disadvantages not associated with the other method. For example, the accuracy with which polygon data represents the field data depends on the accuracy with which the polygon boundaries are encoded. The accuracy of grid data is determined by the grid cell size, as are any parameters generated from the data, such as area. Grid data presents certain advantages for many of the more complex data manipulations of information retrieval and analytical operations. On the other hand, polygon structure is often more compatible with data collection, storage and encoding. Since it is relatively simple to transfer from a polygon format to a grid format, the format used should be selected to optimize the data processing operation to be performed.

There is a direct correspondence between the two encoding formats and the two main plotting methods. Thus, the size of each grid cell is readily defined by the line printer, each cell corresponding to a single digit area. The data associated with each grid cell are encoded and stored by cell location, e.g., line 23, column 58. A somewhat finer grid can be created using an electrostatic plotter which provides more detail, greater accuracy, and greater control over shade densities. Data can be encoded at several levels of density and shading using either display facility. Polygon data are encoded by determining the location of the vertices of the polygon and assigning a value to the polygon. The data can be classified into several levels consisting of: level 1, all the area classified by a prescribed code and may include one or more polygons; level 2, a complete polygon; level 3, a segment of a polygon boundary between two vertices; and level 4, a single point corresponding to one of the many vertices. The creation of polygons from encoded vertices can be done by several schemes, each related to the mapping program being used. The polygon boundaries are plotted using the Calcomp plotter to join the many vertices and form the desired polygons. If the only purpose is to reproduce maps showing the locations of reach boundaries, point sample stations, water quality data and the reach aquatic habitat quality, the polygon method would be directly applicable to aquatic habitat mapping. Thus, using the digitizer in the AUTO mode, the stream course could be recorded at preset increments, down to 0.05 inch. At the same time the locations of key data points, such as of reach boundaries, point sample stations, obstructions, etc. would be digitized. Upon transposing the data to a nine track tape the appropriate symbols can be encoded, indicating the data available for that point.

Considerably more effort would be necessary to create a complete mapping capability, data file storage capabilities, and a multi-disciplinary interactive system.

3.3.2 Map Creation and Presentation

There are two specific mapping software packages currently available for users in the Edmonton area. Both packages are offered by the University of Alberta Computing Services. These packages are SURFACE II and SYMAP. In addition to these packages, several mapping programs have been developed and can be obtained by the user, including CGIS (The Canada Geographic Information System), PIOS (The San Diego Comprehensive Planning Organization Polygon Information Overlay System), MLMIS (The Minnesota Land Management Information System), GIDS (Geographic Information and Display System), GIMMS (Geographic Information Manipulation and Mapping System), and PLUS (Planning Land Use System). Given the time constraints of this study, a comprehensive review of all of these would be impossible.

The Alberta Department of Recreation, Parks and Wildlife (More et al. 1977) has prepared a comparison of three of these systems, CGIS, GIDS and GIMMS. The comparison included an assessment of data input, manipulation, retrieval and display methods as well as determining the ability to operate in both batch and interactive modes. They found that GIDS and GIMMS satisfied most of their requirements in the above areas whereas CGIS was somewhat less satisfactory. The most significant shortcoming of the CGIS was the lack of interactive data manipulation capabilities.

The SYMAP system is offered as a part of MTS capabilities at the University of Alberta (Dougenik and Sheehan 1977). This program uses a polygon format and is composed of several subroutines, not all of which must be used at one time. The system is a batch processing system and data cards for each of the subroutines desired must be submitted at one time. Several map types can be generated using the line printer or electrostatic plotter, depending on the way in which each zone is related to the data. Thus a conformant map displays data by user defined regions, a proximal map displays data type for the nearest data point for each location, a contour map displays data which have been interpolated to provide a smooth surface, a trend surface map displays data using a fit to a polynomial and a residual map displays the difference between a contour map and a trend surface map. No provision is made for data analysis or retrieval of modified information. Resource managers will not find this system useful in the analysis of the many complex problems which they will encounter.

The SURFACE II system is used in conjunction with the Calcomp plotter. Contour maps can be generated using several subroutines. For example, the subroutine SCCONT will produce a contour plot from irregularly spaced data placed on a grid. This system provides no opportunity for analysis and will also be of limited use to resource managers.

