ECOLOGICAL HABITAT MAPPING OF THE AOSERP STUDY AREA: PHASE I

by

M.D. THOMPSON, M.Sc.

M.C. WRIDE, M.Sc.

M.E. KIRBY, M.Sc.

INTERA Environmental Consultants Ltd.

Calgary, Alberta

for

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

PROJECT VE 2.3

June 1978

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONCLUDED)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CONCLUDED)

ABSTRACT

The purpose of this study was to prepare ecological habitat working maps at a scale of 1:50,000 from false colour infrared photographs of the AOSERP study area obtained in 1977, and to evaluate multispectral and multistage remote sensing techniques for application to mapping and monitoring in the study area.

A classification system was devised for mapping vegetation and surficial geology from the 1:60,000 scale false colour infrared photographs; base maps plus a vegetation overlay and a surficial geology overlay were created based on the standard NTS 1:50,000 topographic sheets of the AOSERP study area. Where NTS topographic coverage was not available, similar maps were created from other sources. The development of the legend systems, the vegetation and surficial geology, and their integration in the study area are described in detail. Photo interpretation keys are included.

Multispectral and multistage remote sensing evaluation for ecological habitat mapping and ecological monitoring was accomplished in a systematic manner. Ecological parameters of importance for mapping and monitoring in the AOSERP study area were identified, and the value of various remote sensors, scales and dates of data acquisition estimated using a simple ranking system. An analysis of Landsat analogue imagery is included, as is discussion of several types of aerial photography and thermal infrared imagery.

The potential for the use of automated ecological mapping is evaluated. A demonstration of geocoding of the map sheet is presented, and the value of digital analysis of Landsat data and aerial photography data discussed as applied to ecological mapping and monitoring.

Finally conclusions are drawn based on the study and map preparation, and recommendations are given for completion of

the ecological habitat mapping of the area, establishment of a remote sensing-based monitoring program, and demonstration of automated ecological mapping as a forerunner to a computer-based information for the Alberta Oil Sands Environmental Research Program.

ACKNOWLEDGEMENTS

The principal consultants for this project were:

INTERA ENVIRONMENTAL CONSULTANTS LTD.

B.L. Bullock, Company Principal
M.D. Thompson, Project Manager
M.C. Wride, Chief Classification
M.E. Kirby, Chief Multispectral Studies
J.L. Bernard, Geographer
V.L. Shaw, Geomorphologist
P.I. Van Eck, Remote Sensing-Vegetation
S.R. Lee, Geographer
D. Tucker, Geographer

The sub-consultants were:

BEAK CONSULTANTS LTD.

W.J. Stephen, Head Terrestrial Studies
J.J. Lambiase, Geologist
N. Kenny, Biologist
D.A. Fernet, Fisheries Biologist
D. Young, Wildlife Biologist

TIESSEN MAPPING LTD.

M. Mackin, Manager Drafting

This research project VE 2.3 was funded by the Alberta Oil Sands Environmental Research Program, a joint Alberta-Canada research program established to fund, direct, and co-ordinate environmental research in the Athabasca Oil Sands area of northeastern Alberta.

1. INTRODUCTION

The objective of this project was the preparation of Phase 1 Ecological Habitat Maps at a scale of 1:50,000 for the Alberta Oil Sands Environmental Research Program (AOSERP) study area (Figure 1). A secondary objective was to assess Landsat and the various remote sensors utilized in the 1977 remote sensing data acquisition program for correlations with habitat characteristics. In addition, the use of remote sensing for automated ecological mapping and for ecological monitoring was evaluated.

Beginning with simple air photo interpretation and now involving far more sophisticated airborne and satellite systems, remote sensing has made a significant contribution to the development of environmental survey systems involving vegetation, surficial geology, wildlife habitat, hydrology, soils and land use (Thie 1976). Aerial photographs have traditionally been an important part of mapping in forestry, agriculture and many other fields, and the methodology for such interpretation is relatively standard and well known. In the past several years, a further development in the field of classification has occurred--ecological (biophysical) land classification (Thie 1976)--in which the ecological parameters which have been traditionally mapped separately, such as vegetation, climate, surficial geology and landforms, are integrated into a single biophysical system and mapped as such.

Such biophysical mapping has a wide application for collection of data for environmentally sound resource surveys, and remote sensing imagery forms the basis of such data collection. Many areas in Canada have been mapped in this way using remote sensing as a data source (for example, Thie 1976; Boydell 1974; Howarth 1976; Kirby et al. 1975). Ecological mapping has assumed such importance in recent years that the Canada Committee on Ecological (Biophysical) Land Classification has been formed, whose purpose is to concern itself with the development of a uniform ecological approach to land classification in Canada, and to propagate the use of the integrated reconnaissance approach to

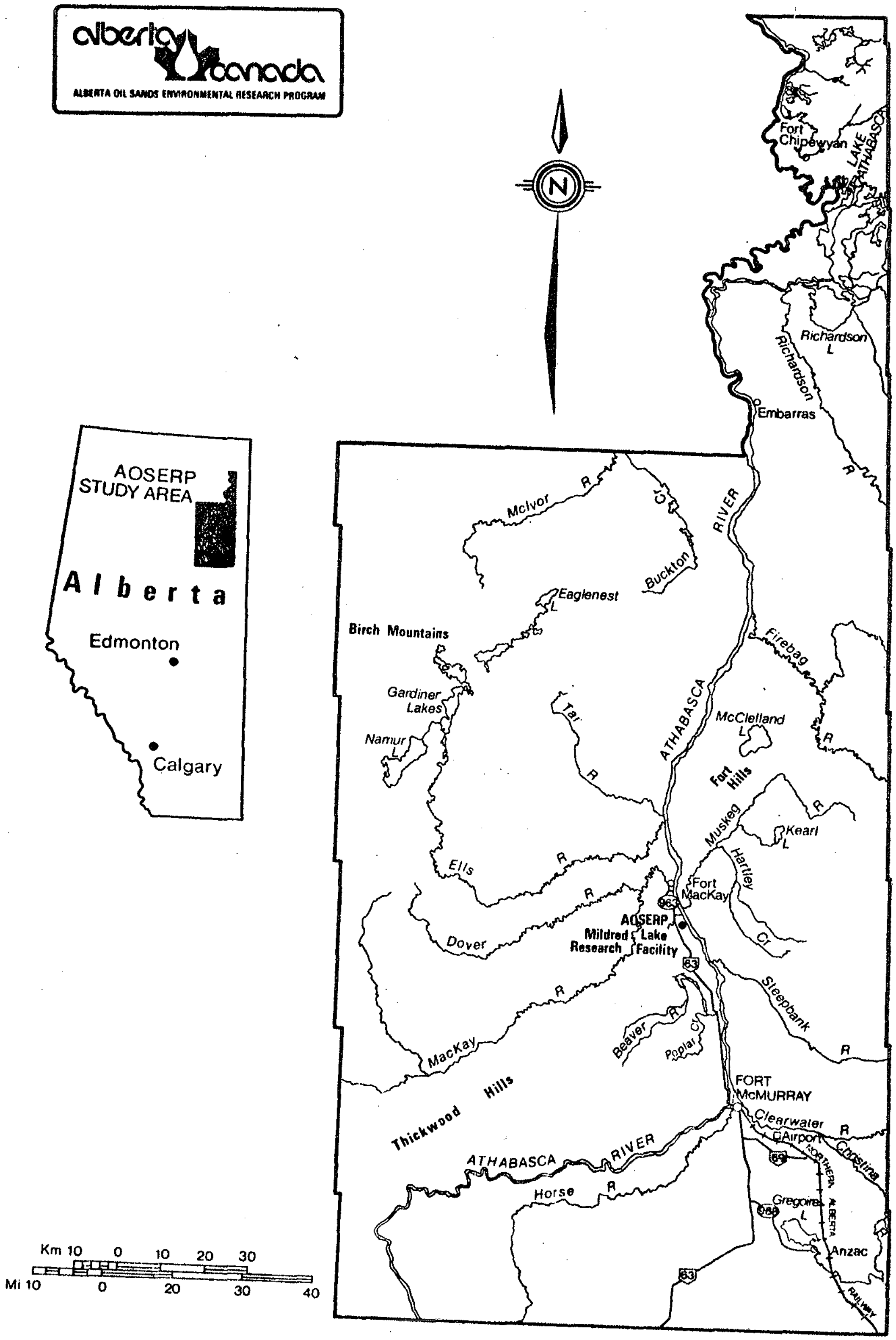


Figure 1. Alberta Oil Sands Environmental Research Program study area.

environmental inventory as a productive and cost-effective management tool.

Concurrent with the development of legend methodology for ecological mapping has been the development of a methodology for interpretation and analysis of new remote sensing systems as applied to ecological mapping. Foremost has been the research applied to the use of Landsat multispectral scanner data, both analogue and digital, and many studies have been completed with excellent results (Thie 1976; Kirby et al. 1975; Lee 1975; Howarth 1976; Boydell 1974; Gimbarzevsky 1974; Anderson and Schubert 1976; Jaques 1977; Kirby and van Eck 1977). Thermal infrared imagery has also been the subject of much research over the past decade, and studies have shown that it has application for ecological mapping in many areas where surface temperature data are needed (Wride and Baker 1977; Tanguay and Chagnon 1972; Weber 1971; Stohr and West 1974; Scarpace et al. 1975).

Newer sensors such as microwave remote sensors, airborne multispectral scanners and others are still in developmental stages, but have great potential for application to ecological mapping and monitoring in the future.

At present, most ecological mapping is still based on the interpretation of aerial photographs using standard techniques. In many cases, however, false colour infrared or colour photographs have replaced the standard panchromatic prints used in the past. In most operational applications it has been found that the advantages of increased resolution and interpretability of the false colour infrared or colour transparencies have far outweighed the disadvantage of their higher cost. In fact, the cost is often defrayed by flying fewer photographs at a smaller scale and still having equivalent or better mapping information from these transparencies.

Interpretation methodology has changed, however, in that now much of the remote sensing data is stored on magnetic tape, for conversion to visible images or computer analysis (Thie 1976; Fleming et al. 1975; Kalensky 1974; Gierman et al. 1975).

This has opened a whole new field of data management, one which is still in an early phase of development (Steiner and Salerno 1975), but one which should be considered in an ecological mapping and monitoring program like that suggested for AOSERP.

At present, no co-ordinated set of biophysical or topographical maps at a reconnaissance scale exists for the AOSERP study area, an area of Alberta in which intensive environmental research is being carried out now and will continue to be carried out in future years. In order to assist those researchers working in the area, it was decided that a set of ecological working maps at a reconnaissance scale should be created containing information on the distribution of terrestrial and aquatic vegetation associations, major landforms, surficial geologic features, water bodies, stream courses, topography, and cultural features (seismographic lines, roads, etc.) updated to 1977. During the 1977 season, false colour infrared photography at a scale of 1:60,000 was flown, part during July and August, and part during October; using these photographs, existing NTS topographic sheets, and several other sources of mapping data, the ecological habitat maps were then prepared.

This report contains a detailed discussion of ecological legend development, and the preparation of the ecological habitat maps using a base map plus two overlays (one for vegetation and one for surficial geology). Complete descriptions of the photo interpretation process are presented and accompanying keys included for use by other researchers. Also a terrain analysis is included which integrates vegetation and surficial geology in the AOSERP study area.

Next an evaluation of multispectral and multistage remote sensing for ecological habitat mapping in the AOSERP study area is presented for selected ecological parameters of importance. Seven remote sensors are evaluated for mapping; in addition, the multistage evaluation discusses the value of three scales of airborne imagery plus Landsat imagery for mapping.

In addition to its use for mapping baseline environmental data, remote sensing imagery has been extensively used over the past several years for monitoring environmental changes in many areas. The large size of the AOSERP study area, its relative inaccessability, and the potential for widespread as well as very localized environmental changes resulting from oil sands development indicates that remote sensing should have an important role in monitoring such changes. This study thus has included an evaluation of various remote sensing techniques and scales for ecological monitoring in the AOSERP study area in future years. These techniques include Landsat, false colour infrared photography at three different scales, thermal infrared imagery, and multiband imagery, most of which were flown during 1977.

Since automated mapping and storage of the information in a computer data base has a potential application for the AOSERP study area, recommendations have been made on the applicability of computer enhancement, mapping and ecological evaluation for remote sensing imagery (Landsat and aerial photography). Also discussed was the possibility of compiling the mapped habitat units in a computer data base by geocoding (transforming the locations of the various class types into a machine-readable form). Portions of one map sheet have been geocoded as an example.

Finally, the results are discussed, conclusions drawn, and implications and recommendations for future work in the study area are given. A complete set of references is included.

2. AOSERP STUDY AREA AND 1977 REMOTE SENSING DATA ACQUISITION

2.1 DESCRIPTION OF THE STUDY AREA

The geographic extent of the Alberta Oil Sands Environmental Research Program Study Area is shown in Figure 1. It covers approximately 28,000 square kilometres in northeastern Alberta.

The area is underlain mainly by sandstones and shales (Cretaceous), with limestones, dolomites and gypsum (Devonian) in the northeast and Precambrian granites in the extreme northeast. The main "oil sands" sandstones are exposed in the valley of the Athabasca River, and are surrounded by shales and sandstone/ minor shale formations. Cretaceous shales with minor sandstone are found in the upland areas (Birch Mountains, Muskeg Mountain, Stony Mountain and the Thickwood Hills).

There are three main types of surficial deposits in the study area: (1) ground and hummocky moraine (till) in the Birch Mountains and Methy Portage Plain (southeast of Fort McMurray); (2) silt and clay lake deposits around the Birch Mountains; and (3) sand and gravel deposits (from river, lake and wind sources) found in the lower valley areas, the eastern parts of the area and the delta area.

Nine major physiographic divisions are found in the study area (Figure 2): three in the Alberta High Plains, four in the Saskatchewan Plain, and one each in the Great Slave Plain and the Canadian Shield. In the Alberta High Plains are found the Birch Mountains Upland (ground and hummocky moraine over upper Cretaceous shales and sandstones), the Stony Mountain Upland (ground and hummocky moraine and some sand and gravel over upper Cretaceous shales and sandstones), and the Algar Plain (lower Cretaceous shales and sandstones with sand and gravel overburden, with one minor area of lake deposits). In the Saskatchewan Plain are found the Muskeg Mountain Upland (upper Cretaceous Shales and sandstones with sand and gravel overburden), the Methy Portage Plain and Firebag Plain (same as the Algar Plain but with no lake

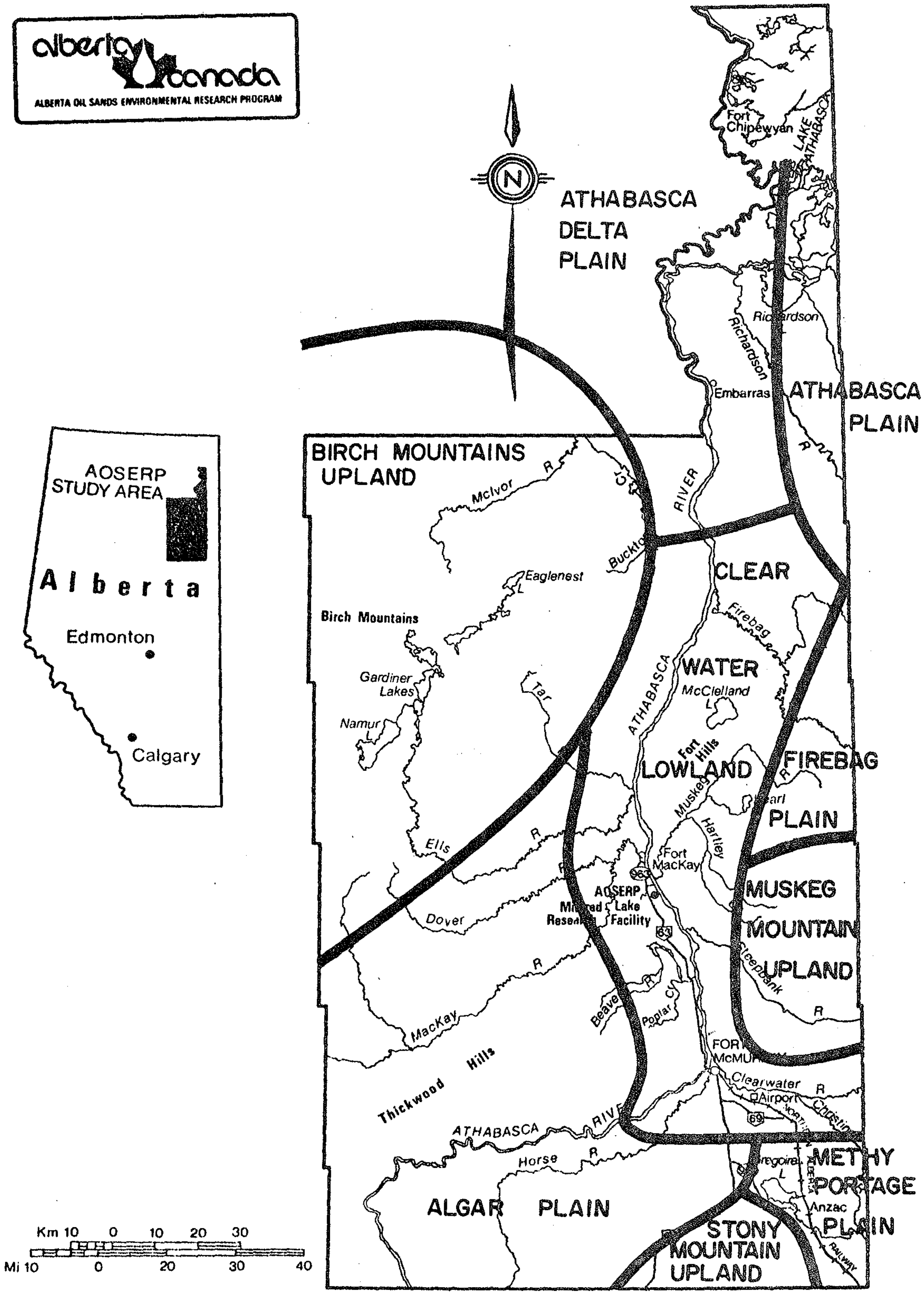


Figure 2. Physiography of the AOSERP study area.

deposits), and the Clearwater Lowland (shales and sandstones in a pre-glacial valley, with varied overburden). In the Great Slave Plain, the Athabasca Delta Plain is found on Devonian limestones, dolomites, and gypsum, covered mainly by lake deposits. Finally, on the Canadian Shield area, the Athabasca Plain is found on Precambrian granites with a sand and gravel overburden.

Vegetation in the AOSERP study area is within the Boreal Forest, with four major subregions as described by Rowe (1972) (Figure 3). The first subregion, the Boreal Mixedwood, is found on clay rich soils on rolling moraine over Cretaceous shales as well as extensive flatlands of lake deposits. Major tree species in this subregion are aspen poplar (*Populus tremuloides*) and white spruce (*Picea glauca*), with jack pine (*Pinus banksiana*) on the sand hills to the east. Black spruce (*P. mariana*) and larch (*Larix laricina*) muskeg is found in depressions while willow shrub (*Salix* spp.) and fen are found in very wet but more freely drained areas. Most of the southern and western parts of the study area fall within this subregion.

In the Upper Mackenzie subregion (Figure 3) a very different ecosystem exists. On the river-deposited alluvial lowlands and the delta are found a complex pattern of terraces, levees and channels. The soil is loosely compacted silt, high in nutrients and with very high soil moisture. On the lower and middle terraces are climax forests of tall white spruce. The vegetation succession on undisturbed alluvial sites is horsetail (*Equisetum* spp.), willow, alder (*Alnus tenuifolia*), balsam poplar (*P. balsamea*) and white spruce (Rowe 1972). The third subregion, Athabasca South, is a jack pine sandplain formed on Precambrian sandstones. On the drier sandy uplands are jack pine and lichens, while in the moister areas the principal plant communities include black spruce and mosses. The fourth subregion, the Northwestern transition, is very limited in extent, appearing only in a small area to the northeast of Lake Athabasca. Coniferous forest, particularly black spruce, dominates most of this subregion, which is found on Precambrian bedrock.

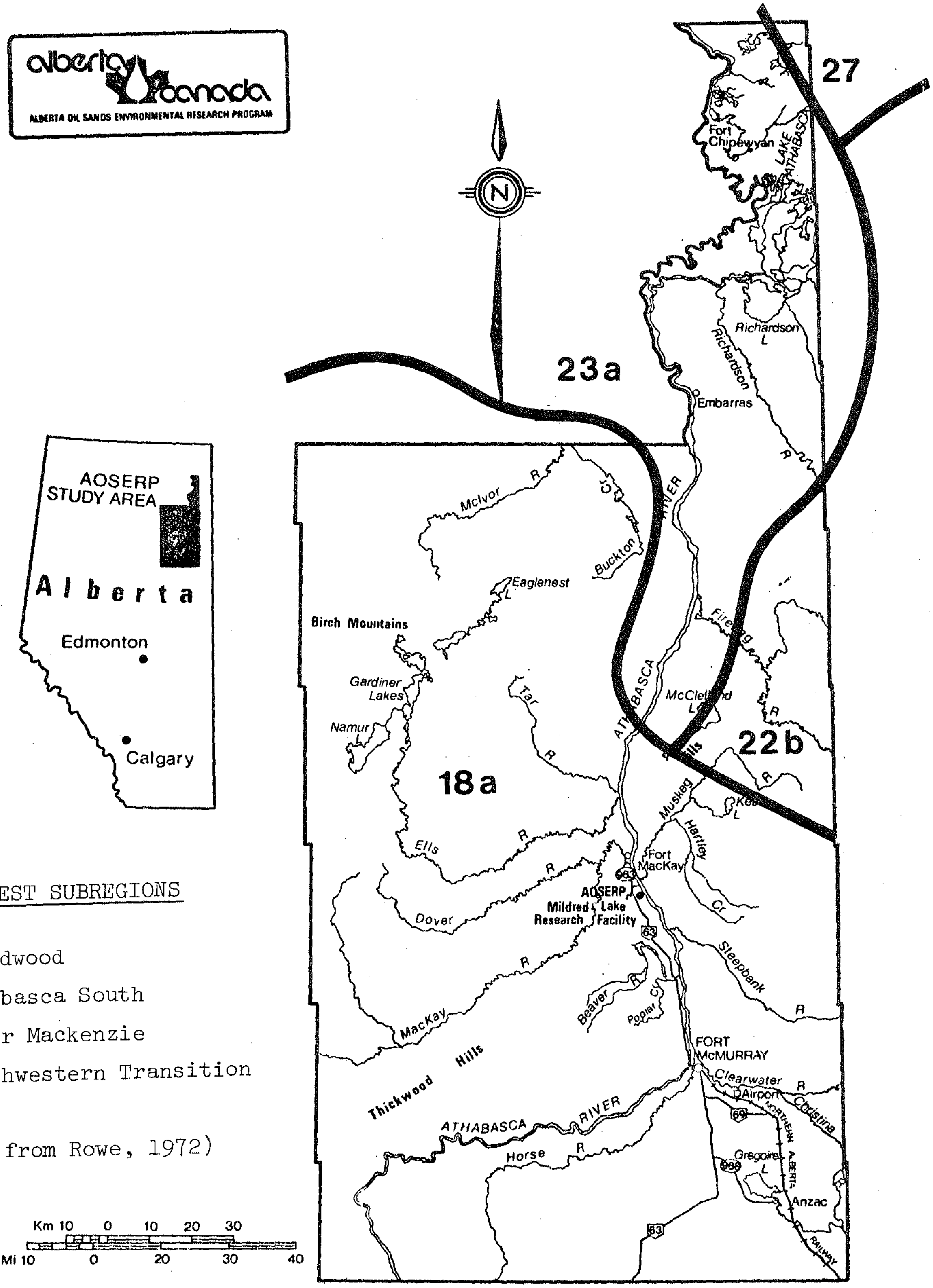


Figure 3. Vegetation of the AOSERP study area.

The climate of the study area is continental in nature, with long, cold winters and short summers. Seasonal temperature range is extreme, with average maximum temperatures in July exceeding 27°C and average minimum temperatures in January ranging from -23°C to -30°C in the study area. Summer temperatures vary considerably within the study area, with the uplands (Birch Mountains, Stony Mountain and Muskeg Mountain) remaining considerably cooler than the valley bottom areas. Most of the annual precipitation falls in summer, with the mean total varying from 36 cm in the northern part of the study area (Upper Mackenzie subregion) to 56 cm in the Stony Mountain Upland south of Fort McMurray. Like temperature, precipitation varies with topography, with mean annual precipitation in the uplands being 10-15 cm greater than in the lowlands along the major rivers (Atlas of Alberta 1969).

The area is characterized by a representative subset of the faunal species of the Canadian Faunal Life Zone. Nutrient levels, poorly drained soils, climate, and limited habitat types prevent this area from supporting more faunal diversity or density. Major ungulate species include moose (*Alces alces*) which is universally distributed over the area, and to a lesser extent the sporadically distributed woodland caribou (*Rangifer tarandus caribou*), deer (*Odocoileus* spp.) and bison (*Bison bison*). Furbearers include beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), otter (*Lontra canadensis*), marten (*Martes americana*), mink (*Mustela vison*), fisher (*Martes pennanti*), weasel (*Mustela erminea*), and lynx (*Lynx canadensis*). The area also has a variety of other large and small species, notably the wolf (*Canis lupis*), black bear (*Ursus americanus*), the varying hare (*Lepus americanus*), northern chipmunk (*Eutamias minimus*) and the red squirrel (*Tamiasciurus hudsonicus*).

The five most important groups of avifauna in the area include raptors, waterfowl, colonial-nesting birds, upland game birds and birds of special interest. Raptors, bald eagles

(*Haliaetus leucocephalus*) and ospreys (*Pandion haliaetus*) in particular merit special attention because of their endangered status. Waterfowl in the area are represented by most inland species of ducks, geese and swans. In terms of colonial-nesting birds, a group of white pelicans (*Pelecanus erythrorhynchos*) are residents of this area. Upland game birds such as spruce grouse (*Canachites canadensis*) and ruffed grouse (*Bonasa umbellus*) occur throughout boreal and mixedwood forests. Of special interest are whooping cranes (*Grus americana*), an endangered species which may stop in the study during their migration to and from the nearby Wood Buffalo National Park.

The fisheries potential of the study area is generally low (Integ 1973). Most lakes and streams are too shallow to support sustained commercial, domestic or recreational fisheries. Some notable exceptions include Namur Lake, Gardiner Lake, Gregoire Lake, Clearwater River, Muskeg River, Ells River, Christina River, Firebag River, MacKay River and Athabasca River. The Athabasca River in particular supports an important and diverse fish fauna.

There are three basic types of fish habitat in the study area, lakes, large rivers and tributary streams. The fishery utilization of these habitat types is quite different (Appendix 11.2). The most important species endemic to the lakes of this region are (scientific names and a more comprehensive species list in Appendix 11.2) lake trout, walleye, lake whitefish and northern pike. The fish fauna of large rivers is much more diverse, including arctic grayling, walleye, rainbow trout, dolly varden, lake whitefish, mountain whitefish, northern pike and goldeye. The fauna of small tributary streams is quite limited, consisting of arctic grayling, mountain whitefish and northern pike. Other species considered to be of lower economic or scientific importance, which are found in all three habitat types, include longnose sucker, white sucker, brook stickleback and slimy sculpin.

Population of the study area is low, with the majority of people located in the town of Fort McMurray. The rest are located in a few small communities, principally along the major rivers or the Northern Alberta Railway. There are several Indian Reserves, one provincial park at Gregoire Lake, and a few government campsites. The majority of the people in the area work in occupations related to the oil sands industry, although there is also some forest industry activity, hunting, fishing and trapping in the area.

2.2 1977 REMOTE SENSING DATA ACQUISITION IN THE AOSERP STUDY AREA

During 1977, the entire AOSERP study area was flown by the Canada Centre for Remote Sensing to produce reconnaissance level photographs for mapping as well as multiband coverage and thermal imagery for co-ordinated studies. In addition to this small scale imagery, larger scale photography and thermal imagery were obtained along seven transects in selected locations within the study area (Figure 4). It had originally been planned that ground surveys would be carried out along these transects to serve as a basis for more detailed as well as reconnaissance mapping, but this was not accomplished due to contract delays.

It had also been planned that all of the remote sensing imagery would be obtained during the height of the growing season, usually the most appropriate time of year for most mapping and monitoring objectives. However, only partial coverage was completed during the third week of July, with some additional low level coverage in the third week of August. The remainder of the area was flown in October, very late in the season (Figure 4) (with the exception of two small areas not covered at all due to cloud). Although this did not pose a problem for the mapping of cultural features and surficial geology, it did hinder the accuracy of the vegetation mapping, as discussed later. For this reason, the areas covered in October should be reflown during July 1978.