The final system to be briefly reviewed is PLUS. This system was developed by Goodchild (1976) for the Lands Directorate of Environment Canada. The system was designed to minimize many of the disadvantages of other systems, while retaining the advantages. Thus, the data are encoded and stored initially in a polygon format, but subsequent data manipulation is carried out using a grid format. This provides the flexibility necessary for wide applicability, and minimizes data processing costs. The interactive subroutines for the PLUS system can be executed on small computers by non-expert operators such as resource managers. Finally the system is capable of interacting with and using existing data banks as well as carrying out statistical analysis of data which have been collected and encoded for a specific project. The disadvantages of this system include the following: the encoding process requires a skilled operator and a large computer; and the PLUS system does not create data banks or files for storage of data, but relies heavily on existing data files. This may pose some problems for the AOSERP study area, and may require the creation of a separate data file program, should computer mapping prove to be required.

To our knowledge, PLUS is not currently available as an operating system in the Edmonton area. The Alberta Department of Recreation, Parks and Wildlife is preparing to evaluate this system for their needs, making it likely that PLUS will be available in the near future.

3.3.3 Data Storage and Retrieval

Data storage bases have been created by the various levels of government for specific inventory purposes. A data base, meeting the requirements for aquatic habitat mapping of the AOSERP region, does not exist at present. In establishing such a data base we recommend that careful consideration be given to the following.

A decision must be made at the earliest stages on the method to be used for data storage. The least expensive method and the one requiring the least storage space would be microfilm records of the field data cards. This method also avoids the problem of transcription errors. Microfilm records would be entirely satisfactory and recommended if the aquatic habitat data are to be analyzed and used in isolation of data from other areas of the Program. On the other hand, if the data are to be analyzed in terms of other studies, then creation of a computer data storage base should be recommended.

The data storage system should define precisely the location to which the data refers. Thus, a uniform co-ordinate system must be chosen and when applied will act as a cross reference to the hierarchal code recommended above for the watersheds.

Assuming a computer data storage system is selected, the file structure should be tailored to include the following:
(1) the data file should have the capability of interfacing directly to a computer mapping system, meaning that in addition to containing a code specifying the precise watershed component, and the values for the habitat parameters, the file must also specify the map co-ordinates of the reach, or sample point, etc.;
(2) the capability for rapid access of each file, for proofing, updating and adding new information; (3) the capability of rapid recall of any or all of the parameters for a number of reaches and the creation of hard copy tabulation of these data; and (4) the data files should have a permanent storage record. All of these capabilities can be designed into the format recommended above for

point sample station data. Disc storage ensures rapid retrieval and update capabilities along with the permanency of records required.

3.3.4 User Competence Requirements

The skills and experience requirements for users of the various computer mapping programs varies with the program and in some cases with phase of data handling. For those programs which offer the capability of interactive data processing, very little prior experience or skill is required. Resource managers could learn very quickly to provide the answers requested by the computer during interactive data processing so that the necessary calculations can be done. These operations also require minimal computer capabilities and in the case of PLUS can be performed with limited computing background.

On the other hand, the process of encoding and reducing the data to a useable form requires a skilled and experienced operator. This phase of data manipulation and compilation must also be done with the larger machines. Separating these two phases of computer mapping builds much more flexibility into the system.

4. SUMMARY AND RECOMMENDATIONS

The report is presented in three major sections: one section dealing with the definition of limiting characteristics for aquatic habitat evaluation and the ground truthing requirements necessary to obtain the required data; a second section dealing with remote sensing; and a third section reviewing computerized mapping techniques. More than four hundred reports and research papers have been reviewed. The appropriate citations are compiled in the bibliography.

Our recommendations are:

1. The watershed systems of the AOSERP study area should be coded. A hierarchical system, beginning with the main river system, is recommended, each tributary or sub-tributary being assigned a code identifying it and each of the larger streams and rivers into which its waters eventually flow. An example can be found in the body of the report.

2. Prior to any field studies being done, field maps should be prepared from interpretations of remote sensing data, historical field data and topographic maps. These data should be used to define research boundaries, areas which require specific evaluation in the field studies, locations for ground truthing and general plans for field studies.