Table 1 summarizes all of the airborne imagery obtained during 1977 for the AOSERP study area. As stated above, primary coverage of the AOSERP study area during 1977 was completed with

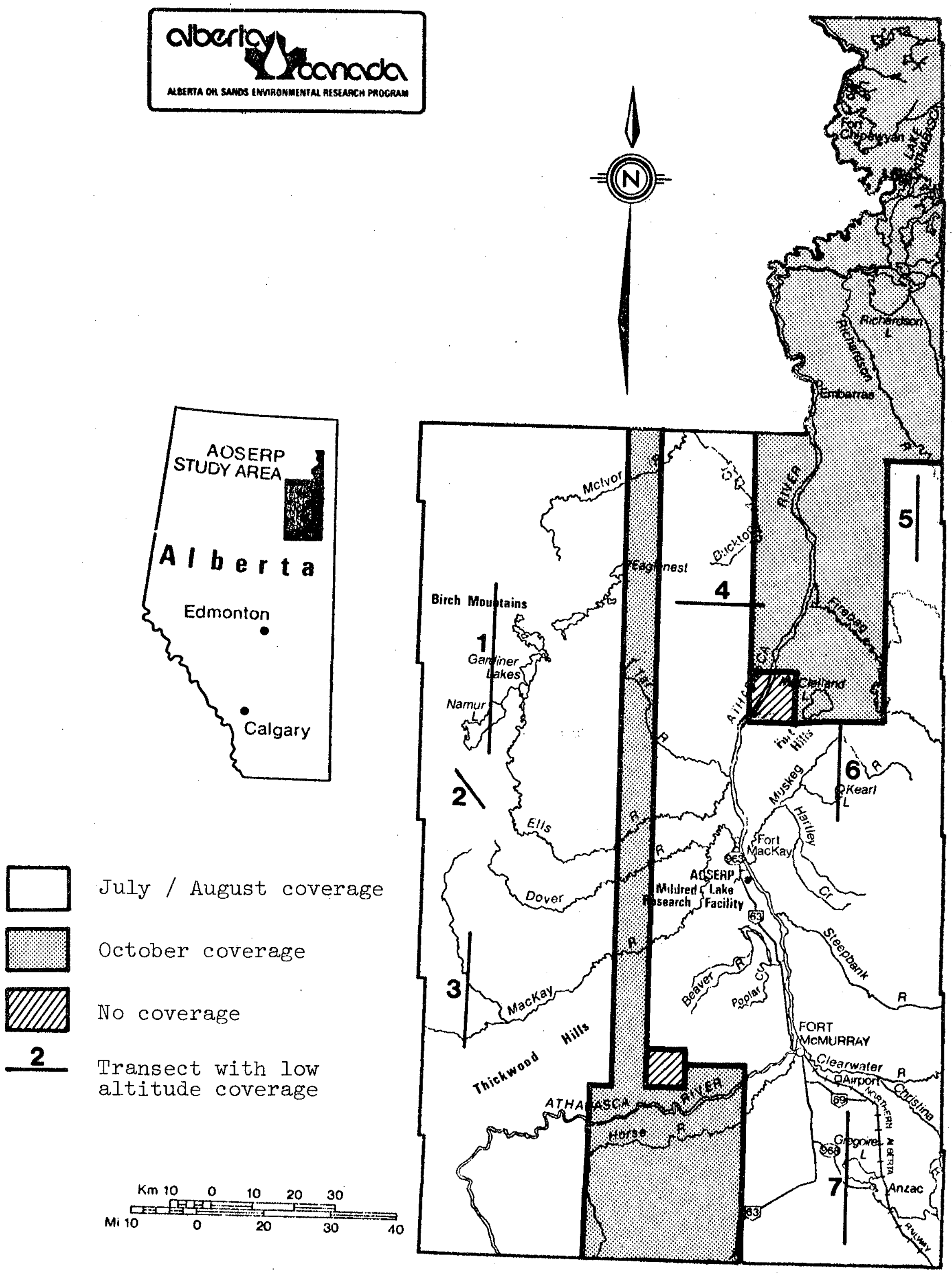


Figure 4. 1977 **remote sensing coverage of AOSERP study area.**

Table 1. Summary of 1977 remote sensing coverage of the AOSERP study area.

	Film	Filter or Bandwidth (microns)	Size	Form[a]	Scale	Date of Acquisition (1977)
FCIR Photography	Kodak 2443	Colour compensated	23 cm	PT	1:60,000	July 22, 24, 25 October 21, 24
					1:30,000	July 25 August 16
					1:15,000	August 16
Multiband Photography	Kodak 2402	.5-.6 (green)	70 mm	PT	1:120,000	July 22, 24, 25 October 21, 24
	Kodak 2402	.6-.7 (red)	"	"	1:60,000	July 25 August 16
	Kodak 2402	.7-.8 (infrared)	"	"	1:30,000	August 16
	Kodak 2445	HF 3	"	"		
Thermal Infrared Imagery		8-14	150 mm	NT	1:115,000	July 22, 24, 25
					1:55,000	July 25 August 16
					1:27,000	August 16

[a] NT - negative transparency
PT - positive transparency

false colour infrared photographs (Kodak 2443 film, Wild RC-10 camera, 152 mm lens) in 23 cm positive transparency format at a scale of 1:60,000. These were obtained to serve as a basis for the reconnaissance level mapping to produce working maps at a scale of 1:50,000 -- the major aim of this project. The false colour infrared (FCIR) photographs from July were excellent for this purpose. Since they had been flown with colour compensating filters they had few of the problems usually associated with FCIR film (i.e. vignetting or darkening of the film toward the edges, and wide range of colour balance from one date, altitude, and film batch to the next). Although the positive transparency format requires the use of a light table for viewing the photographs, the resolution is considerably better than that of paper prints. The scale of 1:60,000 is a medium-to-small scale, relatively standard for the reconnaissance biophysical mapping required for this project. It provides relatively wide coverage on each frame (the frame width covers 11.8 km on the ground) and the resolution is such that most parameters of importance may be mapped. The photographs flown in October were less useful for vegetation mapping. By that time, all deciduous foliage had either fallen or was in the final stage of senescence. It was more difficult to assess heights and crown cover, and differentiate species; however, after an adjustment period interpreters could map effectively at a reconnaissance level.

Seven transects selected as important or particularly representative of the AOSERP study area were also flown at larger scales (1:30,000 and 1:15,000) with FCIR photography. As seen in Table 1, the 1:30,000 scale photography was flown partly in July and partly in August, and all of the 1:15,000 scale photography was flown in August. This three-week separation did not affect the interpretation of the photographs significantly, as the vegetation had not yet begun to senesce at the time of the later coverage. As mentioned above, it had been anticipated that ground surveys would be carried out along these transects to provide detailed information on vegetation, surficial geology, and ecological habitat in general. This ground survey information would then be used as a check for the reconnaissance mapping. However, the ground surveys were not carried out and thus detailed analyses of the seven transects from the larger scale FCIR photographs were not done. However, some sample mapping of vegetation and surficial geology from these photographs to indicate the type of interpretation which could be carried out has been included in Section 3.

The standard package of four Vinten cameras (76 mm lens, 70 mm film) was flown at the same time as the FCIR 23 cm photography listed above. This included colour photographs (Kodak 2445 film), as well as three types of black and white photography, filtered to correspond to Landsat Bands 4 (green), 5 (red), and 6 (infrared). Table 1 lists their specific film and filter combinations. With their 76 mm lens and 70 mm format, they provide partial coverage of the study area at half the scale of the FCIR photographs. For example, at a flying altitude of 9,200 metres above ground, the 1:60,000 scale FCIR photograph covers a swath of 11.8 km on the ground while the 70 mm photograph has a scale of 1:120,000 and covers a swath of 5.9 km. These 70 mm photographs were generally of good quality, although some were obscured by cloud and some overexposed slightly. They were all in positive transparency format and were examined on the roll. Discussion of these photographs is provided in Sections 5 and 6.

Also flown at the same time as the FCIR photography was thermal infrared imagery, obtained with a Daedalus Quantitative Linescan System. This dual channel linescanner records thermal data in two bands -- 3.5 to 5.5 microns, and 8 to 14 microns (Canada Department of Energy Mines and Resources, 1977)--and the imagery is discussed in Sections 5 and 6. The thermal imagery processed for AOSERP by the Canada Centre for Remote Sensing was from the 8-14 micron band, both analogue and digital, in a 130 mm negative transparency format (black and white film), and represented approximate imagery scales of 1:115,000 (12.8 km swath), 1:55,000 (6.4 km swath) and 1:27,000 (3.2 km swath). Thus the study area was fully covered by thermal imagery, all obtained at the time of the photographic missions. The imagery quality was generally good, although there appeared to be some problems with the July imagery in that it is relatively "noisy", and shows tonal variations not related to surface temperature changes, making interpretation difficult. Reprocessing may correct this fault.

Overall, the remote sensing imagery obtained during 1977 for the AOSERP study area was of good to excellent quality and was relatively well suited to its purpose of biophysical mapping. The main limitation to its use for this purpose was incomplete coverage during the time of peak vegetative growth. This and other limitations are discussed in Section 2.3.

2.3 LIMITATIONS ON BIOPHYSICAL MAPPING OF AOSERP STUDY AREA

The main limitations on biophysical mapping of the AOSERP study area were the time allotted for completion of the mapping project, the lack of appropriate ground truth and the incomplete coverage of the area with FCIR photographs at the time of peak vegetative growth.

The AOSERP study area covers about 28,000 square kilometres, and about 33 standard NTS 1:50,000 scale topographic sheets are required to cover the area. This is a large mapping task, even for the reconnaissance level mapping which was carried out. Due to unforeseen difficulties, the contract period was reduced to less than four months and thus it was impossible to complete the mapping of the entire area within this time frame. Because the contract was not signed until December, it was impossible to carry out the ground surveys as originally proposed. This meant that no directly applicable ground data was available for the photo interpretation and mapping; the interpreters were obliged to rely on scattered data sources but primarily their own experience and expertise.

As discussed above, part of the study area was not covered by FCIR photography until 21 and 24 October 1977. Although this did not pose a problem for the mapping of surficial geology, it did significantly affect the vegetation mapping. At this time of year, most deciduous vegetation has lost its leaves or is in the final stage of senescence. This made the mapping of such parameters as crown cover and tree height and the identification of species or species associations more difficult. As a result, some reduction in accuracy can be attributed to the vegetation mapping done from the October photographs. This mapping should be verified against more suitable FCIR photographs if the areas are re-flown in July 1978. For the surficial geology mapping, the timing of FCIR photography data acquisition is not important as long as it is done in the snow-free season. In fact, in some cases the mapping is improved where vegetative cover is reduced by foliage drop, and more of the ground surface may be seen.

3. PREPARATION OF ECOLOGICAL HABITAT MAPS

3.1 INTRODUCTION

The major purpose of this study was:

> "to obtain preliminary ecological working maps at a scale of 1:50,000 of the AOSERP study area showing major landforms, surficial geology, vegetation types, and aquatic habitat types, based on interpretation of remote sensing data with minimal ground truthing. The working maps will be used by all AOSERP study sectors as the base maps for more detailed habitat mapping of areas where more detail is required" (Terms of Reference to Service Agreement between AOSERP and INTERA, dated 22 December 1977).

Additional remote sensing-related objectives in the study are discussed in Sections 4 to 7. The maps were to be based on minimal ground truthing and maximum use was to be made of the 1:15,000 and 1:30,000 aerial colour and FCIR photography of representative transects in the study area. Contract delays forced cancellation of the ground truthing; however, the resulting loss in map accuracy was considered less significant by AOSERP Program Management than having the reconnaissance-level working maps ready for the 1978 field season.

This section presents the approach and results of the classification development activity including suggested requirements from AOSERP researchers and the application of the classification system to the remote sensing imagery. The application subsection includes descriptions of the mapping methodology and the details of the classification legends and keys. Finally, the results of the entire section are summarized.

3.2 CLASSIFICATION SYSTEM DEVELOPMENT

The terms of reference for the Phase I habitat mapping required that a classification system be developed to include the number and composition of terrestrial and aquatic habitat types to be delineated. This classification system was also to be open-ended to provide flexibility for later modification and addition of categories for larger scale mapping. An effort was also made to design the legend to collapse or telescope in order that the data from the reconnaissance or Phase I mapping could be related to larger scale mapped data from later phases. The value of this feature is that research results obtained in the representative but localized regions of the large study area could be expanded or extrapolated to the entire region with reasonable confidence.

As mentioned above (Section 1), there is a growing need for resource managers to prepare more comprehensive ecological maps, often referred to as "biophysical survey" or "ecological land classification" (ELC) projects. Such an approach would have been used in this study, but a number of problems prevented this approach from being practical at the time of mapping. A major problem was the fact that this type of mapping requires a thorough understanding of the ecosystem dynamics and the relationships of interacting ecosystem entities. The limited knowledge of ecosystem dynamics in the study area coupled with the absence of soil data and ground surveys made an ecological approach premature. Perhaps just as important as these factors was the limited time frame available in which to develop a system. Another important factor in this decision involved the question of the suitability of existing ELC approaches for the needs of the AOSERP research community. The majority of ELC systems being developed or currently in use are used on forested land and have a major emphasis on forest management needs. In many cases this is acceptable, but in the AOSERP study area the overall commercial value of the forest is relatively low. A greater emphasis has been put on management of faunal resources. The limited but rapidly growing data bank on the area, the question of actual research needs, and the very short time available in which to prepare maps needed for the 1978 summer field season caused the classification development to be as direct as possible. After the understanding of the study area ecosystems increases and management needs become more apparent, the data mapped in this Phase I may be synthesized into an appropriate and useable ELC for the AOSERP study area in a manner similar to the method used by B.C. Resource Analysis Branch, Ministry of Environment (Walmsley and Barneveld 1977).

The actual procedure for developing the classification included several steps:

1. INTERA reviewed the literature on classification.

2. Input from the appropriate scientists at Beak and INTERA provided first draft of classification system.

3. Classification system was presented to AOSERP management for review and approval.

4. Classification system was reviewed again by INTERA and Beak and input was solicited from AOSERP research users, primarily those in terrestrial habitat work (see 3.1.1).

5. Modifications were made to the system where technically possible to accommodate AOSERP users, resulting in final format of classification system.

6. Mapping was initiated using the system. Minor modifications made as maps were developed.

7. Recommendations were formulated regarding Phase II and other future mapping projects.

The AOSERP research users were contacted and asked what types of information they needed and would like to have on a habitat map (step number 4 above). The responses from these interactions are listed below (these are tentative until the individuals involved have had an opportunity for review). These have been included in the text to show the correlation between the needs of the researchers working on habitat in the AOSERP study area and the resultant information which will be available to them on the 1:50,000 scale ecological working maps.

3.2.1 Terrestrial Fauna Habitat Requirements from AOSERP Researchers

This tentative outline lists the specific habitat requirements of various current AOSERP researchers and in the left margin a coded symbol indicates whether or not that specific parameter was "mapped" under the 1:50,000 Phase I program. The three rating symbols include: A -- the parameter was mapped in essentially the same category designation; B -- the parameter was partially mapped and some relevant information is available; and C -- the parameter was essentially not mapped, although the reason may have been due to scale. The actual parameters have been divided into "vegetation categories" or cover types and "special interests".

Some of the researchers' requirements are obviously technically impossible to map. The occasional symbol "C" means that category or parameter was not mapped at 1:50,000, because it was either not observable or the occurence was spatially too small to be adequately delineated on a map. All cover types could be mapped using larger scale imagery. Also, additional categories can easily be added to the existing legend for use with larger scale imagery.

3.2.1.1 Terrestrial birds. Barry Munson and John Francis, Canadian Wildlife Service, Edmonton (Personal Communication, January 1978).

Mapped*	Vegetation Category
A	jack pine forest
B/A	jack pine/aspen forest
B	jack pine/spruce forest
B	jack pine/aspen/spruce forest
A	white spruce forest
A	white spruce/aspen forest
B-C	white spruce/pine forest
B	white spruce/pine/aspen forest
C	balsam poplar forest
A	aspen forest
A/C	aspen/birch forest
A-B	aspen/pine/spruce forest
C	birch forest
A	black spruce/tamarack muskeg
A	black spruce forest

---

* A mapped on 1:50,000 habitat maps.
B some information relevant to that parameter was mapped on 1:50,000 habitat maps.
C there is no category for this parameter on 1:50,000 habitat maps. The parameter may possibly be mapped on larger scale maps.
A-B complex of A and B
A/B A is for first component, B is for second, etc.

A-B	shrub (willow) muskeg
A	shrub upland
B	sedge/grass wet meadow (fen)
C	sedge/grass dry meadow
B	grass/sedge wet meadow
C	grass/sedge dry meadow
C	grass/forb dry meadow
C	lichen/moss

Special Interests

B-C Stratum Level: Categorize vegetation according to the following height strata:

Ground Stratum - all living plants to a height of 0.5 m.
Understory Stratum - plants from 0.5 to 5 m.
Tree Stratum - plants taller than 5 m.

A-B Overall Canopy or Cover Density in Terms of: scattered, scattered-clumped, open dense, closed.

B Species 1-5: Insert the five most dominant species (or fewer, if fewer than five occur) in order of prevalence and describe according to height.

C Where two Tree Canopies Present: If two distinct canopy layers are present in the tree stratum, describe both layers according to type, density, and height.

B Interfaces: An intrusion of a second major vegetative type having a diameter of 20 m or greater and occuring wholly or partially within a given block will present an interface to be described according to: Type and Juxtaposition.

C Lichen-Moss Density.

B-C Soil - Texture.

B-C Soil - Drainage.

B Topography: Within the block.

B	Form:	Ra - ravine Bl - bluff Kn - knoll De - depression Ir - irregular Fl - flat Sl - continous slope within block
B	S (Slope):	0 = flat 1 = slight: up to 15° 2 = moderate: 15 - 45° 3 = steep: >45°
B	A (Aspect):	N, S, E, W, (or combinations).
A	Water:	Record surficial water within or 25 m from block, as:

La - lake, ≥500 m diameter.
Po - pond, ≤500 m diameter, mostly open.
Bo - bog, acidic
Ma - marsh, fresh, mostly vegetated.
Ri - river, ≥10 m across
Cr - creek, ≤10 m across

3.2.1.2 <u>Rare and sensitive avian species: colony nesters and raptors.</u> C.R. Fyfe and R. Beaver, Canadian Wildlife Service, Edmonton (Personal Communication, January 1978).

Mapped*	Vegetation Categories
A-B	all forest types near shorelines - spruce forest important
	Special Interests
A	forest cover/open areas on islands
B	slope of islands
A	sand and mud bars -- exact material not important
C	shallow water near shoreline areas
A	rapids
A-C	forest age and height class -- presence of large tall trees for perching
A	cliff locations
C	fish population information

3.2.1.3 Semiaquatic mammals. Dr. F. Gilbert, Assistant Professor, Department of Zoology, University of Guelph, Ontario (Personal Communication, January 1978).

Mapped*	Vegetation Categories
B	All types of forest and shrub in riparian habitats separated into homogeneous categories.
B	Aquatic or wetland vegetation-- sedges water lilies, etc.
B	Primary concern here is with air photo interpretation and delineation of vegetative types useful for habitat mapping.
B	There is a real need for aquatic vegetation data for entire AOSERP area.

Would like to see the following types delineated:

1. pure stands (by 10 foot height classes or 5-10 year age classes)

C	white birch
A	balsam poplar
A	trembling aspen
A	black spruce
A	white spruce
A	jack pine
B-C	alder
B	willow
A	tamarack
C	cherry (if any)
B	sedge
A	muskeg
A	bog

2. mixed stands (delineated by % composition of various species; components not simply lumped together)

A	poplar (balsam poplar and trembling aspen)
A	white birch-poplar
A	white spruce-poplar
A/C	white spruce-white birch
A-B	white spruce-black spruce
B/A	jack pine-poplar
B/C	jack pine-cherry

C	willow-alder
B	white spruce-poplar-white birch
C	cherry-poplar-white birch
A-B	alder-poplar (white birch)

They put particular emphasis on riparian habitats (250 m from water interface) and would like to have interpretation as detailed as possible for all such areas.

3.2.1.4 Ungulates: caribou/wolves. T. Fuller, Graduate Student (Wildlife Ecology), University of Wisconsin, Madison (Personal Communication, January 1978).

Mapped*	Vegetation Categories
	Cover types
B	open muskeg (no trees)
A	black spruce muskeg (low to medium density)
A	black spruce (medium to high density)
A	jack pine
A	white spruce
A	jack pine/white spruce mix
A	aspen
A	aspen/conifer mix
B	willow
A-B	conifer burns (lowland and upland)
	Additional cover types
B	tamarack muskeg
A	black spruce/tamarack muskeg
A	spruce/tamarack/willow (black spruce)
C	spruce/willow (upland)
A	aspen/jack pine mix
A	aspen/white spruce mix
C	birch
C	birch/aspen mix
	Special interests
A	Canopy Cover Density
	low (open)
	medium
	high (closed)

A	Tree Height
	0 - 15 ft. 15 - 40 ft. 40+ ft.
A-B	Topography
	Flat Rolling (gently undulating) Hilly (ridges and outcrops; mountain slopes)
C	Requested UTM gridding on the maps.

3.2.1.5 Ungulates: Moose/(Wolves). T. Hauge, Graduate Student (Wildlife Ecology), University of Wisconsin, Madison (Personal Communication, January 1978).

Mapped*	Vegetation Categories
	Upland
A/C	aspen/white birch
A	aspen/white spruce
A-B	aspen/jack pine
A	white spruce
A	jack pine
A/B	aspen/willow
	Lowland
A	black spruce
A	black spruce/tamarack
A	tamarack
A	willow/muskeg
A	open muskeg
	Special Interests
A	height classes
A	densities
A	topography
C	UTM grid

3.2.1.6 Aquatic habitat (tentative) D. Fernet, Fisheries Biologist, Beak Consultants Ltd., Calgary (Personal Communication, January 1978).

Ungulate research was divided into two categories--moose and caribou. Their vegetation classifications are compatible with those proposed by INTERA and described in Section 3.3.3 and it appears this area of research will benefit most from the mapping in the immediate future.

The limitation of using the 1:60,000 FCIR photography is the inability to spatially delineate willow communities because of their limited areal extent and non continuous distribution. The ungulate researchers will be able to use the mapped data very effectively; however, they too would like larger scales (1:12,000 or larger) for more detailed work in specific local study areas.

The only request for digitized data came from the ungulate researchers. They have acquired and are acquiring animal locations using radio telemetry and want to use the data with digitized habitat maps to study animal habitat interactions. In the event that the digitized habitat maps are unavailable, hand plotting for this same purpose would be improved by having the UTM grid on the maps.

Aquatic habitat vegetation is difficult to map at the 1:60,000 scale with the exception of large areas of emergent or submerged vegetation, algal blooms and macrophytes. Hydrologic aspects of streams, rivers and lakes, water turbidity relationships, obstructions of and physical changes in stream channels and shoreline irregularity can be observed in the 1:60,000 photography, but generally mapping of aquatic habitat should be done using helicopter and ground collected data. These inputs should be later included on the 1:50,000 maps using symbols and codes.

The final classification system, described in detail in Section 3.3, will provide a very useful working tool for researchers in the field. The maps contain data on spatial distribution of cultural, vegetation and surficial geology features throughout the study area in a format which will be beneficial to researchers' field work programs. The paper copies may be coloured in or marked up as necessary. Results of intensive habitat work may be correlated with the Phase I maps and extrapolation may result in location of other important habitat areas and certainly result in better habitat classification of the entire study area.

3.3 APPLICATION OF CLASSIFICATION SYSTEM TO REMOTE SENSING IMAGERY

Although most researchers requested larger scale imagery for their study areas, the mapping of the entire AOSERP study area at 1:12,000 would have been too slow, costly and of limited use.

3.3.1 Methodology of Map Preparation

Procedure for preparation of the ecological habitat maps involved preparation of base maps from the 1:50,000 National Topographic Service (NTS) topographic sheets where available. Where these were not available, then new base maps were created as described below. Additional cultural information taken from the 1977 photographs was added to the base maps. Using standard photo interpretation techniques, the 1:60,000 scale FCIR photographs were then interpreted for vegetation and surficial geology, with the mapping done on overlays for each stereo pair. Then the mapped data were transferred to the final scale of 1:50,000 using a Zoom Transferscope (Bausch and Lomb, Model ZT4-H). Using this instrument, the overlay for each stereo pair was optically superimposed on the 1:50,000 base map, adjusted for distortion and the data transferred to the correct scale. The resultant 1:50,000 scale data was then proofed and sent for drafting.

The final base map shows land use and cultural features, plus topographic contours (screened so that they are not prominent) and drainage. Two overlays may then be printed on to this base map -- one for vegetation, and one for surficial geology, as described in detail below. They have been prepared as monocolour maps, as required in the contract, for they are to serve as working maps in the field. However, it should be noted that in future it may be useful to consider shading or colouring of types in the final presentation maps. It may increase their usefulness and readability.

As some of the coverage was not obtained until the end of October, it hampered the interpretation of the photography for vegetation temporarily until interpreters could make the adjustment. Thus, map sheets where the primary coverage was obtained during the summer period, and where 1:50,000 scale base maps from NTS already existed were chosen for mapping first. Next were mapped those with primary summer coverage and no 1:50,000 scale NTS maps (their base maps were created from other sources, as described previously). Those with primarily October coverage were left to the last.

Figure 5 outlines the portions of the AOSERP study area for which 1:50,000 scale habitat maps were completed under this contract. These include base maps and the two overlays for each.

3.3.2 Base Maps

Base maps at a scale of 1:50,000 were prepared from NTS 1:50,000 scale topographic map sheets where available and from other existing data for areas where the NTS maps were not available. The NTS legend was used for all base maps, with the addition of symbols for rapids and falls used on Alberta forest cover maps.

NTS 1:50,000 maps were available for nineteen map sheets (approximately one-half of the study area). These maps were updated by the addition of cultural information (new roads, seismic lines and clearings) taken from the 1977 FCIR photographs (1:60,000 scale). Where individual sheets existed for east and west halves of map sheets, there were combined into one map. The muskeg symbol on the NTS maps was deleted since more detailed information on organic deposits and wetlands is provided on the surficial geology and vegetation overlays.

For areas without 1:50,000 scale NTS coverage, base maps were prepared comparable to the NTS series. Hydrologic features were transferred from the 1:31,680 scale Alberta Forest cover maps (Phase 2), while relief was mapped from contour lines (10 m intervals) on the 1:25,000 orthophoto mosaics prepared by

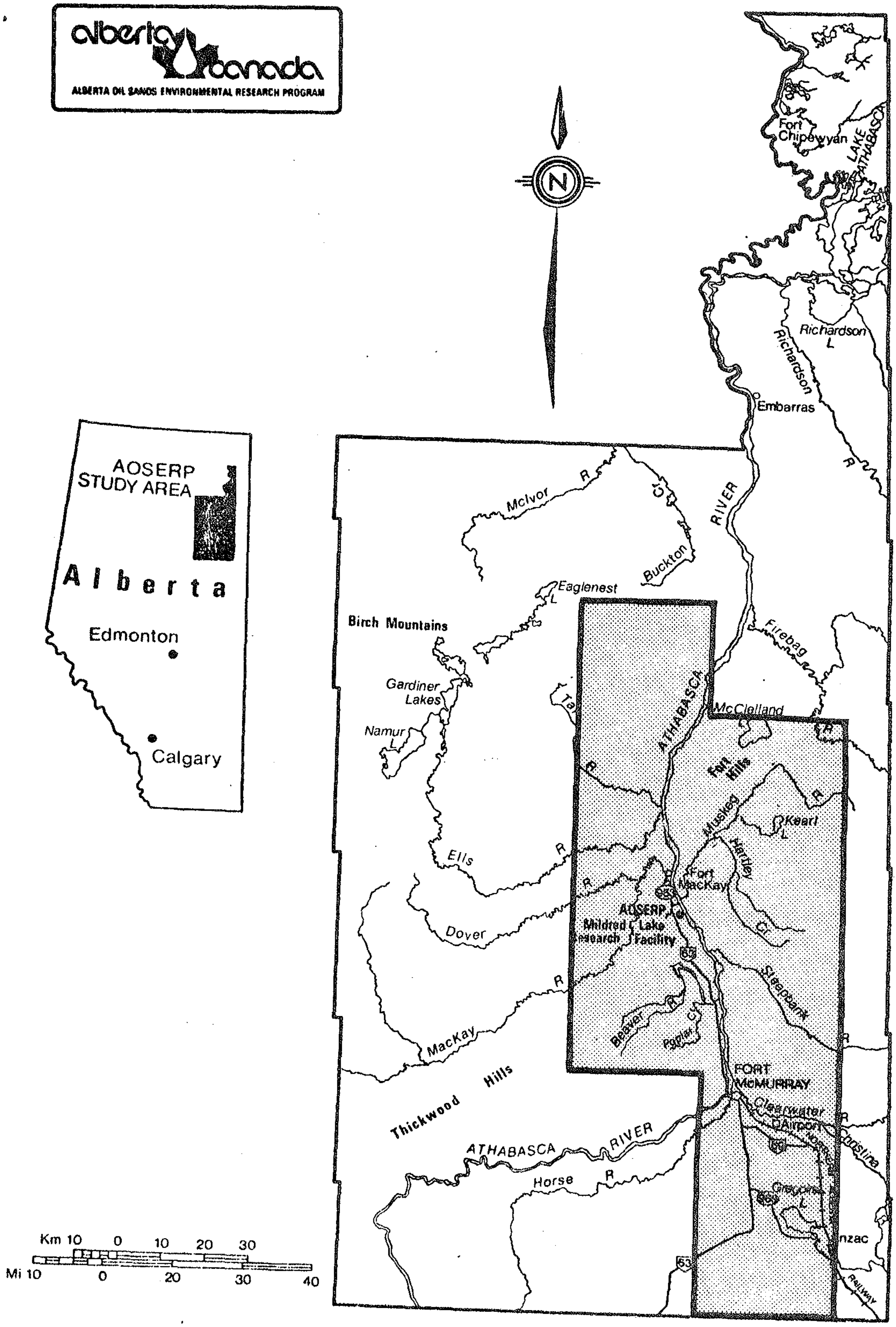


Figure 5. Habitat mapping completed within AOSERP study area.

the Alberta Government (1976); cultural information was mapped directly from the FCIR 1:60,000 photos of the study area.