3. Each river, stream, and lake should be observed using helicopter reconnaissance, noting the data required to complete the research sample card of Figure 2. In conjunction with this reconnaissance, ground sampling of the points identified in the previous stage should be carried out, collecting the data required to complete the point sampling data card of Figure 3.

4. A minimum of ten characteristics must be used to evaluate aquatic habitat quality in rivers and streams. Similarly, ten characteristics are necessary to define the habitat quality of lakes. These are specified in Tables 1 and 2. We have provided an extensive list of parameters, which will define aquatic habitat quality more reliably and which we recommend being adopted if possible. These parameters are listed in Tables 5 and 6.

5. A code and map key have been developed to specify fish species, benthic and invertebrate species, and habitat characteristics that should be used to evaluate aquatic habitat quality.

6. The assimilated data should be mapped at a scale of 1:50,000 using the codes recommended for the habitat characteristics. All of the original data should be retained, either as microfilm records of the data cards, or as a computer generated data file.

7. The imagery characteristics for remote sensing photos are matched to the applications to which they are best suited. Imagery discussed includes panchromatic black and white, colour, infrared black and white and colour, thermal infrared, SLAR, multispectral, and LANDSAT. Representative photos have been included to illustrate and support the discussion.

8. Requirements for camera systems, film and filter combinations, weather conditions, altitudes, interpretation devices and time of day, time of year to ensure an adequate presentation of remote sensing data are suggested.

9. The requirements for computer mapping capabilities are reviewed. This review includes an assessment of computing facilities capable of computerized mapping within the Edmonton area, an overview of the state-of-the-art of computer mapping, and assessment of the usefulness of this technique to AOSERP.

10. Computerized mapping should be considered by AOSERP only if all of the resource and land management data associated with the Program are included in a computerized mapping project. If mapping and data base assimilation are to be compartmentalized, mapping by manual techniques is far more efficient presently than computerized mapping. It would also be cost efficient to store records of data using microfilm as the basis of data storage.

11. A comparative review of three interactive computerized mapping systems is recommended. These systems, CGID, GIMMS, and PLUS are among the most advanced currently available and would be powerful analytic tools in the hands of resource managers.

5. APPENDICES

5.1 GLOSSARY[a]

aquatic macrophytes - multi-cellular plant life growing above or below the water surface. Dominant and co-dominant vegetation is identified by species and genus in the data files.

bank - the rising ground bordering a stream channel below the level of rooted vegetation and above the normal streambed and designated as right or left facing downstream.

bed - bottom of water course.

bogs - bogs are peat-covered areas or peat-filled depressions with a high water table and a surface carpet of mosses, chiefly Sphagnum. The water table is at or near the surface in the spring; and slightly below during the remainder of the year. The mosses often form raised hummocks, separated by low, wet interstices. The bog surface is often raised, or if flat or level with the surrounding wetlands, it is virtually isolated from mineral soil waters. Hence the surface bog waters and peat are strongly acid and upper peat layers are extremely deficient in mineral nutrients. Peat is usually formed in situ under closed drainage and oxygen saturation is very low. Although bogs are usually covered with Sphagnum, sedge may grow on them. They may be treed or treeless, and they are frequently characterized by a layer of Ericaceous shrubs.

cascade - a series of small steps or falls. Total height and length are mapped when available.

channel - a natural or artificial waterway of perceptible extent which periodically or continuously contains moving water. It has definite bed and banks which serve to confine the water.

chute - a confined and inclined section of stream channel usually with bedrock substrate and high velocity, smooth flowing water. Total height and length are mapped when available.

depth - average depth of a river reach or the maximum depth of a lake.

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[a]modified from Chamberlin and Humphries (1977).

ephemeral stream - a stream in which the water wholly or partially disappears during dry periods.

fens - fens are peatlands characterized by surface layers of poorly to moderately decomposed peat, often with well-decomposed peat near the base. They are covered by a dominant component of sedges, although grasses and reeds may be associated in local pools. Sphagnum is usually subordinate or absent with the more exacting mosses being common. Often there is much low to medium height shrub cover and sometimes a sparse layer of trees. The waters and peats are less acid than in bogs of the same area, and sometimes show somewhat alkaline reactions. Fens usually develop in restricted drainage situations where oxygen saturation is relatively low and mineral supply is restricted. Usually very slow internal drainage occurs through seepage down very low gradient slopes, although sheet surface flow may occur during spring melt or periods of heavy precipitation.

form - the appearance of the channel within a reach. It is described as:
- straight - little or no curving
- irregular - no clear pattern of lateral movement
- meandering - clear pattern of lateral movement identified by formation of elbows or winding curves.

gradient - a) reach gradient - the length of reach divided by the range in elevation between the downstream and upstream ends of the reach. Derived from topographic maps, it is expressed to the nearest 0.1% between 0 and 3%, and to the nearest 1% above 3%.

b) point gradient - the slope at a point as read from a clinometer to the nearest 0.5%.

invertebrates - benthic invertebrates - usually identified are insects by order and other arthropods, annelid worms and molluscs for 1:50,000 mapping. Dominant and next most common are noted. Invertebrates identified at a point sample location are identified in data files by species and genus.

lake morphometry - the physical features of a lake and its basin. Includes surface area, depth, etc.

marshes - marshes are grassy, herb dominated wet areas, periodically inundated up to a depth of 2 m or less with standing or slowly moving water. Surface water levels may fluctuate seasonally, with declining levels exposing drawdown zones of matted vegetation or mud flats. Marshes are subject to a gravitational water table, but water remains within the rooting zone of plants during at least part of the growing season. The substratum usually consists of mineral or organic soils with a high mineral content, but there is little peat accumulation. Waters are usually circumneutral to alkaline, and there is a relatively high oxygen saturation. Marshes characteristically show zonal or mosaic surface patterns of vegetation, comprised of unconsolidated grass and sedge sods, frequently interspersed with channels or pools of open water. Marshes may be bordered by peripheral bands of trees and shrubs, but the predominant vegetation consists of a variety of emergent non-woody plants such as rushes, reedgrasses and sedges. Where open water areas occur, a variety of submerged and floating aquatic plants flourish.

obstruction - any object or formation that may impede, block, or hinder waterflow and/or fish migration.

phytoplankton - planktonic, microscopic water plants which have the ability to undergo photosynthesis (algae). Listed in data files by species or as standing crop (biomass) by cell numbers or chlorophyll a concentrations. Best collected with a closing water bottle to ensure capture of small species.

point sample - a spot sample on a stream or a lake. The descriptive location of the point will be given using suitable landmarks. The map location is specified using the co-ordinate system adopted.

pond - a body of still water, smaller than a lake.

reach - the basic biophysical mapping unit. It is characterized by relatively homogeneous properties which will vary according to the scale of the survey. Properties homogeneous within the reach include gradient, channel, and/or biological parameters. Reach boundaries are seldom sharp. A more gradual change from characteristic properties of one reach to those of the next will be the most common experience.

riffle - a shallow rapid in a stream, where the water surface is broken into waves by obstruction wholly or partially submerged. A riffle may be drowned out at high water.

rooted width - the width of the stream channel between rooted vegetation on either bank.

substrate - the material down to about 30 cm that comprises the stream bed or lake bottom. Five size ranges are classified:

silt	:	<0.063 mm
sand	:	0.063-2.00 mm
gravel	:	2.00-256.00 mm
boulders	:	>256.00 mm
bedrock	:	consolidated

swamps - woody plant-dominated areas where standing to gently flowing water occurs seasonally or persists for long periods at the surface. Frequently there is an abundance of pools and channels indicating subsurface water flow. The substrate is usually continually waterlogged. Waters are circumneutral to moderately acid in reaction, and show little deficiency in oxygen or in mineral nutrients. The substrate consists of mixtures of transported mineral and organic sediments or peat deposited in situ. The vegetation cover may consist of coniferous or deciduous trees, tall shrubs, herbs, and mosses. In some regions Sphagnum may be abundant.

terrestrial vegetation - other than a broad classification as coniferous or deciduous it is important to know if aspen, poplar, and willow border an aquatic habitat for beaver suitability.

turbidity - the clarity of the water as measured by a turbidometer and expressed in formazin turbidity units (F.T.U.).

velocity - the rate of motion. Classed in four categories:

Placid	=	0 - 0.20 m/s
Moderate	=	0.21 - 0.45 m/s
Fast	=	0.46 - 1.0 m/s
Very Fast	=	>1.0 m/s

watershed - the area drained by a particular stream or lake.

zooplankton - planktonic, microscopic invertebrates. Listed in data files either by species or as biomass by animal numbers. Collected with plankton nets.