3.3.3 Vegetation Mapping

3.3.3.1 Development of the vegetation legend. The vegetation of the AOSERP study area has been described in several reports, each dealing with localized types and conditions. For example, Dirschl et al. (1974) have described plant succession in the Peace-Athabasca Delta area, and reports for permit-holding oil companies in the area have sections describing vegetation on their respective permits (e.g. Lombard North 1974; Syncrude 1973). The most up-to-date source of vegetation information available covering approximately 60 percent of the study area is the Forest Cover Type maps published by Alberta Energy and Natural Resources at a scale of 1:31,680. These present detailed forestry information, but the presentations of wetlands and shrubland are greatly simplified.

Stringer (1976) conducted an exploratory survey of the study area as a preliminary to a more detailed mapping effort. Some of his objectives were to describe the composition of and delineate the plant communities with special emphasis on wetlands and non-forest vegetation. By cluster analysis a series of distinctive vegetation types were defined, but were restricted to mature vegetation. Vegetation on sites in the early stages of regeneration after fire were not visited.

Since Stringer's (1976) study was the only one containing detailed information on vegetation types for the total area, his report was drawn upon extensively to develop the vegetation photo classes and types used in the interpretation of the 1:60,000 FCIR photography and preparation of the vegetation overlay. Stringer's vegetation types were strictly based on field work. For adaption to photo interpretation with no ground truthing, several modifications were made.

The vegetation overlay has been set up and mapped so that any researcher may select the vegetation communities of interest to him, and if desirable, shade or colour them in for his own work. Some consideration was given during the preparation of these overlays to shading in or outlining some single communities or combinations of communities so that the vegetation overlay would be easier to interpret for vegetation patterns. However, it was decided that since any choice would not suit all or even the majority of researchers no further patterns would be added to the overlay. This was also decided in the interest of time for completion of the contract-- possibly at some future date consideration could be given to shading or colouring of the more important communities or combinations of communities prior to printing of the final habitat maps.

Figure 6 presents the legend for the vegetation overlay as it appears on the map. There are five major categories which have been divided into further subdivisions where possible. Stringer's Sandbar Willow Scrub, Tall Willow-River Alder Scrub, and Tall Willow Scrub classes were combined to form a "Riparian-Deciduous Shrub" class, since each of these types was too small to represent a mapping unit at this scale. Several classes were added: the "Upland Undifferentiated" to accommodate the extensive regenerating burned-over areas not visited by Stringer, "Burn" to describe recent burns; and "Non-vegetated" to include recent slides, slumps and areas were no vegetation was apparent. A "Wetland Undifferentiated" class has been used to describe wetland situations that are very complex or where the distinctive units are too small to be mapped. Stringer's upland Mixedwood and Deciduous Forest type was combined with White Spruce and Aspen Forest since it was impossible to differentiate between paper birch and aspen. Overall there appears to be good correspondence between Stringer's types and the photo vegetation types as they have been used in this legend.

VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar aspen poplar white spruce willow alder paper birch
b. DECIDUOUS SHRUB	willow alder dwarf birch immature aspen paper birch
2. UPLAND COMMUNITIES	
UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites aspen poplar tall willow alder balsam poplar paper birch
a. WHITE SPRUCE - ASPEN FOREST 2aA aspen 2aM mixed 2aC coniferous	white spruce aspen jack pine
b. MIXED CONIFEROUS	black spruce jack pine white spruce
c. JACK PINE	jack pine black spruce white spruce aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES	
UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes low scattered shrubs tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI-OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs sphagnum mosses
4. BURN	
5. NON-VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols		Height Class (m)		Crown Cover	
(Pj)	jack pine	1	0 - 10	A	open
(Sw)	white spruce	2	11 - 20	B	medium
(P)	poplar	3	21 - 30	C	dense
A	aspen	4	31+		
(Sb)	black spruce				
(T)	tamarack				
(W)	willow				
(Q)	aquatic vegetation undifferentiated				
C	conifer				
(D)	deciduous shrub				
O	open				

Figure 6. Vegetation legend for 1:50,000 scale mapping from FCIR photographs.

3.3.3.2 Description of vegetation types mapped from 1:60,000 FCIR photographs.

1. Bottomland and Riparian Communities

a. Bottomland and Riparian Forest

This forest is dominated by large balsam poplar (*Populus balsamifera*) up to 30 m in height (Stringer 1976). Aspen poplar (*Populus tremuloides*) and white spruce (*Picea glauca*) are present occasionally, as is paper birch (*Betula papyrifera*). The understory is composed of a fairly dense tall shrub layer including willow (*Salix* spp.) and alder (*Alnus tenuifolia*) as well as medium-dense low shrub and herb layers.

The community is found on the floodplains of major rivers, such as the Athabasca and Clearwater, as well as in occasional narrow strips or patches along many of their tributaries.

b. Deciduous Shrub

This vegetation type includes the Sandbar Willow Scrub, Tall Willow-River Alder scrub, and Tall Willow Scrub types delineated by Stringer, as these classes could not be distinguished from each other accurately on the photography. Most common dominant species are willow and alder of 5-8 meters in height, although white birch and immature poplar may also be present. Dogwood (*Cornus stolonifera*) oftens forms a lower shrub layer, while the herb layer tends to be sparse.

These shrub communities are found bordering rivers, often forming a zone between the riparian forest, where present, and the river, as well as occupying river bars (primarily sandbar willow) and wet areas along drainage courses and other well-drained depressions throughout the study area.

2. Upland Communities

Undifferentiated

This type has been used to map extensive burned-over areas where the vegetation is still too small to be recognized on 1:60,000 photographs. Species which may be present include aspen poplar, willow, alder, black spruce (*Picea mariana*) and paper birch with low shrub and herb layers of diverse composition. These open areas are generally found on poorly to moderately well drained mineral soil, on level upland areas and upland slopes.

a. White Spruce Aspen Forest

This forest type includes Stringer's (1976) upland Mixedwood and Deciduous Forest, upland White Spruce-Aspen Forest and the upland Mixedwood and Deciduous Forest. The latter cannot be recognized as a separate type. The dominant tree species are usually aspen poplar and white spruce although other tree species, particularly white birch and jack pine (*Pinus banksiana*) may constitute significant portions of the canopy in some areas. Also present are occasional black spruce, balsam poplar and balsam fir (*Abies balsamea*). The relative abundance of the principal tree species varies considerably in different stands, reflecting different successional stages of a sere related to fire as well as site conditions. Aspen dominates the earlier stages, culminating in a climax of mature white spruce stands, perhaps with balsam fir. The understories are equally diverse depending on the type of canopy with the denser shrub and herb layers occurring in the more open, aspen-dominated stands, while closed canopy white spruce forests have sparse shrub and herb layers and an abundance of feather moss species and lichens (Stringer 1976).

This vegetation type is present throughout the study area, most extensively on well-drained sites, but stages of aspen can be found in all but the wettest areas.

b. Mixed Coniferous

This forest type includes Stringer's coniferous forest (part of his upland Mixedwood and Coniferous Forest). The principal tree species are jack pine, black spruce and white spruce with percentage composition varying considerably depending on location and drainage of sites. The understory also is diverse, with few or no tall shrubs, a variety of small shrubs and herbs, and often considerable ground cover by bryophytes and lichens.

This vegetation type occurs on a variety of sites, as the site preferences of the coniferous species involved range from dry sandy soils (jack pine) to mesic and subhydric sites where black spruce becomes dominant. Poorly drained mineral soils on many of the upland slopes appear to have been burned and revegetated by black spruce mixed with some jack pine.

c. Jack pine

Jack pine is the only principal tree species present in this vegetation type, growing up to 15 m in height. Stringer (1976) found that the understory of the stands of this type had no tall or medium shrubs, and only a sparse low shurb stratum, composed mainly of blueberry (*Vaccinium myrtilloides*), bearberry (*Arctostaphylos uva-ursi*), and rice grass (*Oryzopsis pungens*). Fruticose lichens usually (predominantly *Cladina mita*) form a very prominent and distinctive ground cover, which is an obvious distinguishing characteristic for this type of vegetation.

The jack pine vegetation type is limited to very well drained, sandy sites, particularly on aeolian sand deposits.

d. Upland Open

Open areas within the aspen forest are important in terms of animal habitat. Mainly to accommodate this, the "Upland Open" community was established. Since these areas have been determined from the aerial photographs only, without benefit of ground truthing, the vegetation composition is assumed to consist of grasses and a low herb and shrub layer.

3. Wetland Communities

Wetland vegetation types follow those of Stringer (1976); the distinguishing characteristics indicated here have been based on his descriptions.

Undifferentiated (complex)

Many of the poorly drained upland areas consist of a complex pattern of the various wetland types with bog forest and open muskeg interspersed, and fen vegetation occasionally prominent depending upon local drainage and depressions. These areas are often too small to map separately at the present scale of 1:50,000 and so have been complexed together in an undifferentiated class.

Note: Bogs and fens can be characterized by their different surface vegetation: Sphagnum mosses on bogs and sedges on fens (Section 4.2). The infrared return of sedges is much higher than that for sphagnum mosses with the result that fens have a colour varying from pinkish brown to bright red, and bogs are brown on FCIR photographs. An attempt has been made to classify the fens and bogs according to their surface colour.

a. Fen

Fen communities are dominated by broad-leaved or fine-leaved sedges (*Carex* spp.). When the shrub stratum is present it is composed primarily of swamp birch (*Betula pumila* var. *glandulifera*). Semiaquatic forbs and mosses may also be present.

Fens are found in very wet upland areas away from major rivers, although they may be present in upland drainage channels as well as extensive flatter areas. Unlike bogs, they occur in areas where there is some drainage and flow of water, although the water table may be very high.

b. Black Spruce Bog Forest

This vegetation type is dominated by black spruce (less than 10 m in height). Tamarack (*Larix laricina*) may also be present in limited numbers. There are no tall shrubs and the lower shrub and herb layers are sparse with the lower shrubs usually dominated by labrador tea (*Ledum groenlandicum*) and blueberry.

c. Semi-open Black Spruce - Tamarack Bog Forest

Tree species in this type are black spruce and tamarack, constituting a low (less than 10 m in height) forest of sparse to medium density. Labrador tea is the most prominent low shrub species, although others such as bog birch, mountain laurel (*Kalmia polyfolia*), bog nosegay (*Andromeda polyfolia*) and willow may also have extensive cover, particularly in the more open muskeg areas. The herb and wood shrub layers are sparse and may include various sedges.

d. Lightly Forested Tamarack and Open Muskeg

Tree growth is limited in this type to sparse tamarack (less than 5 m in height) and black spruce (to 1-2 m in height). The low shrub layer is prominent and similar to that in the other bog vegetation types, with willow, swamp birch, and labrador tea the dominant species.

Black Spruce Bog Forest, Semi-open Black Spruce-Tamarack Bog Forest and Lightly-Forested Tamarack and Open Muskeg develop on acidic organic soils of thick peat developed on thick deposits of sphagnum and other bog mosses. All three vegetation types occupy the same sort of poorly drained acidic upland and lowland sites.

The gradation from one to type to the next is related to increased moisture, with Black Spruce Bog Forest occupying the drier, more mesic sites, grading into semiopen Black Spruce-Tamarack Bog Forest progressively on wetter sites until Lightly-Forested Tamarack and Open Muskeg is found on the wettest (hydric) sites.

4. Burn

Much of the study area is vegetated by successional communities as a result of burning. Where the revegetating species can be identified these areas are included in the appropriate vegetation type. Thus it is only the very recent burns (less than five years) that are classified as "Burn", since regrowth is minimal as yet, and individual plants are too small to be identified from the photographs.

5. Non-vegetated

Recent slides and slumps that appear non-vegetated on the 1:60,000 scale FCIR photographs are included in this type. Occasional grasses, low forbs and shrubs may be present. Any other areas that have minimal return are included in the category also.
Ground truthing in this category would allow more specificity in the mapping.

Other Information

Aquatic vegetation

Only the presence of aquatic vegetation has been indicated by a Q. No conclusions have been drawn with regard to areal extent or species.

Height and crown cover

In addition to the vegetation community symbol, a visual estimate of height and crown cover has been given for the forest types mapped.

There are four height classes:

1	0 - 10 m
2	11 - 20 m
3	21 - 30 m
4	31+ m

The three crown cover classes are as follows:

A	0 - 35%	open
B	35 - 65%	medium
C	65 - 100%	dense

For the black spruce 3b, 3c and 3d category, no height or density designation has been given, as the height is generally less than 10 m and the stands are very dense.

Vegetation symbols

The following abbreviations have been used on the overlay to indicate additional species information, generally in order of importance. Where the legend expresses the presence of a certain species such as 2 c (i.e. jack pine), the addition of (A) to the legend symbol means that aspen is present within the jack pine stand (e.g. 2 c (A) 2B).

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

3.3.3.3 Photointerpretation keys for the 1:60,000 scale FCIR photographs related to the legend for the vegetation overlay.

In order that a complete description of the vegetation mapping be included in this report, and that other researchers may benefit from the development and implementation of the vegetation interpretation from the 1:60,000 scale FCIR photographs of the AOSERP study area, a key for interpretation of the photographs for the vegetation communities has been prepared.

This key (Table 2) provides the following information for each vegetation community listed in the legend: legend symbol, name of type, components of the type, topographic situation. Then the class is described by its pattern, texture and colour as they appear on the 1:60,000 FCIR photographs. A more complete description of the type is then provided, and finally its relationship to Stringer's (1976) vegetation types given. The terms and colours used to describe the different photo communities are at best general. The same colour may vary throughout each photograph and from frame to frame. Those described in the key are as they would appear near the center of each photograph.

In the key, pattern describes the distribution of a vegetation type. Texture is the impression of smoothness or roughness on the photograph as it appears to the eye. Other terms are defined as follows:

Uniform	alike, without any change
Broken	smaller groupings of a uniform pattern
Mottled	spots of different colour or shade
Stippled	small dots of colour against a background of different colour
Cyan	a mixture of blue and green
Magenta	a mixture of blue and red

Table 2. Vegetation Legend And Photo Interpretation Key For 1:60,000 Scale FCIR Photographs

CLASS	SYMBOL	TYPE	COMPONENTS	SITUATION	PATTERN	TEXTURE	COLOUR	DESCRIPTION	CORRESPONDS TO STRINGER'S VEGETATION TYPE
BOTTOMLAND AND RIPARIAN COMMUNITIES	1a	Bottomland and riparian forest.	balsam poplar aspen poplar white spruce willow alder paper birch	Found on the floodplains of major rivers, such as the Athabasca or Clearwater, lakeshores, and the drier areas on or along drainage courses	Uniform	Coarsely foamy (poplar) Medium to fine (white spruce)	pink to red dark magenta	Balsam poplar or white spruce of various height, generally tall. May occur in pure stands or mixed; height up to 30 meters. Aspen poplar and paper birch may also be present. Generally there is a shrub layer of willow and alder, especially visible around the periphery of the stand on the photograph. The texture of poplar is generally coarser than that of aspen.	Bottomland balsam poplar forest
	1b	Deciduous shrub	willow alder dwarf birch immature aspen paper birch	Bordering rivers, ponds, lakes; occupying river sandbars, on and along drainage courses.	Uniform	Fine	pink to red	Varies from patches too small to map along stream channels, to extensive willow and alder stands in association with fens. Height up to 6 m. On the photograph this community shows little shape or shadow.	Sandbar willow scrub; Tall river alder willow scrub; Tall willow scrub
UPLAND COMMUNITIES	2	Undifferentiated	deciduous or coniferous shrub on burned-over sites too small to be resolved on the photograph	Poorly to medium-drained, level or sloping upland sites	Uniform	Very fine	pinkish grey to grey green	Possible low shrub of fire origin, either deciduous or coniferous, less than 3 m in height. On the photograph this shows as extensive pinkish grey areas. No shadow, shape but very fine texture can be recognized. Intermittent very shallow drainage channels may be present which show as pale pink veins.	
	2aA	White Spruce - aspen forest	aspen birch	Most extensive on well to moderately drained upland sites, but can be found in all but the wettest areas.	Uniform, sometimes broken	Fine to very fine	red to pink	Generally extensive, pure stands of aspen, up to 20 m in height, forming a very dense canopy. As the stand matures the canopy tends to break open. Occasionally clones (groupings of genetically similar trees) can be detected by colour or pattern differences. When associated with deciduous shrub, (D) is added to the legend symbol: 2aA(D). The photograph shows generally extensive pink to red areas.	
	2aC	White Spruce - aspen forest	white spruce jack pine balsam fir	Similar to 2aA but tall stands are occasionally found on well drained, north-facing, river slopes.	Uniform	Fine to medium	magenta	Pure stands of coniferous vegetation, generally white spruce. Height occasionally in excess of 35 m. White spruce can often be found as an understory or emerging through the canopy of the aspen forest. Both white spruce and jack pine can be found as a mixture with the aspen.	Upland white spruce and aspen forest. Upland mixed wood and deciduous forest.
	2aM	White Spruce - aspen forest	Various mixtures of aspen and white spruce	Similar to 2aA and 2aC	A mixture of 2aA and 2aC with various amounts of magenta or red stippling depending on the amount of mix.			In general, an aspen stand with up to 20% coniferous vegetation has been considered pure aspen. With more than 20% coniferous trees the stand has been typed as a mixed stand. White spruce with up to 20% aspen has been typed as a pure white spruce stand.	
	2b	Mixed coniferous	black spruce jack pine white spruce	Poorly to medium-drained level or sloping upland sites, with inclusions of bog or covered by a thin discontinuous veneer of peat.	Fairly Uniform	Fine to medium	magenta	Relatively tall, very dense, coniferous stands (>6 m), of fire origin, for the greater part pure black spruce with possible mixtures of jack pine and white spruce, depending on site. On the photograph this community appears to have a uniform pattern and fine texture. Shapes and shadow can be made out under high magnification.	Mixed wood and coniferous forest
	2c	Jack pine	jack pine	Dry sandy sites, with aeolian deposits such as sand dunes. Also where these sand dunes are separated by bogs and form small sandy islands.	Uniform to stippled	Fine to Coarse	magenta on white background or magenta	Pure stands of jack pine, up to 15 m in height, on dry sandy sites, sometimes mixed with aspen or intergrading with black spruce where sandy sites and poorly drained upland sites are mixed. Stand density may vary from very open to very dense. The association with *Cladina* spp. makes this community very easy to recognize on the photograph. The *Cladina* spp. forms a white background against which the jack pine is contrasted as cyan dots.	Jack pine forest
	2d	Upland open	grasses, low herbs	Grassy open areas in aspen forest that are not fens	Uniform	Very fine	pink	These open areas occur in the Upland White Spruce-Aspen community, generally in the pure aspen stands. Though of small areal extent, they have been typed because of possible habitat significance.	
WETLAND COMMUNITIES	3	Undifferentiated (usually complex)	-	-	Mottled	Fine to medium		Wetlands are generally easy to recognize but differentiation between bogs and fens (Zoltai *et al* 1977) is difficult on 1:60,000 photographs. This community has been used where a variety of wetland forms exist that cannot be differentiated or that are too small to type individually. Sometimes it has been complexed with an upland type e.g. 3/2b2C, indicating a wetland situation with islands of mixed coniferous vegetation.	
	3a	Fen communities	sedges, swamp birch, sometimes willow and alder	Poorly drained, generally level to very gently sloped upland sites that are part of a slow moving drainage system; draws and low gradient streams and depressions.	Uniform	Very fine	pink	Very wet sites, composed mainly of sedges with a continuous or intermittent low shrub layer, consisting principally of swamp birch. Sometimes larger shrub species such as willow and alder are present which can be observed on 1:60,000 photography and are indicated with 3a(D). Characteristic striping, indicating drainage flow through the plant mass, may be present.	Fen
	3b	Black spruce bog	black spruce	Poorly drained, generally level to gently sloped upland sites; wet depressions within well drained sites.	Uniform	Fine	magenta to brown	Pure stands of even-aged black spruce, generally low in height (up to 10 m), crown cover is dense. Generally in association with organic soils covered with *Sphagnum* spp., *Ledum groenlandicum* and sometimes *Cladina* spp. In more open stands the *Cladina* spp. forms a white background against which the black spruce are contrasted as magenta dots. In low stands it is difficult to distinguish tree height or crown shape on the photograph.	Black spruce bog forest
	3c	Semi-open black spruce bog	black spruce	" " "	Uniform	Fine	brown to tan	Similar to above with the inclusion of tamarack of sparse density.	Semi-open black spruce - tamarack bog forest
	3d	Lightly forested tamarack and open muskeg	tamarack, low willow, dwarf birch	" " "	Uniform	Very fine	tan to pink	Extensive bog areas as defined by Zoltai et al (1977) with scattered tamarack and black spruce stands of low density. On the photograph it has a uniform pattern, and very fine texture. The height of the trees can barely be discerned.	Lightly forested tamarack and open muskeg.
BURN	4	Burn	dead vegetation	May occur anywhere	Uniform	Variable	cyan	Recent burns up to several years old, uniformly coloured blue-green with occasional pink spots, indicating living vegetation.	
NON VEGETATED	5		Occasional low herbs & grasses	Recent slides, slumps	Uniform to mottled	Very fine	cream to grey	No vegetation or possibly very sparse vegetation can be observed on 1:60,000 photographs.	
AQUATIC VEGETATION	Q			Lakes, ponds	Of varying density	Very fine	pink to red	Appears as red to pink streamers of varying density against a blue background.	

3.3.3.4 Possibilities for Large Scale Mapping. One of the important considerations in the development of the classification system was that it be open-ended, so that it could easily be expanded or contracted depending on the level of detail required in the mapping or the scale of photographs available. This section demonstrates that capability, by providing an example of vegetation mapping at 1:60,000 scale using the legend system as described above, as well as an example of 1:15,000 scale mapping in a portion of the area, using the same legend.

In order to test the vegetation legend as a open-ended system with possibilities for expansion for more detailed mapping, four frames from the 1:15,000 scale FCIR photography were examined and interpreted in detail. The legend as used for the 1:60,000 scale photography is by necessity broad, especially since it was based on a preliminary vegetation survey that only sampled the mature vegetation associations in the area, with a minimum of field checking (Stringer 1976). The area selected for detailed mapping was along one of the transects selected for lower altitude photography, and centred on Kearl Lake (located in Tp. 95, 96 R.8 W of 4). This area was selected partly because a map of vegetation around the lake had been made (F. Gilbert, Department of Zoology, University of Guelph, Personal Communication, January 1978) and field checked (although these data were not available to INTERA), so that this might serve as a substitute for ground survey data. Another reason was that the area included a good representation of types--upland aspen and jack pine, mixed white and black spruce stands, pure black spruce stands, bogs, fens, and riparian communities.

Figures 7 and 8 are examples of the 1:60,000 and 1:15,000 scale FCIR photographs respectively. The overlay on each photograph shows the type of mapping which has been carried out using the vegetation legend and an expansion of it for the large scale photograph.

It was found that the legend could be applied quite well and could be telescoped to be more specific. Thus it adequately describes the majority of species in the different

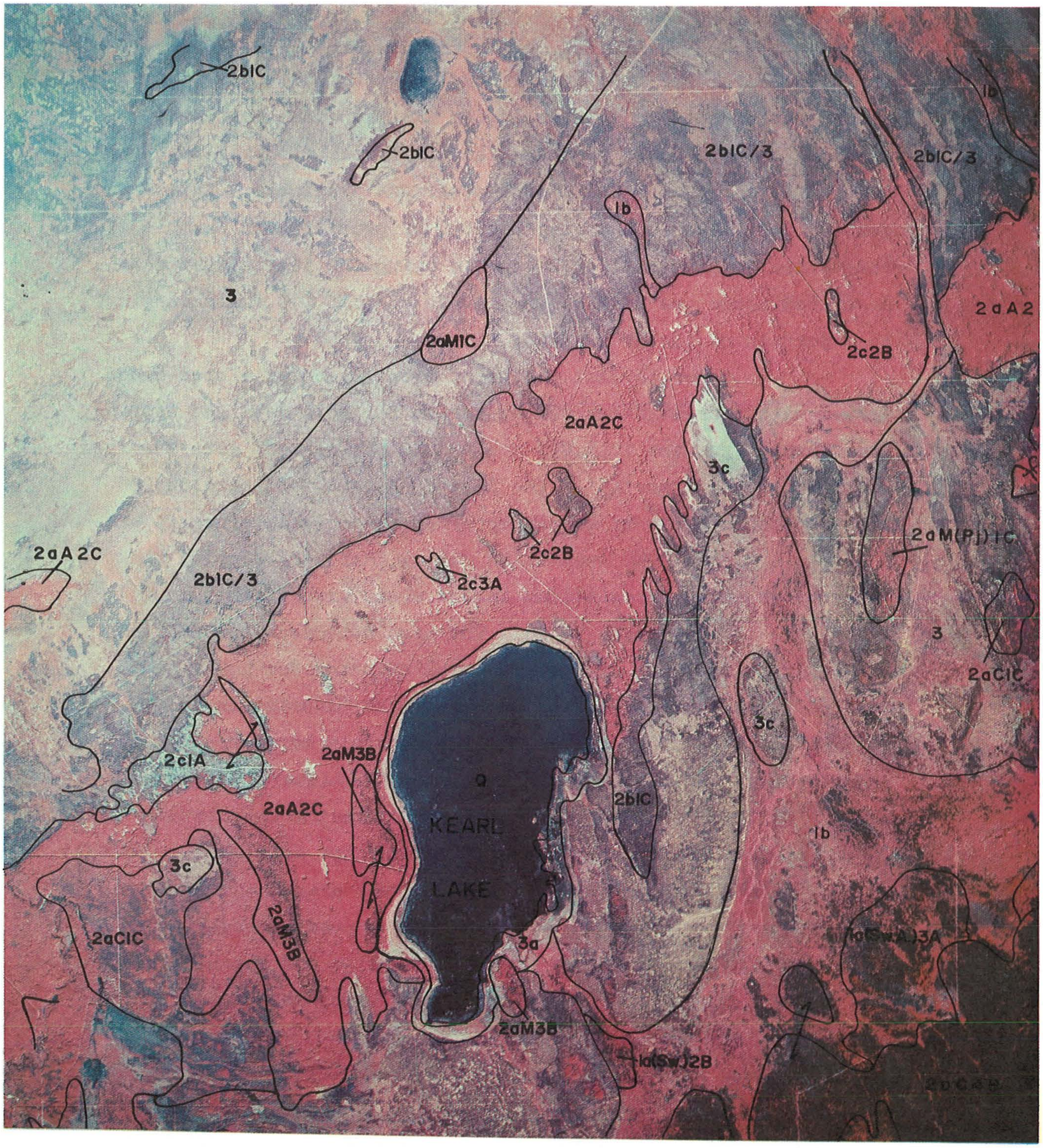


Figure 7. 1:60,000 scale FCIR photograph and overlay showing mapping with vegetation legend, Kearl Lake area.

Figure 8. 1:15,000 scale FCIR photograph and overlay showing mapping with extended vegetation legend, Kearl Lake area.

habitats as they can be recognized from the photographs at the large scale. For instance, 2aM (A, Sw, Pj) 3B means a mixed upland forest where the main component is aspen with white spruce and jack pine in lesser quantities.

Also at this scale it is often possible to determine the species composition of the understory. The understory can be indicated by writing it as the denominator under a dividing line, as

$$\frac{\text{2aA3B}}{\text{2aC(Sw)1C}}$$

Vegetation height and density may be estimated in three-metre and 20 percent intervals respectively, rather than the ten-metre and 33 percent intervals used for the mapping at the 1:60,000 scale.

The separation of sedges and fens on the test area has been done using colour and texture - the smoother texture, brighter red colour, and absence of black spruce are generally associated with fens, while rougher texture, yellow-grey to brownish-grey colour, and presence of black spruce/tamarack appear to indicate sphagnum bogs. Separation of mature aspen poplar and balsam poplar is possible at the 1:60,000 scale through observation of texture and habitat. Balsam poplar stands have been included in the Riparian and Bottomland Communities (1a) Class.

This demonstration has indicated the telescoping legend capability for vegetation. A detailed expansion of the legend system for mapping at this large scale has not been set up here, however, as its exact composition will be determined in large part by the objectives of any researchers wishing to map at this scale.

3.3.4 Surficial Geology Mapping

3.3.4.1 Development of the surficial geology legend. A variety of approaches has previously been utilized in mapping surficial geology. Each approach is dictated by the inherent objectives of the mapping project and the utility of the final product. Basic information describing the genesis, mode of transport, appearance, size and extent of surficial features needs to be included in a recognizable and useful manner. Identification of specific landforms through topographic form, drainage characteristics, photographic tone, and analysis of slope provides significant clues to the composition of the surficial mantle (Ray 1960). This information can be valuable for a variety of researchers including soil scientists, wildlife biologists, foresters and mining and construction engineers, each of whom needs to consider composition of the overburden. Flexibility within the mapping system is necessary to permit future telescoping for larger scale mapping. In the AOSERP study area, mapping has been carried out through identification of individual landform features combined with interpretation and analysis of the extent and relationship of major geomorphic units. Thus, a logical sequence of glacial and postglacial events could be derived and presented in a meaningful form.

The legend used for surficial geology mapping is presented in Figure 9. This legend is a slightly modified version of the landform classification utilized in the soil classification system adopted by the Canada Soil Survey Committee (CSSC) in 1976. Landform descriptions based on material and form for each unit are included by the CSSC to provide parent material information. Adoption of this technique and many of the definitions utilized by the Soil Survey allows those familiar with the national system to readily interpret the maps of the present study. However, since the CSSC system was designed by soil scientists for soil inventory purposes, some modification was necessary. Certain information of interest to geomorphologists and surficial geologists such as landform types, excluded in the national system has been added, while categories in the national system of little relevance to the surficial geology were eliminated from the legend.

Following the style adopted by the CSSC most of the landform information was symbolized alphabetically. This contrasts with the predominantly numeric vegetation classification, Standard: A^{b}_{c} d, e f where,

A - genetic material
b - qualifying descriptor (not always used)
c - surficial expression
d - specific landform information (not always used)
e - local relief
f - modifying process (not always used)

Composite Area:

= both components present in approximate proportions.
— first component more abundant than second

GENETIC MATERIAL

C Colluvial
E Eolian
F Fluvial
L Lacustrine
M Morainal
R Bedrock
U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

QUALIFYING DESCRIPTOR

G Glacial

SURFACE EXPRESSION

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

LANDFORM

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

LOCAL RELIEF

1 less than 10 meters
2 10 - 50 meters
3 51 - 150 meters
4 over 150 meters

MODIFYING PROCESS

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

SYMBOLS

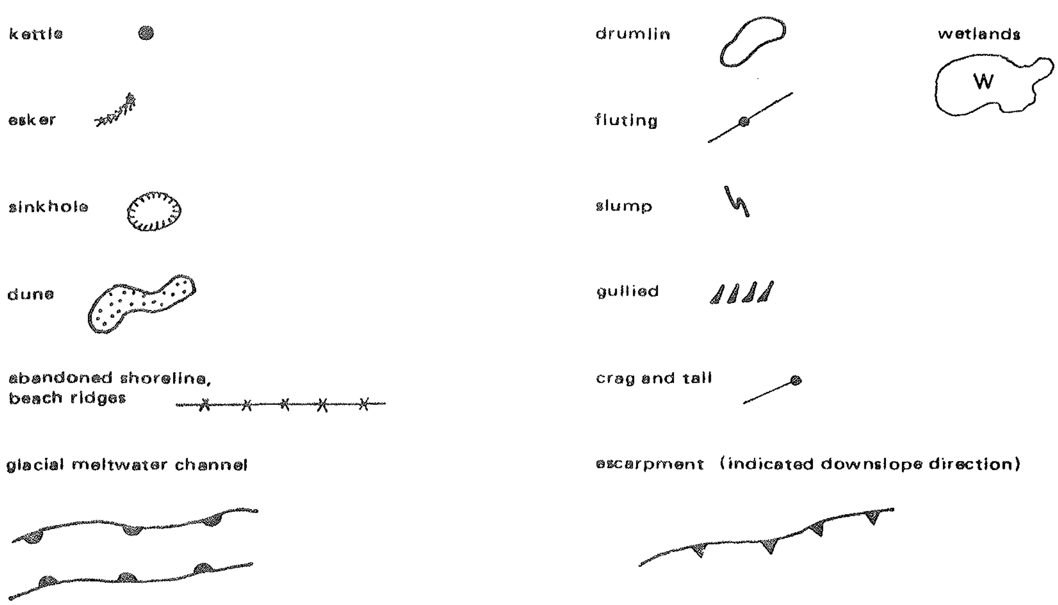


Figure 9. Surficial geology and landforms legend for 1:50,000 scale mapping from FCIR photographs.

decreasing confusion which could result when utilizing both maps simultaneously. Likewise, format adhered to the CSSC system, with a few minor modifications. This is illustrated in the following example:

$A^{b}_{c}d$, ef where

A = genetic material

b = qualifying descriptor (not always used)

c = surficial expression

d = specific landform information (not always used)

e = local relief

f = modifying process (not always used)

A, b, c, and f correspond to the CSSC landform classification system. Terminology and definitions adopted by the CSSC to describe these units are similarly used here with four exceptions subsequently explained in Section 3.3.4.2, Description of Units. Local relief, "e", was substituted for slope in the CSSC classification. When mapping at a scale of 1:50,000 it appeared cumbersome to define slope complexes within individual geomorphic units. For example, hummocky moraine includes a complex sequence of slopes which would necessitate numerous subdivisions. Likewise, each sand dune would be subdivided into two slope units, windward and leeward. At a larger mapping scale this would be useful, particularly for discerning varying wildlife habitats; however, at 1:50,000 it hardly seems practical. Consequently, local relief was included to provide information on topographic variability.

Additional topographic information was included by utilizing a new category, "d". This unit describes the specific landform feature mapped. Recognition of specific landforms provides information as to their textural composition, mode of origin, and genesis. Engineers, for example, could use this information for rapid location of borrow pits, subsurface foundation capabilities, and feasible transportation corridors through muskeg.

Two techniques were utilized to describe specific landforms and landform units: on-site symbols, and an alphabetical inclusion ("d" described above) in the terms describing the unit mapped. Use of each technique was primarily a matter of scale. Individual sand dunes, for example, would be unwieldy to map and label utilizing the complete system. An on-site symbol, however, immediately indicates the specific feature. Relict intermittent beach ridges can easily be portrayed symbolically, yet an attempt to define complete geomorphic units including just the beach ridges would be impossible. Likewise, on-site symbols for features such as eskers, glacial fluting, kettles, sinkhole and abandoned shorelines minimize map clutter yet graphically display the location and extent of these particular features. Symbols, therefore, have been utilized to portray specific features probably deposited over the dominant surficial material. Larger features, such as outwash plains extending over tens of hectares or active floodplains paralleling drainage courses, are designated as units to indicate their areal extent and to minimize clutter. Such features would be too large to portray symbolically.

A final modification of the CSSC system involved the wetlands, "w", classification. Detailed mapping of wetland vegetation communities is included on the vegetation maps; however, the depth of organic material in numerous instances throughout the AOSERP study area is so great that it completely masks underlying topography. Consequently, the genesis of underlying parent material must be inferred, when possible, from the surrounding terrain. Identifying and labelling these deep organic deposits on the surficial geology map should reduce any confusion which could arise in the minds of potential users. For example, engineers concerned with locating potential sources of sand and gravel for construction purposes should avoid areas containing a large number of wetland designations.

Two limitations inherent in landform mapping must be cited in reference to this project. First, many geomorphic boundaries are transitional and definition of an exact limit for many geomorphic units is subjective (although precise boundaries can be indicated for features such as sand dunes and eskers). Second, the lack of opportunity for field checking examples from each of the units, and several specific questionable local features was a serious handicap. For example, an area north of the Clearwater River on map sheet 74D 11 was mapped as an eolian blanket on the basis of photographic evidence, such as the distinctive gully shapes and dendritic drainage pattern limited to this area, but positive identification of the materials present and their mode of origin is impossible without investigation on the ground.

3.3.4.2 Description of units. Classification within the CSSC landform classification is based on the material and form of the landform unit. Material component designations applicable to the AOSERP study area are:

C	Colluvial
E	Eolian
F	Fluvial
L	Lacustrine
M	Morainal
R	Bedrock
U	Undifferentiated

Precise definitions for each category and subsequent subcategories or classes are included in the accompanying glossary (section 11.1).

A qualifying superscript, "G", is included to indicate glacial depositional features. Thus, the symbol "L" indicates recent lacustrine deposition, whereas "L^G" is glaciolacustrine.

The pattern and assemblage of slopes for each unit is described by surface expression. Descriptors used include classifiers distinguishing the depth of unconsolidated genetic materials over underlying units. Descriptors of surface expression are the following:

a	apron
b	blanket
f	fan
h	hummocky
i	inclined
l	level

m rolling
r ridged
t terraced
u undulating
v veneer
x extensively eroded by post-depositional processes

These classes are adopted from the CSSC classification, with one addition, class "x", "extensively eroded by post depositional processes". Extensively dissected areas bearing little resemblance to their morphology at the time of deposition could not be adequately described by any of the previous classes. Inclusion of this additional class does not interfere with the identification of the particular landform, yet provides additional information as to the degree of dissection having occurred since deposition. A kame, for instance, may contain extensive fluvial dissection along a periphery, yet the central core may remain relatively unaffected. Identification of the variability between the two sections provides additional descriptive information about the unit.

Occasionally, a situation arose in the mapping where none of the terms included in surface expressions adequately described the features encountered. When this occurred, no qualifier was included. In most such instances, it was concluded that the information contained in the remainder of the description indicated the type of topography which could be expected.

As described in Section 3.3.4.1, an additional class identifying specific landform features has been added to the CSSC system. The features described in this class and defined in the glossary include the following:

b fluvial bar, fluvial terrace
k kame
t kame terrace
p outwash plain
r outwash bench, outwash terrace, outwash bar remnants
c meltwater channel sediments
o active floodplain, oxbow lake, meander scar

This section can be expanded to include additional units for larger scale mapping. In some instances this category would not be utilized; for example, in describing an aeolian blanket with 10 m local relief the description "Eb,1" would be complete.

Symbols were utilized on the map for the following landform features:

kettles
eskers
sinkholes
sand dunes, sand hills
abandoned shorelines and beach ridges
glacial meltwater channels
drumlins
glacial fluting
slump
crag and tail
escarpments

A definition for each has been included in a glossary (Section 11.1).

As explained in Section 3.3.4.1, local relief has been mapped rather than slope. Four classes were included to describe the average local relief within a unit:

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

Accuracy of relief classification was ensured by co-ordinating the NTS 1:50,000 topographic series of the area with the photographs where possible. Contour intervals over the majority of the mapped area were 25 feet (eight metres) allowing easy class discrimination.

The final descriptive category is modifying process. Adopting the definition utilized by the CSSC, these qualifiers were included to describe "geological processes that have modified or are currently modifying genetic materials and their surface expressions" (CSSC 1976: 163). The processes adopted for use in the AOSERP mapping program are:

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

A definitive problem arose in utilizing the precise definitions adopted by the CSSC for eroded (channelled) and gullied areas, since the CSSC definition for eroded channels is limited to a "surface crossed by a series of abandoned channels ..." (CSSC 1976: 164). For example, a gently inclined glaciolacustrine blanket with numerous intermittent drainage channels which are neither steep-sided narrow gullies nor abandoned channels is difficult to classify. Consequently, the definitions given in the accompanying glossary for these processes have been modified for the AOSERP project to more accurately describe such situations.

3.3.4.3 Photointerpretation keys for the 1:60,000 scale FCIR photographs related to the legend for the surficial geology overlay. Recognition of each of the surficial geology units mapped was based on a series of identifiable characteristics, drawn from a variety of sources including both geomorphic and remote sensing information. The primary identifying features associated with each unit are described in Table 3.

3.3.4.4 Glossary. Surficial geology is repleat with terminology variations, all describing specific features. Geomorphologists recognize the terminology and what each describes; however, to avoid confusion as to the precise meaning implied by the use of these terms, and to facilitate easy use by non-specialized researchers, a glossary has been included in Appendix 11.1. Many of these definitions are standard and can be found in any geological dictionary; the more descriptive terms are adapted from the Canadian Soils Survey Classification System (1976). Definitions taken from the CSSC classification system are indicated by "CSSC" in parentheses. Definitions indicated by "modified CSSC" are based on CSSC definitions with minor modifications in meaning and wording.

Table 3. Surficial geology photointerpretation keys for the 1:60,000 scale FCIR photograph.

	SYMBOL	TOPOGRAPHY	DRAINAGE	EROSION	VEGETATION	LOCATION	PATTERN	COLOUR	SCALE* 1:15,000	SCALE* 1:30,000	SCALE* 1:60,000	EXAMPLE (FLIGHTLINE, FRAME NO.)
FLUVIAL:												
Active floodplain	$F_{i}o$ or $F_{1}o$	gently inclined fluvial plain of varied extent bordering drainage channel	usually internal except in former meander bends where impervious clay layers create wetlands	slumping common along valley walls; downstream lateral migration of meanders creating swell and swale topography	riparian forest and shrub vegetation common	bordering either side of drainage channels, often bounded by valley walls	uniform	usually red to dull red; varied depending on vegetation	/	/	/	Line 11, #103
Oxbow lake, meander scars	$F_{1}o$	generally curved channel remnants of variable extent, level interior bounded by slightly higher levee or channel banks	poorly drained due to high silt-clay content	resistant due to high clay content	initially boggy and wet; vegetation succession eventually climaxes in riparian forest	normally in close proximity to major drainage channel	mottled to uniform	varies depending on the stage of vegetation succession; blue, buff pink to red	/	/	-	Line 10, #135
Fluvial terrace	$F_{i}b$	narrow inclined plain of varied extent bounded by steeply ascending slope on one side and steeply descending slope on the opposite side	internal except in remnant oxbow lakes and meander scars	gully development along steeply descending slope	forested riparian vegetation common	within river valley; distinguished by a distinct steeply descending slope along the riverward edge and steeply ascending slope abutting the valley wall or higher terrace	uniform	red to dull red depending on vegetation	/	/	-	Line 10, #134
Fluvial bar	Fb	level to gently inclined deposit of variable size and shape	internal	continuously modified by stream currents	mid-river bars frequently unvegetated due to rapid bar migration; stabilized bars vegetated by shrub communities (usually sandbar willow)	occur either within a major drainage channel or along its edges	uniform (unvegetated non-stabilized bars) to stippled (partially vegetated and semi-stabilized bars)	buff, pink to red; varied depending on extent of vegetation cover	/	/	/	Line 11 #103
Alluvial fan	F_{f}	laterally convex cone shaped feature of varied extent	internal; numerous abandoned distributory channels; possible occurrence of springs along periphery	resistant	shrub vegetation common, occasionally forested; vegetation density increases along abandoned channels	common when streams encounter a significant gradient decrease, the reduction in velocity decreases carrying capacity resulting in deposition; common where streams emerge from uplands onto plains or valleys	stippled; linear bands of vegetation along abandoned channels sometimes apparent	varied depending on vegetation cover	/	/	-	Line 11, #103
GLACIOFLUVIAL:												
Outwash plain	F_{p}^{G}	broad, gently inclined plain; topographically varies from irregular hummocky mounds indicative of former outwash bars, terraces, and more recent sand dunes to dominantly smooth level surface	through surface drainage only along major channels; ponding and wetlands common; (frequency of ponded surface water indicative of high water level) coarser debris extremely porous; phantom drainage lines common	deflation	bog and fen occurrence common; forested on better drained areas; pine and reindoor moss common on very well drained higher surfaces, particularly sand dunes	lower lying areas particularly along former meltwater channels; may be pitted by kettleholes	mottled; possibly some darker bands indicative of phantom drainage (generally sandy outwash more uniform, granular outwash mottled)	varies from pink to blue	-	/	/	Line 10, #123

* / suitable scale

- unsuitable scale

Continued . . .

Table 3. Continued.

	SYMBOL	TOPOGRAPHY	DRAINAGE	EROSION	VEGETATION	LOCATION	PATTERN	COLOUR	SCALE* 1:15,000 1:30,000 1:60,000	EXAMPLE (FLIGHTLINE, FRAME NO.)
GLACIOFLUVIAL: Contd.										
Outwash bar	$F^{G}r$	ridged, level or inclined surface bounded on all sides by abrupt changes in slope	internal	short V-shaped gullies along edges	generally heavily forested, indicative of better drainage	frequently occurs upon outwash plains between meltwater channels	uniform	red to dark red	- / /	Line 10, #123
Outwash terrace or bench	$F^{G}_{i}r$	inclined level surface with sharp break in slope along edge	internal	V-shaped gullies in gravel	generally heavily forested, indicative of better drainage	often associated with outwash plains and/or till	uniform	red to dark red	- / /	Line 10, #123
Kame	$F^{G}k$	steep sided hill or mound of stratified sands and gravels varying in size and shape	internal drainage in coarser debris; channel development along periphery	short V-shaped gullies	generally heavily forested, some small wetlands in interior depressions	usually surrounded by glacial till or outwash	uniform	red to dark red	- / /	Line 10, #122
Dissected kame	$F^{G}_{x}k$	lumpy hill or mound extensively dissected by post depositional fluvial processes	extensive gully and channel development	V-shaped gullies	generally forested along stable slopes	periphery of kames and kame terraces	uniform	red to dark red	- / /	Line 10, #122
Kame terrace	$F^{G}t$	wide, level to gently undulating, steep sided ridge of varying proportions	internal drainage in coarser debris; channel development along periphery	V-shaped gullies	generally heavily forested	terrace-like ridge surrounded by outwash or glacial till	uniform	red to dark red	- / /	Line 10, #126
Esker		long narrow sinuous ridge	internal, possibly swampy at base depending on underlying material	generally resistant; composed of coarse sands and gravels	heavily forested; vegetation contrasts may occur due to opposing slope conditions	overrides preglacial topography regardless of preexisting drainage characteristics	uniform	red to dark red; color contrast may occur on opposing slopes	/ / /	Line 5, #21
Meltwater channel		smooth gently curving break in slope of varied extent; often occurring in pairs	NA	post glacial reduction of channel sides	forested slopes indicative of better drainage along channel banks, wetlands on channel bottom	frequently occur in groups representing former braided meltwater channels; common in outwash, occasionally superimposed on till	channel banks uniform, channel mottled	dark red along well drained banks; channel floor varies from pink to buff and cyan (greenish) representative of wetlands	/ / /	Line 11, #103
Meltwater channel sediments	$F^{G}c$	level to slightly undulating deposits of variable extent bounded by gently curving pro-glacial channel banks	little through drainage; generally boggy	little	bogs and fens common due to poor drainage conditions	frequently occur between outwash bars	mottled	pink to buff to blues	/ / /	Line 11, #103

* / suitable scale

\- unsuitable scale

Continued . . .

VEGETATION	LOCATION	PATTERN	COLOUR	SCALE* 1:15,000	1:30,000	1:60,000	EXAMPLE (FLIGHTLINE, FRAME NO.)
extensive bogs and fens	normally a narrow band encircling modern lakes	mottled	pinks, blues and buffs	/	/	/	Line 9, #164
varied depending on composition of deposit; wetlands common in lower lying areas, shrubs and forest cover increase upslope reflecting increased grain size and better drainage conditions	normally flanks major upland areas; extending from a thin glaciolacustrine veneer at higher elevations gradually thickening downslope until completely obliterating the underlying topography	nearly uniform; may appear mottled when overlying hummocky moraine	pinks, blues, and buffs	-	/	/	Line 11, #102
forest cover increases, wetlands decrease	normally flanks upland areas; extends from a very thin glaciolacustrine cover gradually thickening downslope	mottled	pink to red, varied depending on vegetation cover	-	/	/	Line 11, #99
generally significant variation between vegetation on ridges (often pine) compared to surrounding material (indicative of higher sand content and better drainage on ridges)	frequently occur in series of parallel curving ridges over glaciolacustrine veneer	speckled	variable dependent on extent and type of vegetation cover (red, dark red, white)	/	/	/	Line 11, #100
variable; forested knobs, fens and bogs in depressions; vegetation patterns reflect different local drainage conditions	normally associated with uplands areas (ex. Birch Hills, Muskeg Mountain)	mottled	red to dark red on knobs, buff to blue or pink in depressions	-	/	/	Line 11, #94
variable; forested knobs, fens and bogs in depressions; vegetation patterns reflect different local drainage conditions	normally associated with upland areas (ex. Birch Hills, Muskeg Mountain)	mottled	red to dark red on knobs, buff to blue or pink in depressions	-	/	/	Line 11, #109
variable; forested ridges, bogs and fens in parallel depressions	upland areas	mottled	red to dark red on ridges; buff to blue or pink in depression	/	/	/	Line 7, #73

Continued . . .

Table 3. Continued.

	SYMBOL	TOPOGRAPHY	DRAINAGE	EROSION
<u>LACUSTRINE</u>:	L	gently inclined level surface of variable extent	dependent on composition; boggy if high clay content	resistant
<u>GLACIOLACUSTRINE</u>:				
Glaciolacustrine blanket	L_b^G	normally gently inclined mantle of variable extent obscuring underlying topography	dependent on composition; internal if sands and silts dominant; a high clay content impedes drainage resulting in bogs and ponds	deflation if high sand c tent; parallel gullies c on inclined blanket
Glaciolacustrine veneer	L_v^G	thin cover of glaciolacustrine sediments only partially obscuring underlying topography; surface expression still reflects underlying topography to some extent	varied, partially dependent on underlying topography	series of parallel gulli descend downslope throug upland tills over veneer towards major drainage channels
Beach ridges and abandoned shorelines		gently curving ridges of varied length and height frequently following contours;often occur as a series of parallel ridges	internal	eolian activity winnows finer sands and silts; c sands remain as a lag de
<u>MORAINE</u>:				
Hummocky moraine	M_h^G	irregular sequence of slopes; knobs and depressions common	erratic drainage; knobs generally better drained, numerous bog-filled depressions, permafrost impedes subsurface drainage in some areas	deflation and some dunin sandy till
Undulating moraine	M_u^G	regular sequence of gentle slopes, knobs, and depressions with little local relief	erratic drainage; knobs generally better drained, numerous bog-filled depressions, permafrost impedes sub-surface drainage in some areas	deflation and some dunin sandy till
Ridged moraine (washboard moraine)	M_r^G	series of parallel ridges and elongate depressions within reworked till	drainage follows parallel elongate depressions, bogs common	deflation and some dunin sandy till

* / suitable scale
  - unsuitable scale

Table 3. Continued.

	SYMBOL	TOPOGRAPHY	DRAINAGE	EROSION	VEGETATION	LOCATION	PATTERN	COLOUR	SCALE* 1:15,000	1:30,000	1:60,000	EXAMPLE (FLIGHTLINE, FRAME NO.)
MORAINE: Contd.												
Glacial grooves and flutings		parallel ridges with elongate depressions between ridges	drainage follows parallel elongate depressions, bogs common	minor amounts of gullying along ridges	variable; forested ridges, bogs and fens in parallel depressions	upland area	mottled	red to dark red on ridges; buff to blue or pink in depression	/	/	/	Line 7, #73
Crag and tail		streamlined ridge paralleling direction of ice movement; occur in clusters	external along crag, internal within tail	short V-shaped gullies	heavily forested	till covered uplands	uniform	red to dark red	/	/	-	Line 7, #73
Drumlin		elliptical ridge of varying width, height and length; often occur in groups with long axis paralleling direction of ice movement	internal; occasionally boggy between groups of drumlins	some gullying along edges	heavily forested	till covered uplands	uniform	red to dark red	/	/	-	
EOLIAN:												
Eolian blanket	E_b	generally flat surface of varied extent obscuring underlying topography	modified dendritic pinnate or feather-like drainage	deep wide U-shaped gullies, vertical walled and flat bottomed; spaced at regular intervals along tributaries	heavily forested (generally pine); near vertical gully walls may remain unvegetated	varied; downwind from source of sand	uniform except for unvegetated gully walls	red to dark red; white on unvegetated slopes	/	/	/	Line 11, #103
Eolian veneer	E_v	thin layer of eolian sand and silt of variable extent partially masking the underlying topography	dependent on subsurface topography and stratigraphy	deflation if unvegetated, elsewhere fluvial activity dependent on underlying material	pine and reindeer moss common	varied; downwind from source of sand	stippled	dark red and white	/	/	/	
Sand dunes and hills		vary from regular to irregular mounds of sand of variable width, height and length	internal; little to no surface drainage, often boggy between dunes	deflation	pine and reindeer moss common on stabilized dunes	generally on gently sloping or level surface downwind from source of sand (frequently occur on sandy outwash plains)	uniform on unvegetated dune, vegetated dunes stippled	unvegetated dunes - white; vegetated dunes red to dark red stipples on white background	/	/	/	Line 8, #21
COLLUVIAL:												
Inclined colluvial	C_i	inclined unconsolidated material flanking a steeper slope and originating higher on that slope	dependent on composition of material	gullying common	varied depending on composition, slope and drainage; often forested	normally flank steeper slopes	usually uniform	varied; often red to dark red	-	/	/	Line 11, #103
Colluvial blanket	C_b	unconsolidated mantle of debris obscuring underlying topography	dependent on composition of colluvium; parallel gullies common	frequent occurrence of slumps and gullying	often forested; depends on composition of debris	normally downslope from unstable escarpment or steep slope	usually uniform	varied; often red to dark red	-	/	/	Line 10, #133

* / suitable scale

- unsuitable scale

Continued . . .

	SYMBOL	TOPOGRAPHY	DRAINAGE	EROSION	VEGETATION	LOCATION	PATTERN	COLOUR	SCALE* 1:15,000	1:30,000	1:60,000	EXAMPLE (FLIGHTLINE, FRAME NO.)
COLUVIAL: Contd.												
Colluvial veneer	C_v	thin mantle of unconsolidated debris partially obscuring underlying topography	dependent on underlying topography	gullying common	composition varied depending on slope and drainage; often forested	normally downslope from thicker colluvial blanket; only mantles underlying topography	usually uniform	varied depending on vegetation	-	/	/	Line 11, #103
Failing colluvial	C,F	inclined blanket of colluvial material with stair step topography due to frequent successive slumps	frequent ponding in rotated backedge of slump; elsewhere drainage dependent on composition of colluvium	numerous slumps	wetlands in depressed area at back edge of each successive slump, usually forested elsewhere	normally downslope from unstable escarpment or steep slope	patterned	depressions buff to pink to blue; remainder red to dark red	/	/	/	Line 7, #73
Slump		displaced mound of colluvium; rotated depressed back edge, raised outer lip, and smooth downward slope	drainage normally impeded in depressed back edge resulting in series of ponds	some gully development	wetlands in depressions, highly unstable slopes may remain unvegetated or vegetated by shrub communities, forested elsewhere	normally along steep escarpments, river banks, and areas of thick colluvial material	patterned	depressions buff to pink to blue; remainder red to dark red	/	/	/	Line 11, #103
Wetlands;	W	varied; size and shape dependent on depth and extent of organic cover; surface varies from level to slightly undulating depending on type of wetland vegetation included	erratic; moderately to severely impeded	occasional duning and deflation if the wetland occurs in a sandy area	bogs in very poorly drained areas, fens in areas with some drainage	variable; common in till, outwash, and glaciolacustrine material; found throughout the area	mottled	buff, blue-green to pink	/	/	/	Line 12, #81
Bedrock:	R	bedrock outcrop of variable size and extent	variable	some gullies	occasionally forested; unvegetated when exposed by a steep escarpment	normally found only in upland areas or exposed along deeply entrenched gullies or river channels	uniform	varied, dependent on presence or absence of vegetation cover; red to dark red, or grey	/	/	/	
Sinkhole:	⊙	funnel shaped, circular to elongate depression	may or may not contain water	NA	variable; series of vegetation rings reflecting increased moisture content toward centre of depression	often occur in linear bands reflecting subterranean drainage channel	NA	variable depending on vegetation	/	/	/	Line 9, #169
Kettle:	●	randomly spaced steep sided depressions with occasional water filled basin; circular elongate or deltoid; often bounded by abrupt break of slope	may or may not contain water, seepage common in coarse outwash	NA	variable; series of vegetation rings reflecting increased moisture content toward centre of depression	common in granular moraines, outwash plains and occasionally glaciolacustrine deposits; often occur in clusters	NA	variable depending on vegetation	/	/	/	
Steep escarpments:		sharp break in slope of variable extent; downslope direction indicated by points on line	dependent on composition of surficial material	slumping and gullies common	vegetation cover dependent on slope and composition of material along escarpment	often found in conjunction with entrenched river channels and slumps	NA	variable depending on vegetation	/	/	/	Line 10, #129

* / suitable scale

- unsuitable scale

3.3.4.5 Possibilities for larger scale mapping. Larger scale mapping of surficial geology enables small features to be mapped in greater detail. For example, gully shape can be more accurately determined through detailed larger scale coverage. Gully shape, in turn, provides important clues as to composition of the surficial material. Discrimination of textural characteristics for the overburden is important in considering a wide variety of economic factors, such as (Ross 1970: 8):

1. the variability of foundation conditions within an area likely to affect transportation corridors and mining operations;
2. potential borrow areas for sand and gravel;
3. slope instability likely to affect mining operations, or which might be affected by such operations;
4. surface drainage conditions requiring regulation or exhibiting disruption; and
5. subsurface drainage conditions requiring monitoring to avoid volume changes, contamination problems, etc.