5.2 RATE SCHEDULES

5.2.1 The University of Alberta External Rate Schedule for Non-profit Organizations, April 1977

MTS RATES

Following are the rates for various computer resources, effective 1 April 1977. To calculate the cost of an MTS job use the following formula:

$$\text{MTS Job Cost} = \sum \left\{ \text{MTS Resource Rate} \times \text{Units of Resource Used} \times \text{MTS Rate Factor} \right\}$$

MTS Resource Rates

Resource		Rate	Units
CPU		$ 36.00	minute
VM-CPU Integral		0.30	page-minute
Magnetic Tape Drive		8.00	hour
Paper Tape Connect		2.60	hour
Paper Tape Punched		0.007	foot
Cards Punched		8.00	1000 cards
Disk Space		0.08	page-month
Cards Read		1.50	1000 cards
Lines Printed	Other	PN	
Standard Ribbon	1.20	0.60	1000 lines
Carbon Ribbon	2.50	1.90	1000 lines
Scanner Ribbon	2.00	1.40	1000 lines
Pages Printed			
Standard Paper		10.00	1000 sheets
Thesis Paper		30.00	1000 sheets
Terminal Jobs[1]			
Start-up to 5:00 pm Monday to Friday		1.2	
All other times		0.8	

OS RATES

$$\text{OS Job Cost} = \sum \left\{ \text{OS Resource Rate} \times \text{Units of Resource Used} \times \text{OS Rate Factor} \right\}$$

OS Resource Rates

Resource		Rate	Units
CPU and memory	118K bytes	$ 43.50	minute
CPU and memory	200K bytes	51.00	minute
CPU and memory	300K bytes	58.50	minute
CPU and memory	400K bytes	66.00	minute
CPU and memory	500K bytes	73.50	minute
Lines printed		1.25	1000 lines
Cards read		1.50	1000 lines
Cards punched		8.00	1000 lines

OS Rate Factors

Rate Factors are applied to all the OS resources.

	Rate Factor
Monday to Friday	1.0
Saturday, Sunday	0.4

CHARGES FOR OTHER SERVICES

No rate factors apply to these services.

Type	Rate	Units
Keypunching and Data Entry[2]		
General	$ 8.50	hour
Rush	11.00	hour
Contract Programming	30.00	hour
Digitizing[2]		
Do-it-yourself	not available	
Half 'n' half	9.30	hour
Complete service	12.50	hour

Optical Scorer[2]		
Processing	0.04	sheet-pass
Operator	5.50	hour
Item Analysis	MTS cost	
Card Storage		
Locker	2.00	month
	10.00	year
Rack Space	free with permit	
Mag Tape Safe Storage	10.00	year

Minimum Monthly Billing

The minimum monthly billing for computer processing, i.e. MTS plus OS, is $5.00.

Restriction

Non-profit Organizations are not allowed to use SIMSCRIPT, COMPACT, IMSL, and ALTRAN.

Royalty

A 25% royalty applies to SPSS.

3 Across Labels	182.00	1000 sheets
1 Across Labels	71.50	1000 sheets
Calcomp Plotting		
Regular Narrow	0.33	foot
Regular Wide	0.66	foot
Mylar Narrow (Plastic)	1.65	foot
Mylar Wide	3.50	foot
Varian Plotting	0.50	minute
Varian Paper	0.50	foot
Terminal Connect	1.50	hour
Network Connect	TBA	

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[1] Rate factors for *PRINT* Lines Printed are the same as Batch Jobs.

[2] Minimum charge $5.00.

MTS Rate Factors

The rate factors for the following MTS Resources are always 1.0: Terminal Connect, Disk Space, Cards Read, Calcomp Plotting, Calcomp Paper, Pages Printed, Paper Tape Punched, Varian Paper, and Network Connect.