In addition to more accurately inferring textural characteristics within the overburden, more specific landforms or features can be mapped at a larger scale. Such features include meander scrolls, recent oxbow lakes containing sizeable volumes of water compared to older oxbows substantially infilled by silts and clays, individual river bars, river terraces, erratics, individual sand dunes, and slumps. Extension of the legend to include anomalous moisture conditions, textural composition, aspect, and/or slope would clearly discriminate physical variations within the larger geomorphic units. Each of the above has direct effects on habitat and habitat variability.

This additional information might be included in an extended legend adapted to the system already utilized on the maps. For example, a telescoped unit might include the following information:

$$\frac{F_i^G p,\ 1D3}{SE\ 1}$$

where,

$F_i^G p$ = glaciofluvial outwash plain,

1 = less than ten metres local relief,

D = some deflation occurs,

3 = moderately coarse textured,

SE = southeast facing,

1 = slope less than 5%

The following example, located in Tp 101, R6, W4, in the northeast section of the AOSERP study area, illustrates the detail which may be mapped at larger scales. In the 1:60,000 coverage (Figure 10), a more extensive area is mapped, but detailed mapping of the sand dunes and river valley is impossible. The amount of detail included at 1:30,000 (Figure 11) increases, yet compared to mapping at a scale of 1:15,000 (Figure 12) the discrimination of features within the river valley particularly is unreliable. The 1:15,000 scale map illustrates modification of the legend to include greater discrimination of features. For example, oxbow lakes are subdivided on the basis of amount of sedimentation occuring since meander migration. "$F_l e$" indicates a very recently formed oxbow lake with minor reduction in size due to infilling. "$F_l i$", however, identifies oxbow lakes partially to nearly completely infilled. Such classification could be useful for analysis of local habitat conditions. Open water would be practically non-existent in an "$F_l i$" oxbow lake, diminishing the site's usefulness for waterfowl, for example, while "$F_i d$", would indicate an active stream channel blocked and flooded by the construction of beaver dams.

Larger scale mapping should not be completed instead of or at the expense of smaller scale mapping. The major geomorphological units within the study area include hundreds of hectares. Consequently, mapping entirely at a scale of 1:15,000 would prevent the researcher from gaining an appreciation of regional process variation. Using only the larger scale photographs,

Figure 10. 1:60,000 scale FCIR photograph and overlay showing mapping with surficial geology legend, Audet Lake area.

Figure 11. 1:30,000 scale FCIR photograph and overlay showing mapping with extended surficial geology legend, Audet Lake area.

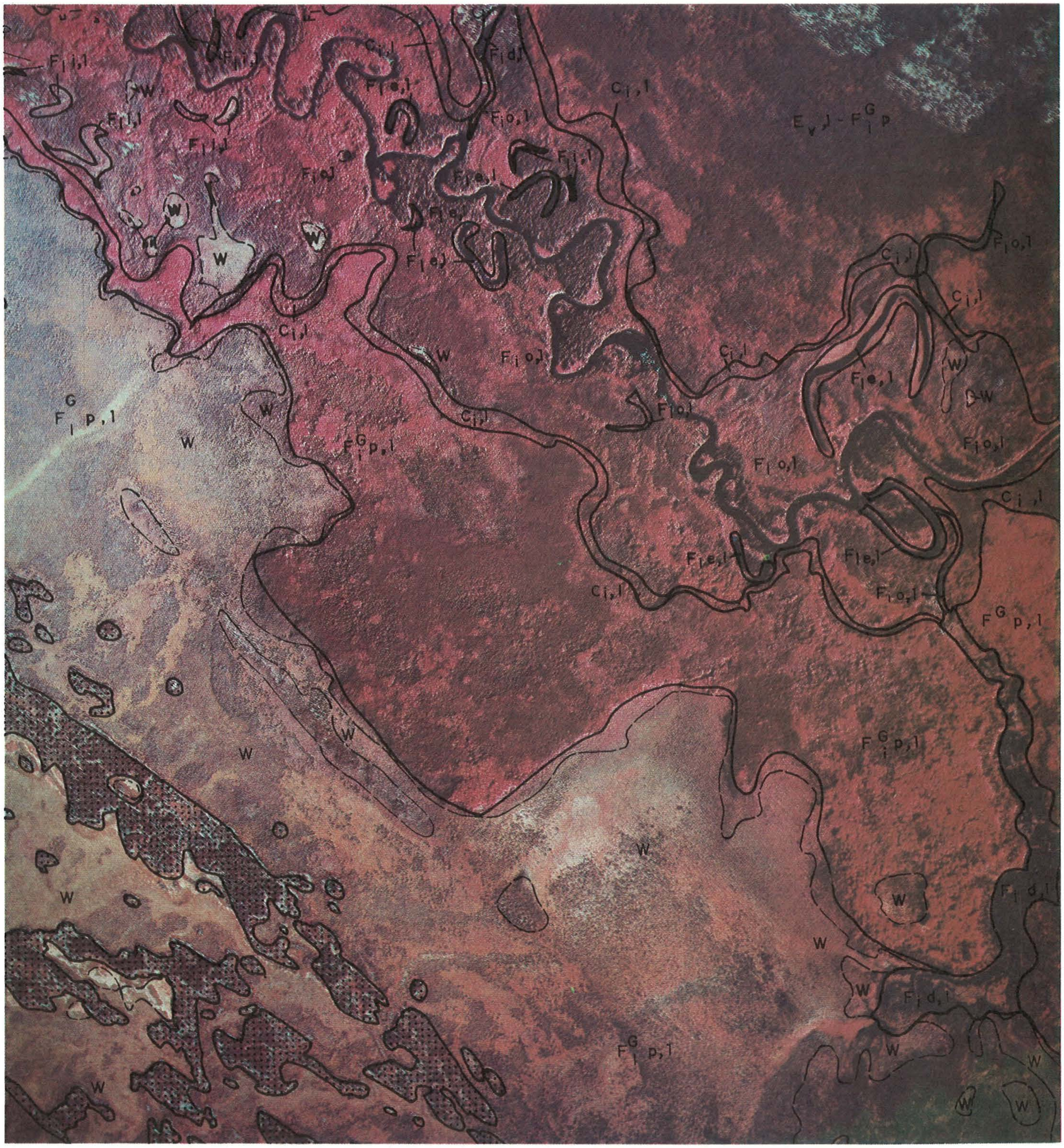


Figure 12. 1:15,000 scale FCIR photograph and overlay showing mapping with extended surficial geology legend, Audet Lake area.

small features could be recognized at the possible expense of acknowledging the predominant formation upon which these more localized features occur.

The ideal situation, therefore, would be to initially complete small scale reconnaissance mapping to discern the major units, conduct field checking in all questionable areas, then complete large scale detailed mapping for selected areas of economic, habitat, or other interest. To ensure a reliable final product field surveys must be conducted with any mapping from aerial photography.

3.4 DISCUSSION OF RESULTS

Prior to the preparation of ecological habitat maps, extensive discussions were held with AOSERP personnel, researchers working in the AOSERP study area on a variety of projects, and other scientists involved in environmental studies and in remote sensing, in order to establish the needs of such researchers for ecological working maps. Following a survey of the pertinent scientific literature, an approach to the preparation of the maps was devised which would satisfy the majority of users.

First the base maps for the study area were prepared, to provide topographic and locational information, in addition to cultural data updated to 1977. Two overlays were prepared for each 1:50,000 scale base map - one for vegetation and one for surficial geology. The legends for each were designed to be open-ended and to telescope, so that they could be later expanded for more detailed mapping of smaller more homogeneous areas within the AOSERP study area. A demonstration of this larger scale mapping has been included in this report, for both vegetation and surficial geology. Also included were photo interpretation keys, to assist other users of the FCIR photography in interpretation and analysis of vegetation, surficial geology and landforms. Thus a complete package is available to a potential user of the maps or photography -- the 1:50,000 scale base map, vegetation overlay and surficial geology overlay with complete legend description, plus the FCIR photography and a detailed photo interpretation key for analysis assistance. One caution must be noted here, as mentioned previously. All of the photo interpretation has been carried out without the aid of ground data, and thus must be utilized only on that basis. This situation will necessitate some field checking of the mapping during the next field season, in order to assess the accuracy of the results.

Map sheets where the primary coverage was obtained during the summer period, and where 1:50,000 scale base maps from NTS already existed were chosen for mapping first. Next were mapped those with primary summer coverage and no 1:50,000 scale NTS maps (their base maps were created from other sources, as described previously). Those with primarily October coverage were left to the last.

4. TERRAIN ANALYSIS IN THE AOSERP STUDY AREA

4.1 SURFICIAL GEOLOGY IN THE STUDY AREA

An overview of physiography in the study area was presented in Section 2. The following presents a more detailed description. The surficial geology of the AOSERP study area consists predominantly of glacially modified features. The impact of the several thousand feet thick Pleistocene ice sheet upon the pre-existing topography is obvious. Except for bedrock control of topography in upland areas, preglacial features are practically nonexistent.

Lowland areas include outwash, meltwater channel sediments, and recent alluvial deposits. Alluvial materials are primarily restricted to drainage channels, their associated floodplains, and alluvial fans. These fans commonly occur when a stream's gradient is reduced when entering a valley or lowland from the mountains. The gradient reduction reduces the stream's carrying capacity and deposition takes place.

Stratified outwash deposited by glacially-fed streams normally occurs below 305 m above mean sea level (a.m.s.l.). These deposits are characterized by outwash bars, terraces, and occasional kettleholes. Occasionally the outwash may show evidence of fluting indicative of a subsequent readvance. Numerous well-defined meltwater channels occur within the study area. Excellent examples occur east of Fort McMurray along the southern bank of the Clearwater River, and along the western bank of the Athabasca River. These channels generally occur below 312 m a.m.s.l., exhibit well-defined curving banks, and are frequently eroded into the underlying material, usually outwash. Within the channel banks, fine grained meltwater channel sediments occur. Because these areas are often poorly drained, channel sediments may be covered by considerable organic deposits of sphagnum and sedge peat.

As elevation increases along either side of the Athabasaca River Lowland, glaciolacustrine deposits are encountered. Likewise, south of the Clearwater-Athabasca junction, glaciolacustrine material flanks the lower slopes of Stony Mountain. The depth of the glaciolacustrine blanket decreases upslope gradually revealing more of the underlying topography. Relict beach ridges are frequently encountered indicating the extent of former glacial lakes. North of Gregoire Lake, for example, an entire sequence of parallel beach ridges occurs. The uppermost level for glaciolacustrine veneers varies from 427 to 442 m a.m.s.l. in the Birch Mountains to 488 m southwest of Fort McMurray. Beach ridges have been identified at elevations from 312 m to 511 m.

Upland areas such as the Birch, Muskeg, and Stony Mountains are normally capped by hummocky to undulating till of varying depth. Bedrock control is dominant in some areas, particularly the Birch Mountains. This nonsorted, nonstratified morainic material varies in depth from 31 m to less than 6 m. Extensive glacial fluting is common within the Birch Mountains.

Ice contact deposits, such as kames, eskers, and crevasse fillings occur thoughout the area. Thus far in the mapping only one esker has been identified within the study area. Numerous kames of varying extent, however, have been encountered. These vary from small individual conical mounds within hummocky till on Stony Mountain to the major kame complex comprising Fort Hills.

Throughout the area aeolian features could be identified wherever a supply of unconsolidated sand and silt was available (i.e. sandy outwash, sandy till). Sand dunes, sand hills, sand blankets and veneers, are typical in these areas, and were probably formed during deglaciation as the majority have stabilized.

Colluvial materials commonly occur along river channels, partially obscuring underlying floodplain deposits. This is particularly observable along the Clearwater and Muskeg River valleys. Elsewhere, the extensive vegetation stabilizes the surficial mantle reducing the likelihood of slumps along drainage channels. The steep eastern slopes of the Birch mountains exhibit extensive slumping, resulting in cover of these slopes by colluvial material. Rotational slumping of the upper slopes is evident from the series of large slump blocks present, while colluvial material extends over much of the area below as a more gently sloping colluvial apron.

4.2 VEGETATION IN THE STUDY AREA

As introduced in Section 2, the AOSERP study area is located in the Boreal Forest Region (Rowe 1972). Characteristic species are white and black spruce, but other principal tree species include balsam fir, jack pine, aspen poplar, balsam poplar and white birch. Following Rowe's classification, four subsections of this region are found in the study area: (1) Mixedwood subregion, (2) Upper MacKenzie subregion, (3) Athabasca South Subregion, and (4) Northwestern Transition subregion (Figure 3).

The Mixedwood subregion includes the major portion of the study area and is characterized by varying mixtures of aspen, poplar and white spruce. Major tree species present are aspen poplar, balsam polar, white birch, white spruce and balsam fir. This boreal forest has been termed a "disturbance" forest (North 1976). Consequently, although white spruce is the climax in most sites, aspen poplar is the cover type of greatest extent since it regenerates rapidly after disturbance (burning) (Moss 1955; Stringer 1976). Glaciation has resulted in undulating to hummocky morainic deposits on uplands and smoother, sloping glaciolacustrine deposits on lowlands. Gray luvisol is the characteristic soil (Rowe 1972).

The Upper MacKenzie subregion is found in the northern part of the study area, including the extensive floodplain of the Athabasca River and extending over the Peace-Athabasca Delta. Alluvial flats in this subregion are characterized by white spruce and balsam poplar while vegetation cover on upland areas is much more variable (North 1976; Rowe 1972; LaRoi 1967). Sandy soils are occupied by jack pine, aspen poplar and birch while black spruce and tamarack are found in moist to wet sites. South of Lake Athabasca balsam fir and birch become prominent. Soils developed on well-drained sites are characteristically gray luvisols and eutric brunisols, while immature profiles are usual on alluvium. Large areas of organic deposits are present (Rowe 1972).

The Athabasca South subregion is found in the eastern portion of the study area and is characterized by jack pine-dominated forest, with black spruce and tamarack becoming the principal tree species in moister, finer textured soil areas. White spruce, aspen poplar and balsam poplar are uncommon except in riparian locations, while white birch is sometimes found in association with jack pine. Soils are principally sandy, derived from sandstone bedrock by glacial action; podzols, gleysols and organic soils are also present (Rowe 1972).

The Northwestern Transition subregion is limited to the area north of Lake Athabasca in the extreme northeastern corner of the study area. Coniferous forest is characteristic of the subregion; black spruce is the most abundant species on all sites with white spruce becoming codominant on well-drained soils. Jack pine, aspen poplar, balsam poplar and paper birch are also present (Rowe 1972; LaRoi 1967). The Precambrian bedrock here has been glaciated, and the land surface is irregular with numerous lakes and small water-filled depressions. Because of its limited extent in the study area, and the absence of aerial photography for the Northwestern Transition subregion, it has not been included in the present mapping, nor has its vegetation or surficial geology been studied in detail.

Ten major vegetation types have been tentatively delineated for the study area by Stringer (1976). These types form the basis for the mapping classification used in the present study. This classification, as adapted from Stringer for interpretation from the available FCIR photography, has been described in detail above (Section 3.2.2). Since no ground truthing was possible for this study, forest communities could be identified only by the dominant species of the canopy and their relative cover percentages where this was evident from the photography.

Data on shrub and herb layers included in Section 3.2.2, as well as the species composition of the nonforested vegetation types, have been summarized from Stringer's work in order to give a more meaningful description of the major plant communities mapped.

4.3 INTEGRATION OF VEGETATION AND SURFICIAL GEOLOGY IN STUDY AREA

The following discussion considers the observed vegetation patterns as they are related to the surficial geology of the study area, since an appreciation of the environmental relationship of landform and vegetation is necessary for a fuller understanding of the ecosystems involved. The distribution of vegetation types is a function of the ecological requirements of the different plant species, and the site characteristics at various locations. These site characteristics include precipitation, temperature, soil moisture and texture, drainage, slope, aspect and parent material.

Superimposed on the vegetation patterns dictated by landform and climate are variations caused by disturbances. Although human activities such as logging do modify the landscape, the major disturbance in the boreal forest is fire (North 1976). Its occurrence at different times and places results in similar sites often supporting very different plant communities, depending on the stage of succession since the last fire. The climax community for much of the upland area, for example, would likely be white spruce forest, but pure white spruce stands are much less common than the aspen poplar or mixedwood communities which are stages of fire successional communities. Although fire affects the detailed pattern of vegetation which has been mapped, the spatial distribution of vegetation types is most closely related to the drainage and soil characteristics of the various landform units. Upland areas of different origin, such as glacial till, glaciolacustrine and outwash sediments, often give rise to similar soil types and vegetation.

In upland areas, gray luvisols have developed on all these materials when the parent material is medium to fine textured and moderately drained to well-drained. The dominant vegetation type here is the White Spruce-Aspen Forest, which is variable in character as described above (Section 3.3.3). Dominance of a particular tree species is related to burning and the stage of succession at any particular site, but is also affected by site variability. Black spruce, balsam poplar and balsam fir become more important on the moister sites (for example, in slight depressions or downslope on glaciolacustrine areas) which may be somewhat finer in texture and less well drained than other sites.

White spruce is dominant on undisturbed mesic sites both on the upland deposits mentioned and on drier portions of alluvial lowlands (river floodplain, glacial meltwater channel sediments and outwash). Forest present on the moister sites within the white spruce-aspen forest tends to become scrubby, with canopy cover decreasing. The understory also changes, with bog plants replacing feathermosses and horsetails (North 1976).

In the drier areas pine becomes more dominant, and is particularly evident in coarser, better drained portions of glacial till (which varies considerably in character from place to place). Some of these tills and most glacial outwash consist of sandy, coarse-grained deposits which are moderately drained to well drained and may form Brunisol soils under a varied forest cover (including the White Spruce-Aspen Forest, Mixed Coniferous Forest and Jack Pine Forest types). On sandy outwash, birch may become co-dominant with jack pine if the site is too dry for aspen poplar. Even the birch, however, is limited to the moister locations which are within the jack pine's range of tolerance. The jack pine forest is characteristically found on the driest and sandiest sites, including eolian deposits. Eolian deposits, being consistently dry and sandy, present the least variation with respect to vegetation site characteristics of the surficial deposits mapped and so are almost always covered (when vegetated) with open jack pine forest. The presence of such a forest does not necessarily indicate the presence of an aeolian deposit, however, since jack pine forest has been mapped on areas of glacial outwash and less frequently till, where sand is locally abundant. Individual features such as sand dunes and abandoned beach ridges are often accentuated by a vegetation type (usually pine) different from the surrounding area.

All of these forest types may be present in areas of great local variability such as ground moraine. Level or undulating ground moraine often provides primarily mesic sites, where the various forest types (mainly White Spruce-Aspen and Mixed Coniferous) can flourish. In areas of hummocky moraine, a wider variety of sites may be present in a small area, resulting in forest types being interspersed with wetland types. Jack pine, aspen and spruce may be found on well drained ridges with jack pine particularly common on areas of southern aspect, while the depressions between hummocks may be vegetated by fen and bog communities. Lacustrine deposits over undulating and hummocky moraine also produce extensive variations in cover, as the finer, often clay-rich glaciolacustrine sediments tend to have impeded drainage compared to the areas of coarser till found on hummocks. Many of the upland communities mapped as "Undifferentiated" are shrub, herb and/or grass communities located on areas of wet mineral soil. When these areas are extensive, they usually are found on nearly flat to moderately sloping areas of glaciolacustrine sediments, which consist of finer particles, primarily clays and silts, and are poorly drained. Local areas of shrub are found along drainage courses where soils are wetter than elsewhere on the slopes. Alluvial fans and other features where soil development is limited (regosols formed rather than the zonal soils) are often vegetated by shrub communities, including willow and alder species. The pattern of revegetation after burns superimposes another pattern of open areas on the study area, and makes correlation of open areas with landform features and drainage difficult. Again, similar sites may be very differently vegetated depending upon the fire history of each location.

Wetland vegetation types are found extensively throughout the study area. Large upland areas have gleysolic and organic soils where drainage is moderately to severely impeded and extensive bogs and fens have developed.

In order to understand the dynamics of wetland formation and the relationship of the different vegetation types with bogs and fens it is necessary to discuss some of the processes involved. Zoltai et al. (1975) found that bogs are formed under closed drainage. The bog surface is raised or level with the surrounding land and has a high water table. The surface waters and peat layers are acid and mineral deficient, and oxygen saturation is low. It is under these conditions that the surface sphagnum mosses grow. Black spruce and tamarack may or may not be present with a frequent layer of ericaceous shrubs.

Fens develop in restricted drainage situations with surface water that has a low level of oxygen saturation and few mineral nutrients. The fen surface is covered with sedges and a low to medium height shrub cover. Occasional stunted black spruce and tamarack may be present. On very low gradient slopes internal drainage may occur which can be observed on the surface of the fen as characteristic flow stripes in the direction of the drainage.

Wetlands can occur in valley areas such as the Muskeg River, which consists of flood plain and glaciolacustrine sediments, or on high plateaus such as the top of the Birch Mountains (mainly moraine areas). As noted above, hummocky moraine and glaciolacustrine sediments (particularly when the latter are found as a blanket or veneer) are often very variable in vegetation cover, with small wetlands occupying the frequent depressions. Drainage becomes impeded at the base of many sloping areas of glaciolacustrine sediments, and ponding may result in wetlands forming where drainage is most impeded. Extensive slumping along the steep slopes of the Birch Mountains has resulted in the formation of numerous small wetlands downslope and in depressions between slump blocks.

Areas of slightly better drainage, with gleyed mineral soils rather than organic soils, may occur on some sites or upslope of the wettest areas and are usually vegetated by shrubs ("Undifferentiated" vegetation type in the Upland class or "Deciduous Shrub" in the Bottomland Riparian class). Specific landform features such as glacial flutings on the Birch Mountains are characterized by complex vegetation patterns with wetland in the flutings in contrast with forest on the ridges. Many of the sand dune areas in glacial outwash, particularly along the Athabasca River Valley, consist of pine-dominated forest communities on the sand dunes with open bog and fen communities in the poorly drained depressions between dunes.

Bottomland and riparian communities are primarily confined to river flood plains and are of large areal extent, mainly along the Athabasca and Clearwater Rivers. Glacial meltwater channel sediments and glacial outwash also occur here, particularly along the Athabasca River, and are of such a similar character that they are often indistinguishable (MacPherson and Kathol 1977). The riparian forest found in these areas is dominated by mature white spruce in the mesic sites and by mature balsam poplar and white spruce in slightly wetter sites, while balsam fir, willow and alder may be present in all sites (North 1976). Variations in relief due to meander scars, terracing, and relict meltwater channels create adjacent sites with considerable variation in drainage characteristics, with the wetter areas being vegetated by deciduous shrub and even fens in the most hydric sites. Extensive flood plain and deltaic sediments in the extreme northern part of the study area form extensive, nearly flat areas with variations in vegetation mainly related to very small differences in elevation and consequently in drainage. These patterns have been studied in detail in the Peace-Athabasca delta (Dabbs 1971; Dirschl 1970, 1973; Dirschl and Dabbs 1977; and Dirschl et al. 1974).

It appears, then, that vegetation patterns are best related to the drainage and soil conditions provided by parent material and landform. The depositional origin of these materials and the large landform units of which they are a part (the major surficial geologic units mapped) are only indirectly evident from the overall vegetation distribution since the detailed vegetation patterns observed reflect the specific characteristics of soils and drainage. Sites with similar characteristics may be found in several types of surficial deposit.

5. MULTISPECTRAL AND MULTISTAGE REMOTE SENSING FOR HABITAT MAPPING IN THE AOSERP STUDY AREA

5.1 INTRODUCTION

The purpose of this section is the evaluation of multispectral and multistage remote sensing for ecological habitat mapping in the AOSERP study area. Multistage and multispectral remote sensing for biophysical resource inventory and analysis programs has been used over the past decade or more (Reeves 1975), but programs have increased in numbers, application, accuracy and efficiency since the launch of Landsat-1 in 1972. The use of satellite imagery added a new dimension to the multistage sampling approach for this type of inventory, as it provides a resource overview not possible with airborne remote sensing techniques. Kirby and van Eck (1977) provided a description of a general multistage remote sensing program, which may be applied to an environmental research program such as is being carried out in the AOSERP study area:

1. Landsat imagery is used to provide a synoptic view of the area for broad policy and planning;

2. Small-scale aerial photography (1:50,000 to 1:100,000) is used to prepare biophysical maps or photomosaics for more detailed analysis and interpretation of vegetation, surficial geology, hydrology and land use over the entire study area;

3. Large-scale aerial photographs are then used for sampling and mapping selected areas of importance or representativeness, to partially replace expensive and time-consuming ground surveys; and

4. Ground surveys of important biophysical parameters are carried out in selected areas of importance or representativeness, for verification in very detailed research areas or for broader surveys and mapping.

This type of multistage approach provides complete coverage of the study area at a reconnaissance level, more detailed coverage in selected areas of importance for research objectives or of particular representative characteristics, and ground data which is only collected where necessary. If properly planned, the entire system is efficient, comprehensive and cost-effective, and provides all of the required data. However, in order that the system will be properly planned to meet all of these objectives, it is first necessary to outline the data requirements, and then the relevant data which may be provided by each component (i.e. its sensitivity) of the remote sensing multistage system.

Equally as important as understanding the data which may be derived from each component of a multistage system is an evaluation of the possible components of a multispectral remote sensing system. Each feature on the earth's surface has particular radiation reflectance and emittance characteristics and as such its own characteristic signature is recorded on remote sensing imagery in different portions of the electromagnetic spectrum. Should any two features have the same signature in one part of the spectrum and a different signature in another part, it is only by examination of the second part or the two parts together that these features may be separated. Thus it may be necessary, for example, to be able to compare the appearance of a feature of interest in both FCIR photography and thermal imagery in order to correctly identify and map it. This is an example of multispectral remote sensing analysis. In any program in which mapping or monitoring of environmental parameters is required, there is likely no single remote sensor which can serve as the "best" tool for all parameters of importance. Mapping of vegetation, for example, may make best use of FCIR photography while mapping of soils may require black and white red band photography. In order that a remote sensing program may be planned to provide the best information for all biophysical features of importance to the objectives of the program, then the various remote sensors must be evaluated for their application to each of those features.

The purpose of this section, then, is the evaluation of multistage and multispectral remote sensing for ecological habitat mapping in the AOSERP study area. The sensors which will be evaluated in the multispectral studies are those used in the 1977 remote sensing data acquisition program (i.e. FCIR, colour, black and white infrared, black and white red band, and black and white green band photographs, and thermal infrared imagery) as well as Landsat analogue imagery (the four multispectral scanner bands--green, red and two infrared-- plus a colour composite image). For the multistage evaluation, four basic imagery scales are discussed (again, those available from the 1977 data acquisition program): the largest scale is 1:15,000, then 1:30,000, 1:60,000 and finally the Landsat imagery scale of 1:1,000,000. It should again be noted here that all of the interpretation and evaluation carried out in this section is done without the benefit of direct ground survey information (although some was used from other sources), and thus accuracies could not be checked. To partially cover for this lack, much of the evaluation has been based on examination of the scientific literature and previous experience with similar sensors and biophysical mapping.

Portions of this section have been covered in Section 3, under legend development and preparation of the ecological habitat maps from the 1:60,000 photography of the study area. This discussion is meant to summarize and synthesize the evaluation of all sensors and scales, rather than simply the FCIR photography as discussed in Section 3.

First, the ecological parameters considered to be important for habitat mapping in the AOSERP study area are described. Then the interpretation of FCIR photography at three different scales is discussed, followed by a discussion of analogue Landsat imagery and its visual interpretation. The multispectral and multistage evaluation is presented in a series of tables, using a simple ranking system for the value of each sensor and scale for mapping each parameter. Finally, the results of the evaluation are summarized.

5.2 ECOLOGICAL PARAMETERS FOR HABITAT MAPPING (INVENTORY) IN THE AOSERP STUDY AREA

In order to evaluate the utility of any remote sensing technique, it is first necessary to specifically define the type of information which is required for the problem at hand, i.e. for ecological habitat mapping in the AOSERP study area. Therefore, five major categories of biophysical information which could be mapped using remote sensing were identified: Vegetation, Terrain and Soils, Hydrology, Land Use, and Wildlife. Fish habitat is not as easily mapped from photographs as wildlife habitat; particularly in the case of small scale imagery. For this reason the emphasis of this report is on mammals and terrestrial birds and to a lesser extent water oriented birds. For the sake of brevity future general references to wildlife will include fish and birds. Within each of these categories, further specific parameters to be mapped have been identified. They are discussed in the following sections.

Four main parameters have been identified in the Vegetation category as being important for habitat mapping in the study area. The first is distribution of plant communities (species associations or even species where possible). A plant community is considered a grouping of plant species distributed in a pattern over the landscape and represents the most generalized mapping unit (Daubenmire 1968). Under individual species, it may also be possible to identify and map tree species, shrub species and grass species depending on the imagery type and scale. A second parameter is vegetation height, and a third vegetation density. Both of these have importance for evaluation of habitat in the area. Finally, wetlands classification has been included under vegetation, although it is a combination of both vegetation and terrain and soils. It is included here since in most cases classification of wetlands from remote sensing is based on the vegetation present. This is a very important parameter in the AOSERP study area, as wetlands cover such a large portion of the area and thus are an important habitat type. The detail at which they may be classified is strictly dependent on the scale of the imagery used, as will be evident in the evalution (S. C. Zoltai, Northern Forest Research Centre, DFE, personal communication re: Wetlands Mapping, December 1977).

The parameters considered important for mapping terrain and soils in the study area are generally those included in the surficial geology legend and discussed completely in Section 3. These include landforms, genetic material, relief, aspect and surface expression. Although soils have not been mapped under this contract, nevertheless they have been included as being important for habitat mapping. They are currently being mapped under contract for AOSERP by the Alberta Research Council. Finally, location of construction materials has been included since it is important for industrial and other development in the study area and requires the identification of specific features (beach ridges, eskers).

Hydrologic parameters which are important for habitat mapping fall into two main divisions: location of water courses, lakes, and other drainage features, and classification of lakes, streams, ponds, springs, impoundments, seeps, etc. Both divisions are also important for evaluation of aquatic habitat.

Land use in the study area has been divided into five main parameters which may be mapped with remote sensing. The first is linear features, which include roads, railways, seismic lines, pipelines and trails. Second are urban areas (towns, villages and hamlets, their residential and commercial areas, plus airports or airstrips). Industrial areas include plant sites (whether oil sands plants such as GCOS or Syncrude, or smaller sites near or in urban areas), campsites for oil sands industry or forestry, and any other evidence of industrial location. Recreation facilities include campsites, cottage areas, parks, boat launching facilities, ski areas, picnic areas, historic sites, outdoor pools, and any other facility which may be recognized on the remote sensing imagery. The final parameter is that of logging disturbance, a type of land use indicative of the presence of the forest industry. It is generally seen as a particular pattern of tree clearing, and is an on-going process in the study area.

Wildlife and fish in the study area may be mapped indirectly (as in this project) in terms of their habitat (terrestrial or aquatic) or directly by census of the population (not done in this project). In the case of aquatic habitat, four parameters have been identified for mapping. The first is the presence of emergent vegetation on lakes or ponds, as it indicates conditions for water fowl staging or nesting, and habitat for semiaquatic mammals. The second is lake and pond depth, an indication of the capability of the waterbody to support fish and fish predators and of limitations for overwintering fish populations. Third is the stage of eutrophication (state of enrichment of lakes or ponds as seen by algae blooms), which is related to capability to support fish and fish predator populations. Finally, the presence of rapids and spawning areas indicate resting areas (open in spring) for early waterfowl migration, habitat for salmonids, and support for fish predator populations.

In addition to these parameters, the previously mentioned hydrologic parameters of stream and river size as well as the degree of waterbody shoreline irregularity are of value in aquatic habitat mapping.

For terrestrial habitat, the vegetation species or species associations present are important and may be mapped with remote sensing. Also important are the successional stages of the vegetation, as local terrestrial faunal species are distributed largely as a function of successional stages of vegetation. For example, food requirements for moose are enhanced in early successional stages (post-burn, logged areas). The juxtaposition of habitat types is also important in habitat mapping. The numbers and distribution of terrestrial species are largely functions of the degree of habitat interspersion or spatial relationships of the basic requirements of food, cover and water.

For census or estimation of wildlife and fish populations with remote sensing, it is likely that only three types may be assessed. The first is waterfowl on waterbodies, primarily ducks and geese (Heyland 1972, 1973). The second is census of ungulates which may be done in certain areas under special conditions (Wride and Baker 1977). The third, census of beaver, may be carried out indirectly through census of active beaver lodges.

5.3 EVALUATION OF REMOTE SENSING TECHNIQUES FOR ECOLOGICAL HABITAT MAPPING

5.3.1 Multistage FCIR Photographs

In Sections 3.3.3 and 3.3.4, examples were presented of mapping of vegetation and surficial geology at two and three different scales of FCIR photography. The purpose of that demonstration was to illustrate the capability of both legends to be open-ended, i.e. to be expanded or contracted depending on the level of detail required in the mapping. The discussion of those examples will not be repeated here; however, it should be noted that they also indicate the sensitivity of remote sensing imagery (in this case FCIR photography) for mapping, depending on its scale. At a scale of 1:60,000, for example, units of vegetation, surficial geology, or any other parameter, may be mapped to a size of approximately 14 hectares (400 m^2), while at a scale of 1:15,000 units may be mapped to a size of approximately 1 hectare (100 m^2). The "sensitivity" of the mapping depends on conditions at the time of data acquisition (e.g. cloud, atmospheric attenuation), film condition, processing of the film, and other physical factors. Another important factor is simply the width of the line to be drawn around the unit; theoretically no unit smaller than a dot can be mapped, although it may be seen on the imagery. Practically, only a unit which can be mapped and labelled in some way should be defined.

In almost every remote sensing interpretation program, more information is seen on the image than can be physically mapped. This can be seen in Figures 7, 8, 10, 11 and 12 and is also obvious in the following description of interpretation of Landsat imagery. Thus, a definition of sensitivity according to scale is somewhat arbitrary.

5.3.2 Discussion of Landsat Imagery for Ecological Habitat Mapping in the AOSERP Study Area

The following section discusses the utility of Landsat imagery for ecological habitat mapping in the AOSERP study area, based on conventional photo interpretation of analogue imagery. The imagery used for this analysis was from July 1975, and included all four standard bands, plus a colour composite image.

Because descriptions of Landsat, its various data products, and all of its characteristics are found in many other reference sources (Harper 1976; NASA 1975) they will not be repeated here. However, it should be noted that the imagery used in this analysis represents the following spectral bands:

Band 4	0.5 to 0.6 micrometres (green)
Band 5	0.6 to 0.7 micrometres (red)
Band 6	0.7 to 0.8 micrometres (infrared)
Band 7	0.8 to 1.1 micrometres (infrared)
Band 8	colour composite from Bands 4, 5 and 7

In order to test the utility of the Landsat analogue data products for habitat mapping in the AOSERP area, a number of images were evaluated for their technical quality before a final selection was made. An image taken on July 10, 1975 was chosen and positive transparencies of Bands 4 to 8 were obtained, at their original scale of 1:1,000,000. Interpretation of the transparencies was carried out using conventional photo interpretation techniques, as described below.

Since the habitat mapping from 1:60,000 scale FCIR photographs completed first during this project covered the area around the Athabasca River valley, a portion of the Landsat image between the latitudes of Gregoire Lake and McClelland Lake and along the valley was selected for interpretation. Each band was studied separately by first outlining areas on the image with similar spectral characteristics. Once the interpretations for each band had been completed, a comparison of the results was made to see which features or habitat types could be discerned in the various bands. Finally the interpreted images were compared with the larger scale (1:50,000) habitat maps previously completed.

As the interpretation of the imagery progressed from one band to the next, it became apparent that there was a significant difference between recognizable features in the two visible bands (4 and 5) and the two infrared bands (6 and 7). For example, due to the attenuation characteristics of the intervening atmosphere, Band 4 exhibited very little contrast between the habitat classes. Most of the features appeared flat in tone except in areas of high activity where the vegetation had been stripped away (near the townsite of Fort McMurray and around the Syncrude plant). Water sediment patterns were also quite apparent in Band 4.

The information that could be mapped from the Band 5 image was very similar to that from Band 4, with an improvement in contrast due to the reduced effect of the atmosphere. Both of the infrared bands proved to be significantly better in terms of their contrast characteristics. The boundaries between the habitat classes were clearly defined, especially land/water interfaces. In some cases, it was possible to identify water-filled kettle and sink holes. However, it was not possible to delineate in the infrared imagery areas of man-made disturbances where the vegetation and humic overburden had been removed.

The colour composite band (Band 8) was by far the most useful image, since it combined the spectral characteristics from three of the individual bands. An evaluation summary of the identifiable features from the analogue Landsat imagery is presented in Section 5.3.3.

Perhaps the most significant limitation related to interpretation of the analogue imagery is its small scale (1:1,000,000). Even though it is possible to distinguish the various boundaries between the categories, this scale is too small to allow all of the classes which can be identified to be mapped. When the imagery was optically enlarged, however, the possibilities for habitat mapping became greater.

Another limitation with Landsat imagery is the problem of obtaining cloud free images. Although the imagery is available on an 18 day cycle, many of the satellite passess do not produce usable information as the area is obscured by cloud. This constitutes a significant loss of data and limits the application of Landsat as a tool in the AOSERP study area.

Future use of the analogue Landsat imagery should involve photographically enlarged imagery at scales of 1:500,000 or 1:250,000. Even though these enlargements are more expensive than the 1:1,000,000 scale imagery (they may cost twice as much), the utility of the analogue product would be proportionally increased since the delineation of the habitat class borders is much easier. The loss in resolution of the enlargements would not significantly degrade the interpretability of the data. The interpretation of enlarged images should be conducted in combination with the small scale transparencies of the same area.

The results of habitat mapping done on an enlarged (1:500,000) portion of the Landsat image are shown in Figure 13. Original mapping for the overlay was done on the positive transparency rather than the colour composite print; since considerable detail is lost in printing, future mapping should also be done on transparencies. Visual interpretation of the image resulted in the various areas outline, which could then be compared to vegetation types mapped in the area from the FCIR 1:60,000 photographs.

While Landsat imagery appears valuable for mapping certain forest types, its use in delineating all vegetation classes is somewhat limited. Mature deciduous and coniferous forest stands could be distinguished clearly on the Landsat image as areas of bright red and dark brown respectively. Other vegetation types were more difficult to separate. Mixedwood forest was sometimes identifiable, but could be confused with coniferous or deciduous shrub types, as all of these appear similar in tone. The most severe limitation in using Landsat imagery for mapping habitat in the AOSERP study area is that wetlands are not readily distinguishable at this scale. Although the more extensive areas of wetlands become apparent on close examination of the image and very large fens and open muskeg areas can be mapped, much of the study area consists of complexes of small wetlands and intervening uplands. None of these areas were discernible on this image.

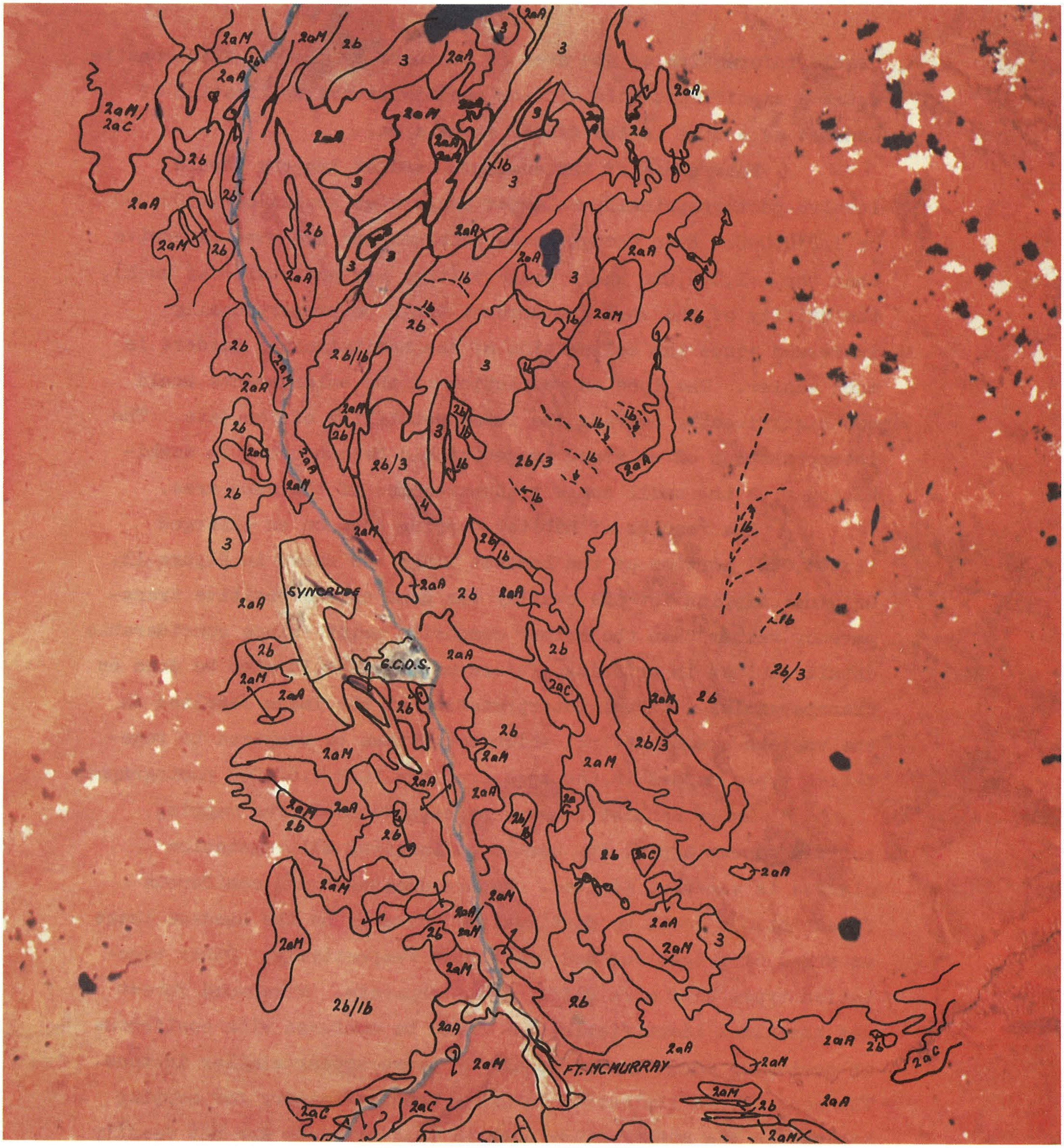


Figure 13. 1:50,000 scale LANDSAT colour composite image (bands 5, 6 and 7 combined) of central portion of AOSERP study area.

Interpretation is complicated by the fact that variation in tonal value is not only related to changes in vegetation type from place to place but appears to reflect different successional stages as well. Repeated burning of the study area has resulted in large areas of the present forest being at various stages of regrowth. Many areas distinguishable on the FCIR photographs (1:60,000) as stands of the same vegetation type but of different height classes appear on the Landsat image as areas of different tone. Thus, if lines were drawn to separate areas on the basis of tone on the Landsat imagery, many of these would be fire boundaries rather than boundaries between different forest types.

If visual interpretation of analogue imagery is to result in accurate vegetation mapping, it would be preferable to do a multidate analysis of imagery from summer, fall and winter. Deciduous forest can be readily distinguished on summer imagery, while fall imagery (after senescence of deciduous tree species) would show coniferous and mixedwood stands most clearly and winter imagery (assuming adequate snow cover) would be most useful for delineating unforested areas, particularly sedge wetlands. Lightly forested bog and open muskeg might also become apparent. While summer imagery alone may be insufficient to accurately delineate vegetation species, the data provided on successional stages of forest stands could be valuable for wildlife researchers interested in the productivity of various stands, since this is related to the stage of succession. This use would be applicable only for larger areas, however.

From the analogue Landsat evaluation it is apparent that the imagery is limited in its utility as a mapping tool at a scale of 1:1,000,000. However, the comprehensive overview of the study area that is provided by the imagery is especially useful for gaining insight into the associations between larger features such as lake and river systems, surficial geology, and vegetation distributions. Upon close examination of the imagery, it was possible to identify a number of smaller features in greater detail.

Water courses, lakes, ponds and water-filled sinkholes were quite visible in Bands 6, 7 and 8. The effects of construction and industrial activity along the banks of the lakes and rivers can be seen as sediment patterns in the water bodies in Bands 4, 5 and 8, with some evidence in the infrared bands where the concentrations were heavy.

Since the chlorophyll in vegetation reflects infrared radiation, Bands 6, 7 and 8 were very useful in delineating the boundaries and distribution of plant communities. Information regarding species associations and species could be gathered, provided the areas were large enough. Height-related data could not be collected, but some indications of vegetation density were seen. Wetland vegetation was visible when the vegetation communities were above the surface of the water and were large enough for delineation. Vegetation disturbances such as fires, construction and oil sands operations were apparent in Bands 4, 5 and 8, but were almost totally unrecognizeable in the infrared bands.

Land use activities involving linear features (such as roads) as well as urban and industrial areas could be seen in Bands 4, 5 and 8, while recreation facilities could not be delineated (they are too small). Newly cleared areas were more apparent than regions previously disturbed in which the vegetation had a chance to grow to a more mature stage.

Terrain and soils could be identified primarily through association with the vegetation cover types. Landsat imagery is of little use for mapping surficial geology, since lack of stereo coverage and poorer resolution than other types of imagery make terrain features extremely difficult to identify.

However, in some cases it was possible to identify exposed bedrock and landforms. There were a few examples of erosion of top soil which exposed the underlying sand deposits. Evidence of slumping could be seen along the sides of the Athabasca River valley. Soil moisture anomalies were not visible. However, with the inclusion of a thermal band on Landsat-C (to be launched March 5, 1978), it should be possible to identify large regions of wet soils as well as heavily vegetated bogs.

Finally, a comparison of the Landsat bands with some of the other multispectral data products was conducted and is discussed in Section 5.3.3. Perhaps the predominant difference between the data products was related to scale. Since the Landsat imagery was very small in scale compared with the multispectral airborne data, the level of detail was significantly different as would be expected.

5.3.3 Evaluation of Remote Sensing Techniques for Ecological Habitat Mapping in the AOSERP Study Area

In order to carry out the evaluation of the multiband and multistage remote sensing imagery for ecological habitat mapping in the AOSERP study area, three tables were prepared. Each makes use of a simple ranking system of four choices, indicating the application of the sensor to the parameter to be monitored.

Rank	Description
1	very valuable
2	valuable
3	of some value
4	of little or no value

Such a ranking system is subjective, but is the most systematic method of evaluation short of actual imagery interpretation, ground checking the results, and deriving estimates of mapping accuracy. This latter was of course not possible in this particular study. The rankings assigned within the tables which follow and discussed in the following pages are based on (1) examination of the AOSERP imagery from 1977; (2) examination of the pertinent scientific literature; and (3) previous experience with each sensor and its application to the parameter to be monitored.

Table 4 presents the evaluation of each remote sensing technique (five types of photography, thermal infrared imagery, and five Landsat bands) as applied to each selected ecological

Table 4. Evaluation of photography, thermal imagery and LANDSAT bands for ecological habitat mapping.

	PHOTOGRAPHY (1:60,000 Scale)					THERMAL IR	LANDSAT (1:1,000,000 Scale) Bands				
	FCIR	Colour	B/WIR	Red Band	Green Band	Altitude AGL 4600 m	4	5	6	7	8
VEGETATION											
Distribution											
Plant Communities	1	2	2	3	3	3	4	4	3	3	2
Species	2-3	3-4	3-4	3-4	3-4	4	4	4	4	4	4
Height	2	2	2	2	2	4	4	4	4	4	4
Density	2	2	3	3	3	4	4	4	4	4	4
Wetland Classification	2	2	3	2	3	3	4	3	2	2	2
TERRAIN & SOILS											
Surficial Geology											
Landforms	1	1	1	2	2	3	4	4	3	3	3
Genetic Material	1	2	3	1-2	3	3	4	3	4	4	4
Relief	1	1	1	1	1	4	4	4	4	4	4
Aspect	1	1	1	1	1	4	4	4	4	4	4
Surface Expression	1	1	1	1	1	3	4	4	3	3	3
Soils	2	2	3	1-2	3	3	4	4	4	4	4
Construction Materials	2	2	3	1-2	3	4	4	4	4	4	4
HYDROLOGY											
Location of water courses, lakes	1	2	1	2	3	3	3	3	2	2	2
Classification of lakes, streams, etc.	2	2	3	2	2	3	4	3	3	3	3

Continued ...

Table 4. Concluded.

	PHOTOGRAPHY (1:60,000 Scale)					THERMAL IR	LANDSAT (1:1,000,000 Scale) Bands				
	FCIR	Colour	B/WIR	Red Band	Green Band	Altitude AGL 4600 m	4	5	6	7	8
LAND USE											
Linear features	1	2	2	1	1	2	3	3	4	4	2
Urban areas	1	2	3	1	1	3	3	3	4	4	2
Industrial areas	1	2	3	1	2	3	3	3	4	4	2
Recreation facilities	2	2	3	2	3	3-4	4	4	4	4	4
Logging disturbance	1	1	3	1	2	3	4	4	2	2	2
WILDLIFE											
Aquatic Habitat											
Emergent vegetation	2	2	2-3	3	3	4	4	4	3	3	3
Lake and pond depth	2	2	3	3	3	3	4	4	3	3	3
Stage of eutrophication	3	2	2	2	2	3	4	4	3	3	3
Rapids, spawning areas	3	3	3	3	3	4	4	4	4	4	4
Terrestrial Habitat											
Vegetation species or communities	2	2-3	3	3	3	3	4	4	3	2	2
Successional stages	2	2-3	3	3	3	4	4	4	4	4	3
Juxtaposition of habitat types	2	2	3	3	3	3	4	4	3	3	3
Waterfowl on waterbodies	4	4	4	4	4	4	4	4	4	4	4
Census of ungulates	4	4	4	4	4	4	4	4	4	4	4
Beaver lodges	1	1	2	2	2	3	4	4	4	4	4

1 very valuable 3 of some value
2 valuable 4 of little or no value

parameter (Section 5.2) using the ranking system. It should be noted that it has been assumed that all of the photography is at a scale of 1:60,000 (a suitable reconnaissance-level photo scale which was available for all photo sets), that the thermal imagery is at a similar scale of about 1:60,000 (obtained at about 4600 m above ground level), and that the Landsat imagery is at the original scale of 1:1,000,000. It is also assumed that all of the remote sensing imagery was obtained during the summer period under similarly good conditions, and that there is stereo coverage for all photography (this is of course not possible for thermal imagery or Landsat imagery).

For mapping of the distribution of vegetation, FCIR photography appears to be the best for plant communities, although colour and black and white infrared are also good. For mapping individual species, however, at this scale none of the techniques are very valuable, but FCIR photography is better than the rest. Landsat Band 8 appears to be valuable for mapping plant communities on a rather gross scale. Vegetation height may be mapped equally well with all of the photographic techniques, as stereo coverage is available, while thermal imagery and Landsat imagery are not useful for this purpose. Vegetation density may be mapped best with FCIR and colour photography. Wetland classification may be carried out to a certain extent extent with FCIR, colour and red band photography, and at a grosser scale with Landsat Bands 6, 7 and 8.

For terrain and soils parameters, in general most of the photographic sensors are more useful than the thermal or Landsat imagery. FCIR photography appears to be best overall, although colour photography and red band photography are nearly as valuable. In most cases, the lack of stereo coverage and less resolution in the thermal imagery and the Landsat imagery hampers the use of these remote sensing techniques for such parameters as relief, landforms, aspect, surface expression, construction materials and genetic materials.

Under Hydrology, there is a relatively wide variety of 'best' sensors as applied to the two parameters. FCIR and black and white infrared photography are the most valuable for simply locating and mapping drainage courses, lakes and other hydrologic features. However, classification of such features may be carried out with several types of photography in many cases. Thermal imagery is of some value for both parameters, while Landsat imagery in Bands 6, 7 and 8 (those involving the infrared) is valuable in some cases.

For mapping land use parameters, FCIR and red band photography are generally the most valuable. However, since recreation facilities are usually fairly small features, they require a slightly larger photo scale in order to be mapped accurately. Thermal infrared imagery is valuable for mapping linear features such as roads, because of the thermal contrast between them and their background. The same is true for the other land use parameters, but the value of thermal imagery for identifying and mapping these is reduced because of its low spatial resolution at this scale. Landsat is of some value for mapping land use features where they occur on a relatively gross scale, and in particular Bands 4 (green), 5 (red) and 8 (colour composite) are useful for these features. None of the Landsat bands is valuable for mapping recreation features as they are usually too small to be resolved.

For the many wildlife parameters, it appears that FCIR and colour photography are the most valuable remote sensing techniques. They are valuable for identification of terrestrial and some aquatic habitat categories, although at this scale mapping of rapids and spawning areas may be difficult. For these aquatic and terrestrial habitat parameters, thermal imagery is of some value, as are the Landsat Bands 6, 7 and 8. However, since analysis of habitat under these parameters is generally somewhat detailed, in many cases thermal infrared imagery and Landsat imagery cannot resolve the features of interest. For example, as seen in this table, no direct wildlife census may be undertaken with any of the sensors listed at these scales, since they simply cannot be resolved; however, indirect information can be resolved e.g. beaver lodges may be counted.

The second table (Table 5) evaluated two major airborne sensors (FCIR photography and thermal infrared imagery) for monitoring the selected ecological habitat parameters in terms of scale differences and differences in date of data acquisition. These are the two major data acquisition variables affecting the usefulness of the resultant imagery for ecological habitat mapping. For the evaluation, three different photo scales were chosen-- 1:60,000, 1:30,000 and 1:15,000. The reason for their choice is obvious, in that all three were acquired in the 1977 remote sensing coverage of the AOSERP study area, and were thus available for examination. For the thermal imagery, two imagery scales were evaluated-- that obtained at 9200 m above ground (approximate scale of 1:115,000) and that at 2300 m above ground (approximate scale 1:27,000). To illustrate seasonal coverage, imagery from the summer data acquisition period (July, August) is compared with that obtained in October. This applies to both the FCIR photography and the thermal imagery.

For mapping vegetation parameters, it can be seen that as expected the largest photo scale is the most valuable, since vegetation may be mapped in greater detail and with possibly greater accuracy at this scale. Individual species may be mapped (particularly tree species) at this scale, and in some cases shrub and even grass species. Although vegetation height may be determined at all scales, the accuracy becomes greater with increase in photo scale, as do estimates of vegetation density. Thermal imagery is of some value to no value for the above parameters, although its usefulness increases with scale. However, for vegetation height and identification of species, it has virtually no use. For classification of wetlands, the value of FCIR photography increases with scale while thermal imagery is of some value only, mainly because of its ability to distinguish wetlands from drier areas by their thermal properties. For

Table 5. Effects of scale differences and seasonal differences on FCIR photography and terrain imagery for ecological habitat mapping.

	FCIR PHOTOGRAPHY					THERMAL IMAGERY			
	Scale			July Imagery	October Imagery	Altitude AGL		July Imagery	October Imagery
	1:60,000	1:30,000	1:15,000			9200 m	2300 m		
VEGETATION									
Distribution									
Plant Communities	1	1	1	1	3	4	3	3	4
Species	3	2	1	1	2	4	4	3	4
Height	2	1	1	1	3	4	4	4	4
Density	2	1	1	1	3	4	3	3	4
Wetland Classification	2	1	1	1	3	3-4	3	3	4
TERRAIN & SOIL									
Surficial Geology									
Landforms	1	2	3+	1	1	3	3	*	*
Genetic Material	1	2	3	1	1	3	3	*	*
Relief	1	1	2	1	1	4	3	*	*
Aspect	1	1	2	1	1	4	3	*	*
Surface Expression	1	1-2	3	1	1	3	3	*	*
Soils	3	2	1	2	1	3	3	*	*
Construction Materials	2	2	2	2	2	4	3	*	*
HYDROLOGY									
Location of watercourses, lakes	1	1	1	*	*	3	1-2	*	*
Classification of lakes, streams, etc.	2	2	2	*	*	3	1-2	*	*

Continued ...

Table 5. Concluded

	FCIR PHOTOGRAPHY					THERMAL IMAGERY			
	Scale			July Imagery	October Imagery	Altitude AGL		July Imagery	October Imagery
	1:60,000	1:30,000	1:15,000			9200 m	2300 m		
LAND USE									
Linear features	1	1	1	*	*	2	1	*	*
Urban areas	1	1	1	*	*	3	2	*	*
Industrial areas	1	1	1	*	*	3	2	*	*
Recreation facilities	2	1	1	*	*	3-4	2	*	*
Logging disturbance	1	1	1	*	*	3	2	*	*
WILDLIFE									
Aquatic Habitat									
Emergent vegetation	2	2	1	*	*	4	2	*	*
Lake and pond depth	2	2	2	*	*	3	3	*	*
Stage of eutrophication	3	3	2	*	*	3	2	*	*
Rapids, spawning areas	3	2	1	*	*	4	3	*	*
Terrestrial Habitat									
Vegetation species or communities	2	1-2	1	1	3	3	3	3	4
Successional stages	2	1-2	1	1	3	4	4	4	4
Juxtaposition of habitat type	2	1-2	1	1	3	3	2-3	3	4
Waterfowl on waterbodies	4	4	4	4	4	4	4	4	4
Census of ungulates	4	4	3	4	3	4	3	4	3
Beaver lodges	1	1	1	2	1	3	2	3	2

* no seasonal difference
+ but 1 for small feature identification

1 very valuable
2 valuable
3 of some value
4 of little or no value

mapping vegetation, July imagery is more valuable in every case than October imagery. However, it should be noted that after deciduous leaf fall it is sometimes more useful to have October imagery for analysis of understory characteristics. The example is the recognition of coniferous understory in aspen forest, or mapping special communities such as juniper or bearberry. Also in the fall additional species identification may be done, as birch separated from aspen by branch colour. These types of special studies usually involve larger photo scales.