Rate factors are applied to only the following MTS Resources: CPU, VM-CPU Integral, Magnetic Tape Drive, Cards Punched, Lines Printed, Paper Tape Connect, and Varian Plotting.

Type & Priority	Rate Factor
Batch Job	
Deferred (D)	0.4 Weekend
Low Priority (L)	0.6 Overnight
Normal Priority (N)	0.8
High Priority (H)	1.1
Rush Priority (R)	1.6

5.2.2 The University of Alberta External Rate Schedule for Commercial Businesses, April 1977

MTS RATES

Following are the rates for various computer resources, effective 1 April 1977. To calculate the cost of an MTS job use the following formula:

$$\text{MTS Job Cost} = \sum \left\{ \text{MTS Resource Rate} \times \text{Units of Resource Used} \times \text{MTS Rate Factor} \right\}$$

MTS Resource Rates

Resource	Rate	Units
CPU Time	$ 72.00	minute
VM-CPU Integral	0.60	page-minute
Magnetic Tape Drive	10.00	hour
Paper Tape Connect	4.00	hour

Paper Tape Punched		0.01	foot
Cards Punched		11.00	1000 cards
Disk Space		0.12	page-month
Cards Read		3.00	1000 cards
Lines Printed	Other	PN	
Standard Ribbon	2.00	1.00	1000 lines
Carbon Ribbon	3.50	2.50	1000 lines
Scanner Ribbon	2.65	1.65	1000 lines
Pages Printed			
Standard Paper		21.00	1000 sheets
Thesis Paper		60.00	1000 sheets
3 Across Labels		276.70	1000 sheets
1 Across Labels		115.75	1000 sheets
Calcomp Plotting		0.65	minute
Calcomp Paper			
Regular Narrow		0.60	foot
Regular Wide		1.20	foot
Mylar Narrow (Plastic)		3.00	foot
Mylar Wide		6.00	foot
Varian Plotting		1.30	minute
Varian Paper		0.90	foot
Terminal Connect		3.00	hour
Network Connect		TBA	

MTS Rate Factors

The rate factors for the following MTS Resources are always 1.0: Terminal Connect, Disk Space, Cards Read, Calcomp Plotting, Calcomp Paper, Pages Printed, Paper Tape Punched, Varian Paper, and Network Connect.

Rate factors are applied to only the following MTS Resources: CPU, VM-CPU Integral, Magnetic Tape Drive, Cards Punched, Lines Printed, Paper Tape Connect, and Varian Plotting.

Type and Priority Class	Rate Factor
Batch Jobs	
Deferred (D)	0.4 Weekend
Low Priority (L)	0.6 Overnight
Normal Priority (N)	0.8
High Priority (H)	1.1
Rush Priority (R)	1.6
Terminal Jobs[1]	
Start-up to 5:00 pm	
Monday to Friday	1.2
All other times	0.8

CHARGES FOR OTHER SERVICES

No rate factors apply to these services.

Type	Rate	Units
Keypunching and Data Entry[2]		
General	$ 11.00	hour
Rush	not available	
Digitizing[2]		
Do-it-yourself	not available	
Half 'n' Half	not available	
Complete service	26.00	hour
Optical Scorer[2]		
Processing	0.05	sheet-pass
Operator	5.75	hour
Item Analysis	MTS cost	
Card Storage		
Locker	2.00	month
	10.00	year
Rack Space	free with permit	
Mag Tape Safe Storage	10.00	year

[1] Rate factors for *PRINT* Lines Printed are the same as Batch Jobs.

[2] Minimum charge $5.00.

Minimum Monthly Billing

The minimum monthly billing for computer processing is $5.00.

Restriction

Commercial clients are not allowed to use SIMSCRIPT, TSP, COMPACT, IMSL, ALTRAN, and SURFACE II.

Royalty

A 25% royalty applies to SPSS.

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6. AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
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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
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15.	ME 3.4	A Climatology of Low Level Trajectories in the Alberta Oil Sands Area
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22.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
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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
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31.	VE 2.3	Ecological Habitat Mapping of the AOSERP Study Area: Phase I
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33.	TF 1.2	The Relationship Between Habitats, Forages, and Carrying Capacity of Moose Range in the AOSERP Study Area
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Alberta Oil Sands Environmental Research Program
15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta
T5K 2J6