For terrain and soils, there is a reversal in the utility of large versus small scale photography. Many of the features involving landforms, genetic materials, surface expression, aspect and relief are of such large proportions and cover such an extensive area on the ground that the smaller scale photographs are more useful for the "overview" or reconnaissance approach used for mapping these features. Although finer detail may be mapped at the larger scales, in many cases such is not necessary. Some landforms in the study area (such as sand dunes) may be mapped in greater detail at a 1:15,000 scale, but in general the smaller scales are more useful. Thermal imagery is of little value for most of these mapping requirements, but in general the better resolution of the larger scale improves its value. For soils the larger photo scales are more valuable, since mapping soils requires great detail. Construction materials may be located at any scale. In most cases, for terrain mapping there is no appreciable difference in the value of imagery obtained in July or October. For soils mapping, however, it was felt that more detail could be seen in October when deciduous leaf fall had occurred and more of the ground surface was visible.

For hydrology, all photo scales are very valuable for locating drainage courses and lakes, and thermal imagery is also valuable at the larger scale. For classification of hydrologic features, all photo scales are valuable, while thermal imagery again is most valuable at the larger scale. There is no appreciable difference in the value of July or October imagery for mapping hydrologic parameters.

For mapping land use, generally all photo scales are valuable with simply more detail on the same features mapped at the larger scales. However, for recreation facilities which are usually smaller in size, the larger scales will help in recognizing and mapping the features. Thermal imagery is of some value for mapping land use features, because it records the usually large thermal contrast between man-made features such as roads, industrial sites and urban areas, and their usually vegetated surroundings. However, because of its lower resolution, it generally is less valuable than photography for this purpose. As with terrain and soils, and hydrologic parameters, there is no real seasonal difference in the value of the remote sensing imagery for land use mapping.

Finally, for identification and mapping of wildlife parameters, it may be said that the larger scales are usually more valuable as they provide greater detail and more accuracy in identification of variables. This is particularly true for smaller scale features such as rapids and spawning areas, identification of individual vegetation species or small habitat types, and successional stages in vegetation, which are important to the analysis of habitat. Thermal imagery, in most cases the larger scale, is valuable for mapping some of these parameters, such as emergent vegetation, stage of eutrophication of lakes and ponds, and juxtaposition of habitat types. Census of waterfowl cannot be carried out with any of these remote sensors or scales because a still larger photo scale is necessary. However, in some special cases ungulates may be identified on the 1:15,000 scale photographs. A more valuable remote sensing tool for this purpose is thermal infrared imagery. At the large scale some ungulates may be detected, particularly in the October imagery. However, ungulates may only be properly censused with remote sensing by using very large scale thermal imagery (flown at 300 m) obtained with snow cover on the ground to maximize the contrast between the animals and their background (Wride and Baker 1977). Beaver lodges may be censused at all scales of photography. For most of the above parameters, the July imagery provides the best mapping tool, particularly where mapping of vegetation is involved. However, for the aquatic habitat, in many cases there is no appreciable difference between the usefulness of the July and October imagery. The exception is census of active beaver lodges which are best censused for activity in the fall.

Table 6 summarizes the ranking scores from each of the five ecological categories for the different remote sensing techniques presented in Table 4 and for the different scales and dates of data acquisition presented in Table 5. These totals are presented only to give an indication of the relative rankings of each sensor, scale and date, but are by no means meant to provide the absolute answer for an ecological habitat mapping program. The lower the rank total, the higher the value indicated, since these totals are calculated from the ranking values 1 to 4, with 1 indicating the highest value. There are many important variables which have not been included in the discussion to this point. These include area of coverage, resolution, cost of coverage, method of interpretation and analysis, cost of interpretation and analysis, quality and accuracy of interpreted data, and many other factors, many of which will be discussed later.

The rank totals by sensor type (taken from Table 4) show that FCIR photography appears to provide the best overall tool for ecological habitat mapping at the scale of 1:60,000. Colour photography and red band photography are also of value, while black and white infrared and green band photography rank the lowest of the photographic sensors. However, it should be noted that the 'best' sensor varies according to the general category to be mapped. For example, FCIR photography appears to be the most valuable for vegetation, while both FCIR and red band photography are best for hydrology and land use. The red band photography appears slightly better than FCIR photography for terrain and soils. Colour photography appears to be the most valuable overall sensor for wildlife, slightly better than FCIR photography.

Table 6. Summary of ranked totals for ecological habitat mapping by sensor type, scale and season (From Tables 4 and 5) (smaller numerical values indicate higher value).

	PHOTOGRAPHY					THERMAL	LANDSAT				
	FCIR	COLOUR	BWIR	RED	GREEN	IMAGERY	4	5	6	7	8
Vegetation	9	11	13	13	14	18	20	19	17	17	16
Terrain & Soils	9	10	13	8	14	24	28	27	26	26	26
Hydrology	3	4	4	3	5	6	7	6	5	5	5
Land Use	6	9	14	6	9	14	17	17	18	18	12
Wildlife	25	24	29	30	30	35	40	40	35	34	34
TOTAL	52	58	73	60	72	97	112	109	101	100	93

	FCIR PHOTOGRAPHY					THERMAL IR IMAGERY			
	Scales			Season		Altitude (AGL)		Season	
	1:60,000	1:30,000	1:15,000	July	Oct	9200 m	2300 m	July	Oct
Vegetation	10	6	5	5	14	19	17	16	20
Terrain & Soils	10	11	16	9	8	24	21	-	-
Hydrology	3	3	3	-	-	6	2	-	-
Land Use	6	5	5	-	-	14	9	-	-
Wildlife	44	19-22	17	13	17	35	28	21	21
TOTAL	73	44-47	46	27	39	98	77	37	41

Thermal imagery at an approximately equivalent scale ranks lower in every case because of its relatively poorer spatial resolution and lower mapping accuracy. Landsat imagery at a 1:1,000,000 scale and with only analogue interpretation also generally ranks lower than either the photographic sensors or thermal imagery. However, it should be noted that these rankings would increase in general were enlargements of the Landsat imagery used for the interpretation, or other methods of analysis used. These are later discussed in Section 7. Among the Landsat bands, the colour composite Band 8 appears to provide the best overall information. In fact, it was the most valuable or among the most valuable for each of the five categories. Only slightly less valuable than Band 8 are the two infrared bands, 6 and 7. In every category except land use they rank higher than the two visible bands. For land use, however, Bands 4 and 5 generally show features very clearly, as described in Section 5.3.2.

The lower half of Table 6 indicates the rank totals for the various scales of FCIR photography and thermal imagery (as taken from Table 5) as well as for the two dates of data acquisition, July and October. Generally it may be said that the largest photo scale provides the most valuable data for ecological habitat mapping, although for the terrain and soils category the reverse is partially true (as explained above). For hydrology, it appears that there is little difference in the value of photo scale, as most features of importance may be mapped at all three scales. For thermal infrared imagery, the larger scale of imagery is the most valuable for mapping in all five cases. No real generalization may be made about the usefulness of seasonal imagery. For mapping parameters involving vegetation usually July imagery provides the most complete information, whereas for terrain and soils October imagery may be slightly more useful in that more of the ground surface may be seen after deciduous leaf fall. For the two remaining categories, hydrology and land use, there is no appreciable difference in the value of either July or October imagery.

5.4 DISCUSSION OF RESULTS

In this section, multispectral and multistage remote sensing has been evaluated for ecological habitat mapping in the AOSERP study area. Remote sensors included in the evaluation were those used in the 1977 data acquisition program: FCIR, colour, black and white infrared, red band and green band photography, thermal infrared imagery, and Landsat imagery (five bands). In addition to the comparison of these remote sensors with each other, a multistage dimension was introduced to the evaluation by considering FCIR photography at three different photo scales and thermal infrared imagery at two scales. Also imagery obtained at two different times of year was evaluated.

First, a number of ecological parameters under five major headings (vegetation, terrain and soils, hydrology, land use, and wildlife) were selected as important to habitat mapping in the AOSERP study area. Then the remote sensing techniques were evaluated. Actual mapping of vegetation and surficial geology at three photo scales, as demonstrated in Section 3, was discussed, as was the interpretation of Landsat analogue imagery at the 1:1,000,000 scale. Then, using a four-part ranking system, each remote sensor was ranked for its value in mapping the selected ecological parameters. The imagery at different scales and from different times of year were similarly ranked. A great many generalizations have been made in the interest of the vastness of the subject to be covered here, but an attempt has been made throughout not to oversimplify when possible.

On the basis of the rank totals, FCIR photography appears to provide the best overall tool for ecological habitat mapping, that generally more detailed and accurate mapping may be carried out at larger imagery scales, and that July imagery is preferred over October imagery. Among the Landsat bands available for analogue interpretation, the colour composite imagery provides the most valuable information. However, it is important to note that these are generalizations only, and that for different ecological mapping objectives, other sensors, scales and times of data acquisition may be more valuable.

These results do not differ from the general consensus found in the scientific literature. As an overall tool for ecological mapping, FCIR photography does provide the best information. Although the other remote sensors may be more useful for mapping some of the ecological parameters, in most cases the difference between their value and that of FCIR photography is minor. Other authors agree. Thie (1976) for example states that interpretation of small scale colour infrared photographs is the most effective method for biophysical classification. The study has also shown that even at a scale of 1:60,000 a great deal of very detailed information may be mapped from the FCIR photography. Most of the ecological data which should be mapped over the AOSERP study area to serve as a baseline for further work may be obtained from these photographs using standard aerial photo interpretation techniques.

Examination of larger photo scales has shown that much more detailed mapping may be carried out, but that in many cases this may not be necessary. For example, terrain may in many cases be better mapped from smaller scale photographs where a better overview of the landscape may be gained, and little value is seen in simply producing a larger scale map.

The value of large scale photographs is seen for use in more localized, intensive research programs where the mapping of small important areas must be carried out. These are used in conjunction with small scale mapping to provide the type of multistage approach recommended by such researchers as Kirby and van Eck (1977).

A brief comparison of the two dates of remote sensing data acquisition has shown that in general the time of peak foliage development is best for data acquisition. However, this applies mainly to the reconnaissance level photography for general ecological habitat mapping. For the more specialized, large scale, localized studies, there is a wide variety of "best" times of year to choose from. Ungulate census is best done in winter with snow on the ground, analysis of vegetative understory is best done in fall after deciduous leaf fall, some hydrologic studies are best carried out in spring immediately after breakup, census of active beaver lodges is best done in early fall, and so on. The conclusion is, then, that summer is best for reconnaissance-type photography acquisition, while time for specialized projects is best chosen on an individual basis.

The same is true for the scale of remote sensing imagery for specialized projects. Conifer regeneration may be mapped on fall photography flown at 300 to 600 m above ground, ungulates may be censused thermally from 300 m above ground, scanning for thermal effluent in rivers may be done at 600 to 2000 m, scanning of tailings ponds or dikes for leaks should be done around 400 m, mapping of sand dunes may be done from 2500 m, and so on.

Analysis of the Landsat analogue imagery at a scale of 1:1,000,000 has shown that it can be a useful tool for ecological habitat mapping. It can be used for a broad overview of the AOSERP area for any ecological parameters which are found at a large enough scale to be resolved and mapped accurately. These include vegetation associations, vegetation disturbance, drainage systems, terrain, and many types of land use. It is felt that the mapping may be better carried out at a larger scale, possibly from photographically enlarged analogue imagery. However, the real value of the Landsat imagery lies in its repetitive nature, so that it may be used as a unique tool for monitoring of environmental parameters and their change over time. This is discussed in Section 6 in detail.

6. REMOTE SENSING FOR ECOLOGICAL MONITORING IN THE AOSERP STUDY AREA

6.1 INTRODUCTION

The need for ecological monitoring of the biophysical environment in the AOSERP study area encompasses many important physical parameters as they are related to the effects of oil sands development on the environment. This need is specified by AOSERP as follows under the heading of Research Criteria:

> To assess and report on all physical, chemical and biological disruptions of the terrestrial ecosystems in the study area resulting from oil sands development (AOSERP 1977);
>
> To assess and report on all physical, chemical and biological disruptions of the aquatic ecosystems in the study area resulting from oil sands development (AOSERP 1977);
>
> To critically assess the relationship between people and the changing urban and natural environments of the region, including utilization of various resources by the population ...... (AOSERP 1977).

Although remote sensing will not identify all of the parameters necessary to provide a complete picture of the environmental changes resulting from oil sands development, nevertheless it does provide a unique perception of the spatial effects of disturbance on the physical environment as expressed by its spectral characteristics. The following section describes the various remote sensors which could be utilized for biomonitoring within the AOSERP study area and their application to its particular environmental problems.

Depending on the nature of the parameter to be monitored, there are various remote sensors which are applicable. The purpose of this section is to identify the particular parameters within the AOSERP study area and related to oil sands development which may be monitored with remote sensing. In order to do this, the characteristics of the natural and urban environments (vegetation, terrain and soils, hydrology, land use, and wildlife) must be taken into account and possible effects of development of the oil sands listed. Then those for which change may be monitored using a remote sensor are summarized, and the best remote sensing tool identified.

6.2 CHANGES IN VEGETATION, TERRAIN AND SOILS, LAND USE, HYDROLOGY, AND WILDLIFE IN THE OIL SANDS AREA WHICH MAY BE MONITORED USING REMOTE SENSING

Several reports have indicated the potential effects of oil sands development upon the environment, and much research is continuing for further understanding of the actual and potential effects upon vegetation, habitat, soils, topography, hydrology, atmosphere and people in both the immediate industrial development areas and their surrounding areas. Examination of these documents (e.g. Integ 1973) has shown that effects of oil sands development which could possibly be monitored using remote sensing techniques may fall into five major categories:

1. Vegetation
2. Terrain and Soils
3. Hydrology
4. Land Use
5. Wildlife (mammals, birds and fish)

In order to assess the value of remote sensing for monitoring changes in these categories, each has been sub-divided into more specific parameters (Table 7). The following describes these parameters and the manner in which oil sands development may be expected to affect them.

6.2.1 Vegetation

Various types of disruptions related to oil sands development may cause changes in the composition of the vegetation communities in the area over time, i.e. changes other than those related to natural succession. A second effect is disturbance of the vegetative cover, most often involving complete removal. This type of disturbance may be caused by natural or man-caused fires, logging, road building, or urban expansion, but the largest effect is likely to come from oil sands operations. These include

Table 7. Evaluation of photography, thermal imagery and Landsat bands for ecological monitoring.

	PHOTOGRAPHY (1:60,000 Scale)					THERMAL IR	LANDSAT (1:1,000,000 Scale) Bands				
	FCIR	Colour	B/WIR	Red Band	Green Band	4600 m AGL	4	5	6	7	8
VEGETAION											
Change in communities over time	2	2	2	3	3	4	4	4	3	3	3
Disturbance of vegetation	1	1	2	1	3	4	3	3	2	2	2
Reclamation/revegetation success	1	2	2	2	3	4	4	4	3	3	3
Stress in vegetation	2	3	2	3	4	3	4	4	3	3	3
TERRAIN & SOILS											
Erosion	2	2	3	1	2	4	4	4	3	3	3
Terrain failure	2	2	3	2	3	4	4	4	3	3	3
Soil Moisture Irregularities	2	3	3	3	4	3	4	4	4	4	4
Topographic changes	1	1	1	1	1	4	4	4	4	4	4
HYDROLOGY											
Drainage changes	1	2	1	2	3	3	4	4	3	3	3
Erosion	2	2	3	1	2	3	2	2	3	3	2
Water quality	2	1	3	2	2	2	4	4	3	3	3
Conduit Irregularities	3	2	3	3	3	2	4	4	3	3	3

Continued ...

Table 7. Concluded.

	PHOTOGRAPHY (1:60,000 Scale)					THERMAL IR	LANDSAT (1:1,000,000 Scale) Bands				
	FCIR	Colour	B/WIR	Red Band	Green Band	4600 m AGL	4	5	6	7	8
LAND USE											
Linear features	1	2	2	2	2	3	3	2	4	4	2
Urban areas	1	2	3	2	2	3	3	2	4	4	2
Industrial areas	2	2	3	2	2	2	3	2	4	4	2
Recreation facilities	2	2	3	2	2	3	4	4	4	4	4
Logging disturbance	2	2	3	2	2	3	4	4	2	2	2
WILDLIFE											
Aquatic Habitat											
Emergent vegetation	2	2	3	3	3	3	4	4	3	3	3
Lake and pond depth	2	3	3	3	3	3	4	4	3	3	3
Eutrophication	3	3	3	3	3	3	4	4	3	3	3
Terrestrial Habitat											
Change in communities	2	2	3	3	3	4	4	4	3	3	3
Succession stages	2	2	3	4	4	4	4	4	4	4	3
Census of waterfowl	4	4	4	4	4	4	4	4	4	4	4
Census of ungulates	4	4	4	4	4	4	4	4	4	4	4
Beaver lodges	1	1	2	2	2	3	4	4	4	4	4

1 very valuable 3 of some value
2 valuable 4 of little or no value

overburden stripping, construction of access roads, seismic lines, camp sites, bitumen processing plants, tailings ponds, dikes, and many other associated industrial activities.

A third parameter which may be monitored is the success of reclamation/revegetation. After surface mining has been completed, the mined area is to be restored to its original level of productivity. When dikes for tailings ponds are built, it will be necessary to revegetate their sides to prevent wind erosion.

Stresses in vegetation caused by oil sands development constitutes the fourth parameter to be monitored. Vegetative stress may be caused by airborne pollutants (exhausts from machines, stack emissions from processing plants) or waterborne effluents. Major pollutants are expected to be sulphur dioxide, nitrogen oxides, particulates and hydrocarbons. While the effects of many of these will be very localized, some effects will be seen ten miles or more from a stack source (D. S. Davison, Intera Environmental Consultants, personal communication re: turbulence and SO_2 dispersion, February 1978). Other stresses will result from groundwater and surface water changes caused by seepage, dike failures, drainage from soil piles, construction activities, or from industrial accidents (pipeline failure, accidental release of pollutants in liquid or other form).

6.2.2 Terrain and Soils

In the category of terrain and soils, there are four main parameters to be monitored using remote sensing. First is erosion. This may be erosion of top soil in areas cleared for stripping of overburden, logging, construction of industrial facilities, road and seismic lines, on newly constructed dikes, and on areas in the first stages of reclamation/revegetation. A second type of erosion which can be monitored is that along drainage courses, whether old and under stress due to increased flows, or newly created due to alterations in the topography from overburden stripping or surface mining. A second parameter is terrain failure, a larger scale type of erosion occurring on slopes and valley sides extensively throughout the study area, which may be accelerated by changes in the ground or surface water patterns in certain types of glacial materials, by mining (undermining) or by added moisture.

The third parameter to be monitored is that of irregularities or anomalies in soil moisture. These may result from changes in drainage, in groundwater or in surface waters, due to overburden stripping and surface mining, seepage from dikes or tailings ponds, drainage of overburden, topographic changes, construction of roads, campsites, seismic lines, plant sites, stream diversion or changes in lake or stream levels. The last parameter is that of changes in the topography. The topography will be altered by stripping of the overburden, surface mining, dike construction and tailings placement, and will be restored by reclamation.

6.2.3 Hydrology

There are also four major hydrologic parameters which may be monitored using remote sensing. The first is changes in drainage, both for surface waters and groundwater. These are likely to occur due to surface mining and overburden stripping, construction activities, stream diversion, spoil pile drainage, and changes in lake or river levels. The second parameter is erosion of banks and channels along drainage courses which may result from various construction activities (e.g. road building, cutting of seismic lines, logging) or other effects of industrial activity such as increased stream flow from overburden drainage.

Water quality is another very significant parameter which may be monitored using remote sensing. Not every aspect of water quality will be assessed with this tool, but sedimentation, turbidity, and presence of thermal effluents from industry and construction could be assessed. Changes in water quality may result from hot water extraction, overburden drainage, dike construction, stream diversion, seepage from tailings ponds or presence of tailings slurry in drainage courses due to pipeline leaks. A final parameter is that of conduit irregularities. In areas of sinkholes or possible sinkhole development (some regions of the Devonian limestone), calcium carbonate contaminated waters may reach the surface through upwelling.

6.2.4 Land Use

Land use in the AOSERP study area will ultimately be affected to a large extent in localized areas and the effects may be summarized under five heading: linear features, urban areas, industrial land use, recreation facilities, and logging activity. Linear features include transportation systems, pipelines, and seismic lines. Growth of urban areas may be monitored using remote sensing, as may industrial land use. The latter includes campsites, oil sands processing plants, gravel pits, site clearing, overburden stripping, tailings ponds, well sites for in situ plants, reclaimed areas, etc. Growth of recreation facilities is inevitable as the population of the area increases. Remote sensing may monitor presence of campsites, cottage areas, boat launching and other facilities, access roads, and many other recreation-associated facilities and their impact on the environment. Finally, areas utilized for logging activities may be monitored.

6.2.5 Wildlife

Assessment of oil sands development effects on wildlife may be accomplished by monitoring their habitat as well as the fauna themselves where possible. Changes in aquatic habitat may be assessed by monitoring emergent vegetation, lake, pond and stream depth, stage of eutrophication and water quality. These will all be affected by industrial activity involving stream diversion, overburden drainage, changes in lake and river levels, and sedimentation, addition of thermal effluent or other pollutants to surface or ground waters, and many other factors. The monitoring of hydrologic parameters already mentioned also has importance in aquatic habitat. Changes in terrestrial habitat which may be monitored with remote sensing includes changes in community composition and successional stage due to disturbance of vegetation from many types of industrial activity (previously discussed).

Monitoring of wildlife populations may be undertaken for waterfowl (ducks, geese) where they are found on waterbodies, for ungulates under special conditions and indirectly for beaver by counting active beaver lodges, using remote sensing techniques. This could assist in establishing effects of oil sands development on migrating and non-migrating wildlife populations.

6.3 EVALUATION OF REMOTE SENSING TECHNIQUES FOR ECOLOGICAL MONITORING IN THE AOSERP STUDY AREA

The remote sensing techniques chosen for evaluation are the same as those in Section 5.

In order to carry out the evaluation of these remote sensors for monitoring of ecological parameters related to oil sands development in a systematic manner, three tables were prepared. Each makes use of the same ranking system described in Section 5.3.3, indicating the application of the sensor to the parameter to be monitored.

6.3.1 Evaluation of Remote Sensors for Ecological Monitoring

Table 7 compares the values of each type of remote sensing for monitoring each selected ecological parameter. Thus, the five photographic remote sensors, thermal imagery, and five types of Landsat imagery have been ranked for their value in monitoring the selected parameters for vegetation, terrain and soils, hydrology, land use, and wildlife. It has been assumed that all of the photography evaluated is at a scale of 1:60,000 (a suitable reconnaissance-level photo scale which was available for all photo sets), that the thermal imagery is at a similar scale of about 1:60,000 (obtained at about 4600 m above ground level), and that the Landsat imagery is at the original scale of 1:1,000,000. It is also assumed that all of the remote sensing imagery was obtained during the summer period (e.g. July to early August) under similarly good conditions, and that there is stereo coverage for all photography (this latter is of course not possible for thermal imagery or Landsat imagery).

Table 7 indicates the value of each remote sensing tool first for the vegetation parameters to be monitored. Generally the red and green bands are less valuable than the other photographic sensors, while both colour and false colour infrared are valuable in most cases. The thermal infrared imagery at this scale is of little value. The values for Landsat are generally lower than for the photographic sensors, mainly due to the much smaller scale of the imagery. However, the infrared bands and the colour composite imagery are valuable for monitoring, particularly for disturbance of vegetation.

For terrain and soils, most of the photography is valuable, although the black and white infrared photography appears to be the least useful overall. The best overall sensor appears to be the FCIR photography, although the red band is slightly more valuable for monitoring erosion. All photography is very valuable for assessing topographic changes (assuming stereo coverage). As was the case for vegetation, the thermal infrared imagery is of little value, and even the Landsat imagery is no better. Many of these parameters are either too small to be seen on Landsat imagery or require stereo coverage.

Monitoring of hydrologic parameters may be carried out with a variety of sensors, as no one sensor appears to be the most valuable. Both FCIR and black and white infrared are best for identification of drainage changes, the red band for erosion and colour for water quality and conduit irregularities. Thermal imagery also is valuable for monitoring water quality and conduit irregularities. It should be noted here that while one sensor may be useful on its own, its rating almost invariably will go up when interpretation is carried out on two imagery types at once. An example of this is seen in the analysis of water quality. A good assessment of water quality may be made from colour photography, but when thermal imagery is also examined a much more complete analysis may be made. This type of analysis will be taken into account in the recommendations for monitoring. Landsat Bands 4, 5, and 8 appear to be valuable for monitoring erosion (when it is of large enough scale to be resolved).

For monitoring changes in land use, false colour infrared photography appears to be slightly more valuable than the rest, although all are valuable (with the exception of black and white infrared). Thermal infrared imagery is of some value for all parameters, Landsat Bands 5 and 8 appear to be valuable for most parameters with the exception of recreation facilities which are generally rather small to be monitored by Landsat.

Many of the wildlife parameters which need to be monitored are quite small and thus it is difficult to monitor them with 1:60,000 scale photography. Most of the aquatic habitat parameters may be monitored with any type of photography, while the terrestrial habitat is best monitored with colour or FCIR photography. At this scale, neither waterfowl nor ungulates may be monitored, but beaver lodges may be counted. Thermal infrared imagery is of some value for monitoring aquatic habitat, although this is a rather small scale for this purpose. Landsat imagery at a scale of 1:1,000,000 is of value only for monitoring aquatic habitat and some terrestrial habitat, in Bands 6, 7 and 8 only.

6.3.2 Evaluation of Remote Sensing for Ecological Monitoring by Scale and Date of Data Acquisition

Table 8 evaluates two airborne sensors (false colour infrared photography and thermal infrared imagery) for monitoring the selected ecological parameters in terms of scale differences and differences in date of data acquisition (the two major data acquisition variables affecting the value of the resultant imagery for ecological monitoring). For the evaluation, three different photo scales were chosen: 1:60,000, 1:30,000 and 1:15,000. The reason for their choice is obvious, in that all three were acquired in the 1977 remote sensing coverage of the AOSERP study area. For the thermal imagery, two imagery scales were evaluated - that obtained at 9200 m above ground (approximate scale of 1:115,000) and that at 2300 m (approximate scale 1:27,000). To illustrate seasonal coverage, imagery from the summer data acquisition period (July, August) is compared with that obtained

Table 8. Effects of scale differences and seasonal differences on FCIR photography and thermal imagery for ecological monitoring.

	FCIR PHOTOGRAPHY					THERMAL IMAGERY			
	Scale			July	October	Altitude AGL		July	October
	1:60,000	1:30,000	1:15,00	Imagery	Imagery	9200 m	2300 m	Imagery	Imagery
VEGETATION									
Change in vegetation Communities	2	1	1	1	2	4	3	3	4
Disturbance of vegetation	1	1	1	1	3	4	3	3	4
Success of revegetation/ reclamation	1	1	1	1	2	4	3	3	4
Stress in vegetation	3	2	1	1	3	3	3	3	4
TERRAIN & SOILS									
Erosion	2	2	1	*	*	4	3	*	*
Terrain failure	2	2	1	*	*	4	3	*	*
Soil moisture irregularities	2	1	1	*	*	3	2	*	*
Topographic changes	1	1	1	*	*	4	3	*	*
HYDROLOGY									
Drainage changes	1	1	1	*	*	3	1-2	*	*
Erosion	2	2	1	*	*	3	1-2	*	*
Water quality	2	2-3	2-3	*	*	2	1	*	*
Conduit irregularities	3	3	3	*	*	3	1-2	*	*

Continued . . .

Table 8. Concluded.

	FCIR PHOTOGRAPHY					THERMAL IMAGERY			
	Scale			July Imagery	October Imagery	Altitude AGL		July Imagery	October Imagery
	1:60,000	1:30,000	1:15,00			9200 m	2300 m		
LAND USE									
Linear features	1	1	1	1	1	3	2	*	*
Urban areas	1	1	1	1	1	3	2	*	*
Industrial areas	2	1	1	1	1	3	2	*	*
Recreation facilities	2	1	1	1	2	3	2	*	*
Logging disturance	2	1	1	1	1	3	2	*	*
WILDLIFE									
Aquatic Habitat									
Emergent vegetation	2	2	1	1	1-2	3	2	3	4
Lake & pond depth	2	2	2	3	3	3	3	3	3
Eutrophication	3	2	2	2	3	3	2	3	4
Terrestrial Habitat									
Change in communities	2	1	1	1	2	4	3	3	4
Successional stages	2	2	1	1	2-3	4	4	4	4
Census of waterfowl	4	4	3	3	3	4	4	4	4
Census of ungulates	4	4	3	3	3	4	3	4	3
Beaver lodges	1	1	1	2	1	3	2	3	2

* no seasonal differences

1 very valuable
2 valuable
3 of some value
4 of little or no value

in October. This applies to both the FCIR photography and the thermal imagery.

For monitoring vegetation, Table 8 shows that in general FCIR photography is valuable to very valuable, and that the larger scale photographs are more useful than the smaller scale (mainly because the vegetation may be monitored in greater detail). July photography is generally more valuable than that from October, because the vegetation is seen in its peak of growth state at that time and a more uniform assessment of its condition made. For thermal imagery, the largest scale is usually the most useful, as is that from July; however, overall its use for monitoring vegetation is low.

Table 8 shows that for monitoring terrain and soils, again FCIR photography appears to be the more valuable tool, ranging from valuable to very valuable for the four parameters. As was seen for vegetation, the largest scale of photography is generally ranked the most valuable as features may be monitored in greater detail. However, in some cases, the difference between the medium and large scales is negligible. For both the FCIR photography and the thermal imagery, there is no appreciable distinction between the July and October imagery in terms of value for monitoring. The thermal imagery is of low value for monitoring most of these parameters, with the larger scale being somewhat more useful than the smaller scale. However, it becomes valuable for monitoring soil moisture irregularities at the larger scale.

Both FCIR photography and thermal imagery appear to be valuable for monitoring hydrologic parameters as seen in Table 8. FCIR photography is best at all scales for monitoring drainage changes, is slightly less valuable for erosion and water quality, and is questionable for conduit irregularities. Thermal imagery at the larger scale is valuable to very valuable for all of these parameters, particularly for water quality (involving thermal changes in lakes and streams). As was the case for terrain and soils, there is no appreciable distinction between the July and October photography or thermal imagery.

For monitoring land use changes in the AOSERP study area, FCIR photography is a very valuable technique, mainly because of its high resolution and capability of monitoring the particular spectral characteristics of man-made alterations in the landscape. In most cases, all three scales are equally valuable, depending on the scale of the features to be monitored. However, generally small features such as recreation facilities, industrial areas and logging disturbance may be monitored slightly better on the medium and large scale photographs. In general, there is little difference between the July and October imagery for monitoring land use.

Monitoring wildlife parameters may be carried out by FCIR photography, although its value varies rather widely according to the parameters to be measured. Where the parameter is related to vegetation, FCIR photography is generally valuable to very valuable, depending on the scale and date of acquisition. In these cases, the largest scale and the July photography are considered very valuable. However, for the parameters related to hydrology and direct census of wildlife these photographs range from valuable to of no value. Census of beaver lodges is best done with FCIR photography at all scales, and in October. In most cases, there is little difference between the July and October photography. Thermal imagery is of low value for monitoring these parameters. Only for monitoring emergent vegetation and stage of eutrophication does it appear to be of value in the larger scale. It should be noted that census of ungulates could be carried out under specific conditions (Wride and Baker 1977), but this table does not include such large scale, winter imagery.

6.4 SUMMARY OF EVALUATION

Table 9 summarizes the ranking scores from each of the five ecological categories for the different remote sensing techniques presented in Table 7 and for the different scales and dates of data acquisition presented in Table 8. These totals are presented only to give an indication of the relative rankings of each sensor, scale and date, but are by no means meant to provide

Table 9. Summary of ranked totals for ecological monitoring by sensor type, scale and season (From Tables 7 and 8) (smaller numbers indicate greater value).

	PHOTOGRAPHY					THERMAL IMAGERY	LANDSAT				
	FCIR	COLOUR	BWIR	RED	GREEN		4	5	6	7	8
Vegetation	7	8	8	9	13	15	15	15	11	11	11
Terrain & Soils	7	8	10	7	10	15	16	16	14	14	14
Hydrology	8	7	10	8	10	10	14	14	12	12	11
Land Use	8	10	14	10	10	15	17	14	18	18	12
Wildlife	20	21	25	26	26	28	32	32	28	28	28
TOTAL	50	54	67	60	69	82	94	93	83	83	76

	FCIR PHOTOGRAPHY					THERMAL IR IMAGERY			
	Scales			Season		Altitude (AGL)		Season	
	1:60,000	1:30,000	1:15,000	July	Oct	9200 m	2300 m	July	Oct
Vegetation	7	5	4	4	10	15	12	12	16
Terrain & Soils	7	6	4	-	-	15	11	-	-
Hydrology	8	8	8	-	-	11	4	-	-
Land Use	8	5	5	5	6	15	10	-	-
Wildlife	20	18	14	16	18	28	23	27	28
TOTAL	50	42	35	25	34	84	60	39	44

the final recommendation for ecological monitoring. There are many important variables which have not been included in the discussion to this point. These include area of coverage, resolution, cost of coverage, method of interpretation and analysis, cost of interpretation and analysis, quality and accuracy of interpreted data, use of multistage, multisensor and multidate analysis, and many other factors. These will be discussed later.

The rank totals by sensor show that FCIR photography is ranked above all other sensors as the most valuable for ecological monitoring. It is followed by colour, red band, black and white infrared, and green band photography. All of the photographic sensors rank higher than either the thermal infrared imagery or the Landsat imagery (the latter mainly because of its much smaller scale). Among the Landsat bands, the colour composite imagery (Band 8) appears to be the most valuable, followed by the two infrared bands, then the red band and the green band. This was generally expected, in that atmospheric attenuation in the red band and to a greater extent in the green band decrease the detail which can be resolved on that imagery, as compared to the infrared bands. The colour composite band is usually most useful, because it combines the information from three bands and presents them in colour, making interpretation easier.

The totals for FCIR photography ranked by scale indicate that the largest scale is the most valuable and the smallest the least valuable. The same is true for the thermal infrared imagery. These results are intuitively obvious, since much more detail may be interpreted from the larger scale imagery and it therefore becomes more valuable for monitoring. This is a good example, however, where other factors such as cost of data acquisition and interpretation time must be weighed against the amount of monitoring data which is necessary in any particular program, and scale of imagery chosen more practically. The most valuable imagery for monitoring in the AOSERP study area is the smallest scale which can be used to provide the required monitoring data. This important point is taken into account in Section 9 (Recommendations).

Comparison of the totals for the July imagery and the October imagery show that for both the FCIR photography and the thermal imagery the July imagery is the most useful. It should be noted, however, that in the majority of cases there was no real difference in the value of summer and fall imagery. For analysis of terrain and soils, hydrology, and land use the time of data acquisition made no appreciable difference, whereas for those parameters involving analysis of vegetation (i.e. vegetation and most of the wildlife parameters) the July imagery was preferred.

From the factors taken into account up to this point, then, it appears that FCIR photography, obtained in July and at a scale chosen according to the needs of the program, is the best overall sensor for environmental monitoring.

6.5 DISCUSSION OF RESULTS

"The primary purpose of monitoring is to accumulate knowledge about ecosystems and the dynamic interrelationships between elements of these systems. This is basic to resource management as well as to impact assessment" (Thie and Wachmann 1974: 302-303). This statement is applicable to the Alberta Oil Sands Environmental Research Program in that it is seeking to do just that. This section has dealt with the ecological parameters which it was felt should be monitored in the AOSERP study area, and the most valuable method of monitoring them using remote sensing. The list of parameters is by no means complete, as there are many more very specialized studies which are being carried out and will be carried out in future in the AOSERP study area. However, they do provide a general outline of important fields to be considered.

The results of the evaluation showed that in most cases FCIR photography is the most valuable remote sensor for ecological monitoring in the AOSERP study area. It was also shown that the larger the imagery scale, the more detailed mapping and monitoring may be carried out, as was intuitively obvious. However, it provides an indication of the usefulness of a multistage appraoch to ecological monitoring using remote sensing, as discussed in

Section 5.4 for ecological habitat mapping. Comparison of the value of dates of imagery acquisition showed that while July (or the peak of foliage development) imagery is generally the most useful, there are definite instances in which remote sensing obtained at other times of year is equally or more valuable.

The evaluation has also provided an indication of the value of the multispectral approach to ecological monitoring. In many cases, one remote sensor may provide 80% of the required information about an ecological parameter, but interpretation of a second set of remote sensing imagery may provide the additional 20% for a complete data set. As discussed in Section 5.4, interpretation of two or even three or more sets of remote sensing may be necessary to provide the required data. However, when a remote sensing monitoring program is established, the value of additional sensors for interpretative purposes must be weighed against the cost incurred through data acquisition, and additional time required for interpretation. These factors are taken into account in the recommendations made in Section 9.

7. AUTOMATED ECOLOGICAL MAPPING

The subject of automatic remote sensing data management is a broad one, encompassing such aspects as data transmission, data storage and retrieval, data input and output, image processing and pattern recognition, with emphasis on machine processing (Steiner and Salerna 1975). This field as a whole is relatively new and in many cases not fully operational, although automatic techniques should shortly begin to gradually increase in operational capacity (Steiner and Salerna 1975: 611). The purpose of this section is to discuss a small part of this discipline, the geocoding of AOSERP habitat maps for computer data storage and retrieval, and the evaluation of digital Landsat and aerial photography data for ecological mapping and monitoring in the AOSERP study area.

7.1 GEOCODING OF 1:50,000 SCALE HABITAT MAP DATA

A number of geocoding methods were considered for demonstration of the state of the art technology in the digitizing of the mapped data from the AOSERP study area. Access to digitizing systems was explored and their relative utility and expense were evaluated.

The first method considered involves manually digitizing the base map and its two overlays (vegetation and surficial geology). The border of each habitat class is manually followed with a cursor on a digitizing tablet. This allows the creation of a digital file on tape or cards for each of the classes. Each file would require a header block with class identifier information. Close examination of the manual digitizing process showed that a significant amount of time would have to be invested in the creation of the digital files. It was estimated that it would take the same amount of time to manually digitize a map sheet as it took to transfer the interpreted photo data to a base map. In addition, a certain amount of software development would have to be undertaken before the digital data could be generated in a useful format.

The second alternative for geocoding the ecological habitat data involves a more automated approach. Two systems are available at the Canada Centre for Remote Sensing (CCRS) for these purposes. The first system (known as the PDS) is still being developed and will not be available for public use until later in 1978. On this system, mapped data in transparency or paper format is scanned by an optical processor, which scans the map with a coherent beam of light; the returning light is transmitted to a detector which converts the intensities into an electrical pulse. This pulse is used to generate a digital value in discrete units related to the aperture size of the emitting source. The advantage of the PDS is that it is interfaced with the CCRS. General Electric Image 100 computer analysis system (Economy et al. 1974) and they can be used interactively with relative ease.

The second system that is available through the Canada Centre for Remote Sensing is known as the Scanning Micro-Densitometer (SMD) and works on similar principles as the PDS. However, the SMD uses a drum scanning device with an image mounted on a rotating circular drum which is illuminated by a narrow beam of light. The transmitted light through the image is gathered by a receiving detector with a predefined aperture size. The illuminating and receiving apertures can be set to 25, 50 or 100 microns. A scan line is created across an image as the drum rotates with the sensing system progressing from line to line on a supporting carriage that moves parallel to the drum axis. The transmitted light that impinges upon the receiving detector generates an electrical pulse that is used to create a corresponding digital value that is recorded on magnetic tape in the form of 8 bit bytes. Each byte of information represents the amount of light that was transmitted through the point on an image that corresponds to an area related to the predefined aperture setting. The scanned image is then comprised of a large matrix of these individual points (referred to as pixels). Once the digital tape has been created, manipulation of the digital data can be conducted by computer.

Since the PDS system is presently being developed and is not yet ready for general use, the SMD system was employed for the geocoding of the AOSERP habitat maps. The geocoding involved the following basic steps:

1. Photo reduction of the maps into negative transparencies,

2. Scanning of the transparencies at various aperture settings and the creation of computer compatible files on the tape,

3. The loading and manipulation of the digital files on the Image 100,

4. Generation of data products, and

5. Evaluation of the final products and subsequent recommendations for future tasks.

Since the automated geocoding of the maps was conducted for demonstration purposes, it should be indicated at this point that a full exhibition of the existing capability could not be performed due to time restrictions. The 1:50,000 habitat maps arrived in Ottawa in early March with the negative transparencies becoming available by 16 March. The negatives were then scanned in two stages on 22 and 23 March. The Image-100 session occurred 28 March. Each of the above steps was completed as a one-time event with no time to redo unsatisfactory tasks. In other words, it was assumed that each step was originally completed in a workable format. This proved to be less than satisfactory for reasons that are described below. Each of the geocoding steps has been further outlined in detail in the text that follows.

A map sheet near the Syncrude plant (NTS 74 E/4) was selected for geocoding. Copies of the base map information, surficial geology and vegetation cover maps were forwarded to Ottawa. Upon close examination of each of the three map copies, it was apparent that there was a noticeable lack of high definition of the line boundaries. Some of the very thin or fine lines were not continuous in parts. For future geocoding of maps the original map sheets would be used for photo reduction purposes. Nevertheless, the maps that were provided were of a quality that could be used in a demonstration.

One major consideration that had to be carefully planned involved a decision on the most appropriate size for the photo reduced maps. The SMD has a limit of 9" x 9" format size for scanning purposes. However, an 81 square inch image would result in a very large amount of digital data. In addition, since the Image-100 is restricted to an image size of 512 x 512 pixels, it is most desirable to have an image that is as small as possible. On the other hand, if the maps are significantly reduced, it may not be possible to resolve the small annotated subscripts and superscripts of the habitat classes. This was particularly true for the surficial geology map. As a result, a photo reduced format size of 4" x 5" was selected as a viable compromise.

The resulting negatives proved to be suitable in size for the definition of fine lines and small alphanumeric annotations, but were too large for a single data file for manipulation on the Image 100. However, there is a way to work with large data files on the Image 100 which is described below. Due to the relative lack of high contrast with the map copies, the photo reduced negatives displayed similar low contrast characteristics.

Before the scanning process could be performed, a number of critical scanning conditions had to be attended to, including tape formats, scanning densities and record lengths. Perhaps the most important conditions to be considered were the illumination and reception aperture sizes as well as the raster size (where the raster refers to discrete digital scan line size). Usually the two aperture sizes and the raster size are selected so that they correspond to one another for the digitizing of each image. As previously mentioned, these sizes can be specified at 25, 50 or 100 microns for the SMD.

Since it was not known which aperture setting would be most appropriate for the geocoding, each map was scanned at all three aperture/raster settings. This resulted in nine separate digital files (6 magnetic tapes). Due to the urgency of the scanning request, it was not possible to run a quality control check on the tapes.

Due to the introduction of spurious digital information from the tape drives during digitization, it was not possible to read five of the tapes into the Image 100 system. End of file indicators were encountered on four of the tapes and parity errors on the fifth. The only tape that could be read contained files with the surficial geology information at 50 and 100 microns. Subsequent analysis was performed on this tape and is discussed below.

The first file to be examined was the 50 micron scan of the surficial geology map. This file contained a total of 2260 bytes of information which exceeds the limits of the Image 100. Therefore in order to display the entire file on the system, it was necessary to decimate the file. Decimation involves a sampling of every fourth or sixth pixel (byte), for display and results in a loss of information. A segment of this scene was selected for full scale display. It is indicated in Figure 14 as Window 1.

The raw data were examined on the Image 100. A portion of this map data is presented in Figure 15 in a printout from a Gould printer/plotter. The large lines indicating an escarpment are apparent but the finer lines are barely distinguishable from the background (the background is evident because the original negative transparency was not entirely opaque allowing some transmission of light through it during digitization). In addition the line and alphanumeric data were not entirely transparent on the negative. The combined effect of the above characteristics resulted in a lack of contrast between the map information and the background. The alphanumeric data are just slightly legible because of this contrast problem and aperture size of 50 microns. Some enhancement techniques were subsequently employed in an attempt to improve the contrast.

A radiometric channel correction algorithm was used to smooth the variability within the dynamic range of the spectral signatures of the digitized map. A quantization or smoothing through averaging occurred. In Figure 16 it is apparent that the contrast between the background and the data of interest has been

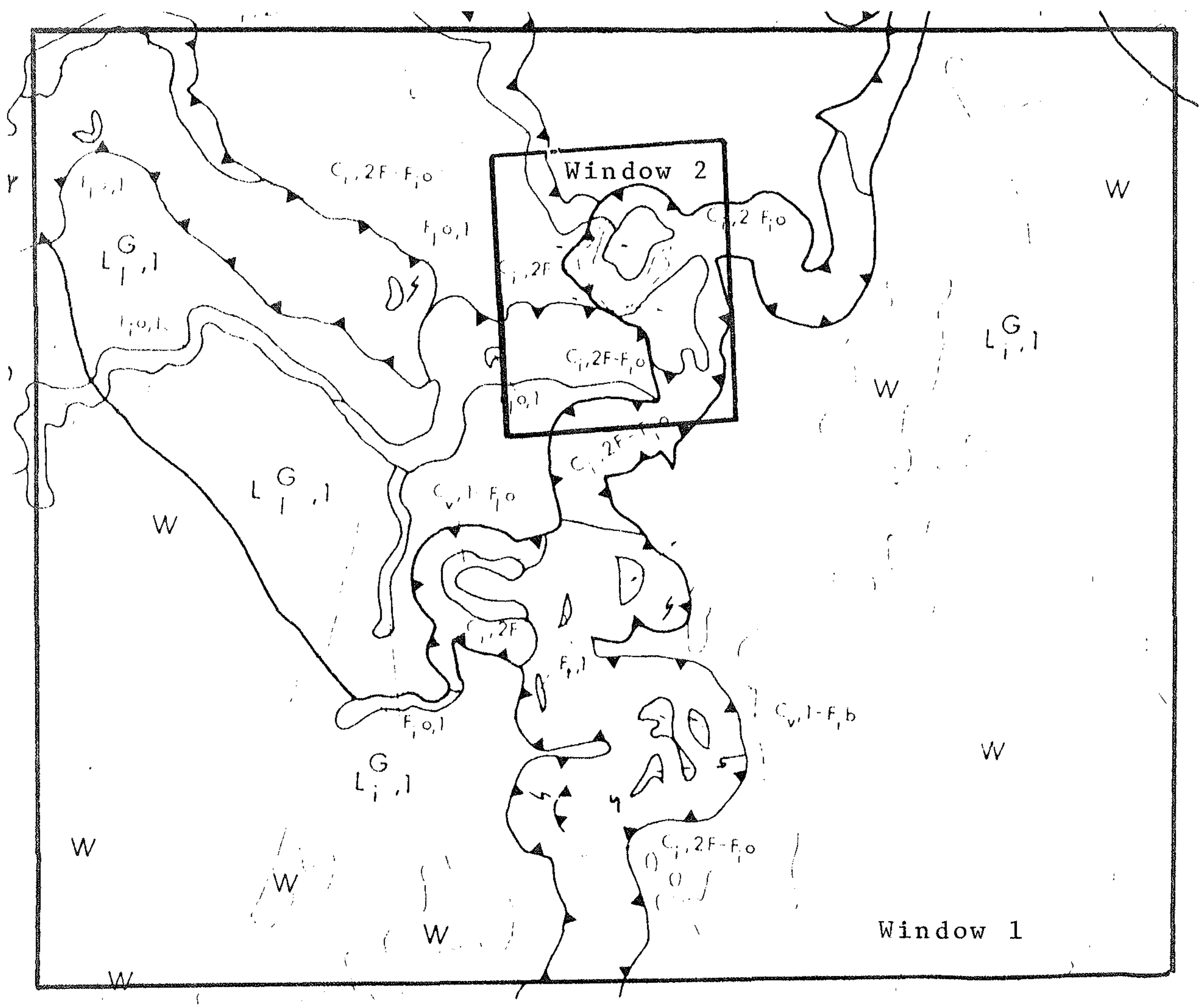


Figure 14. Locations of windows 1 and 2 for geocoding of surficial geology overlay (Map 74E/4).

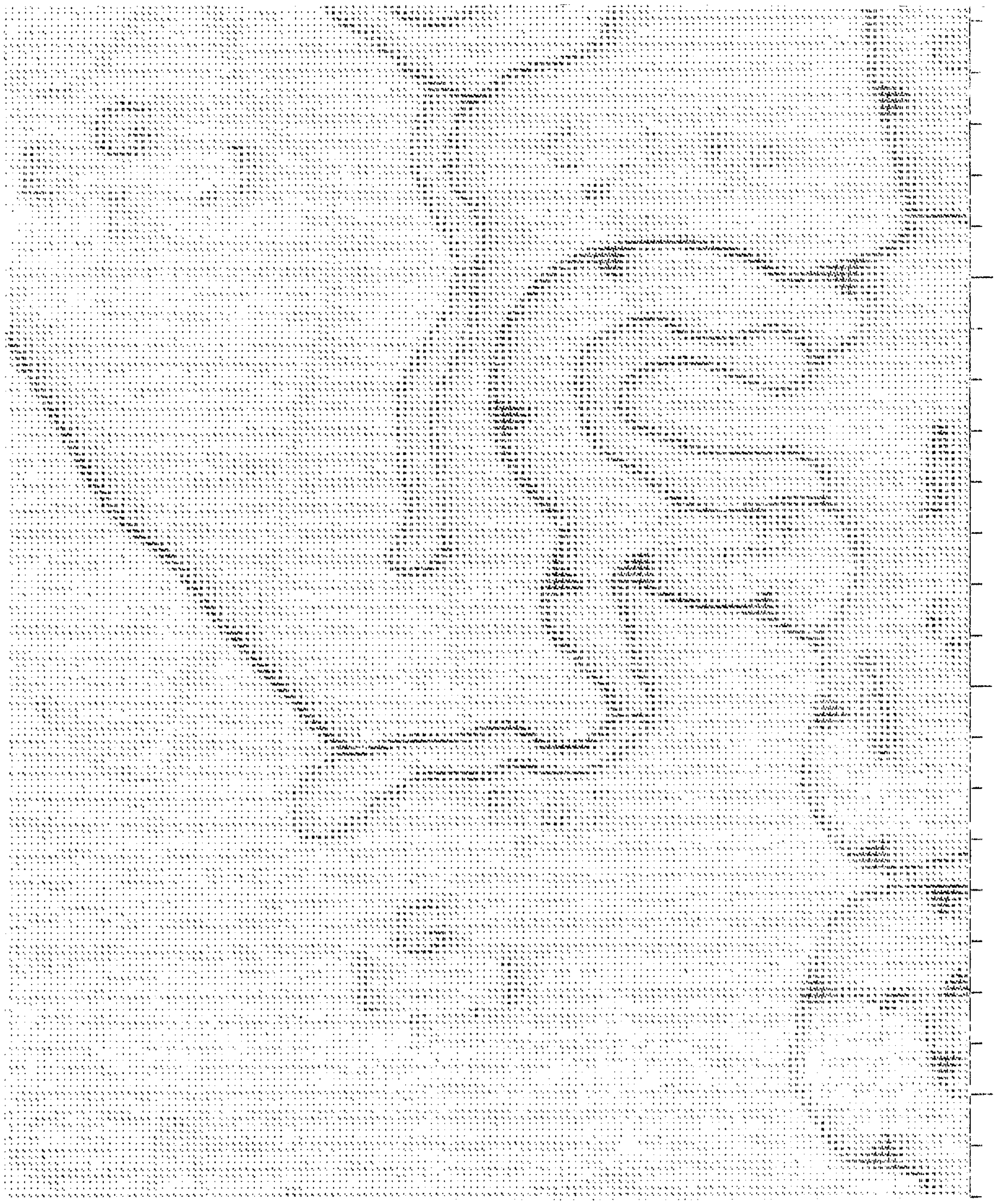


Figure 15. Geocoded surficial geology map: raw data (50 micron aperture setting).

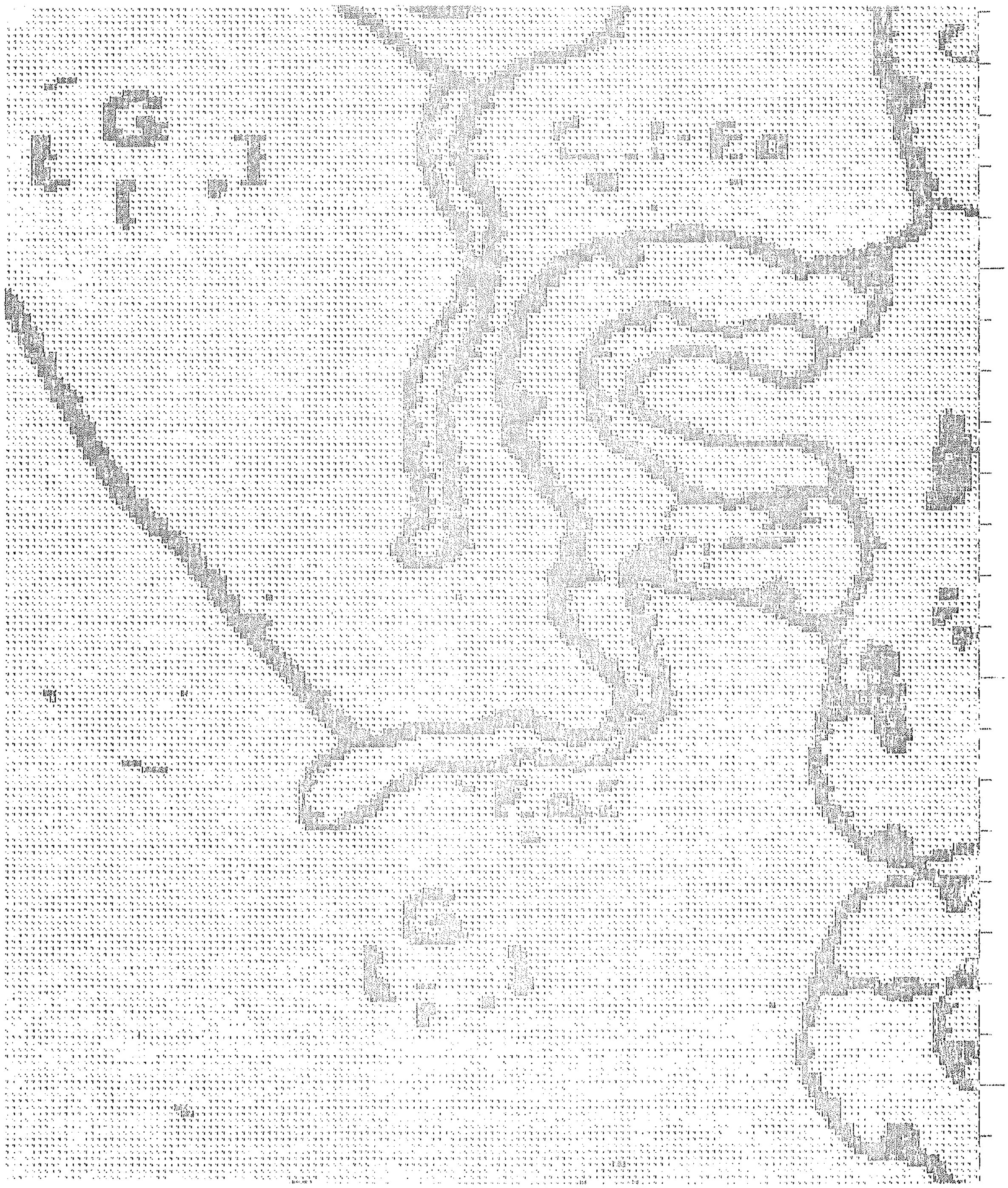


Figure 16. Geocoded surficial geology map: radiometric channel correction (50 micron aperture setting).

increased, but with the loss of definition in the alphanumeric annotation. Next, a high pass spectral filter was applied to the data for the purpose of performing an edge enhancement between the background and the mapped lines (Figure 17). The edges are enhanced (the lines are thinner) but there still remains an overall lack of contrast and character definition.

At this point there was some question as to the number of spectral levels that exist in the data. In order to gain some appreciation of this, a small window (Window # 2 in Figure 14) was selected from the data and blown-up to a larger scale. The resulting image was then printed out on the Gould printer (Figure 18). There are seven individual spectral levels in the data (each individual square represents a pixel with a separate digital value). From this close examination it was decided that density slicing followed by a contrast stretch could be performed to improve the results. Figure 19 depicts the results of the density slice and the contrast stretch. This has the greatest potential for producing a legible product with suitable contrast. The procedures could be modified further for improved results in future work. Examination of the geocoded surficial geology data from the 100 micron scan on the Image 100 showed that the 100 micron aperture size was too large for the definition of the map lettering.

The automated geocoding of the habitat maps was conducted as a demonstration of available techniques. The exercise provided an assessment of these methods and thus made it possible to formulate a number of feasible recommendations for improving the quality of the data products. A significant saving in time and effort was made using the automated approach compared to a manual one. For example, it has been estimated that an average navigational chart with a total of 3000 inches of mapped lines and 500 names could be manually digitized (assuming that the necessary software and hardware have been fully developed) in 38 hours (Boyle and Sharp 1972). In contrast, the same map in a 4" x 5" transparency format could be automatically digitized at a 25

Figure 17. Geocoded surficial geology map: high band pass filter (50 micron aperture setting).

Figure 18. Geocoded surficial geology map: enlarged scale, window 2 (50 micron aperture setting).

Figure 19. Geocoded surficial geology map: density slice and contrast stretch (50 micron aperture setting).

micron aperture setting in 1.5 hours (including set-up time). For a region such as the AOSERP study area the saving in time for the geocoding of the entire area would be quite significant. Should the entire AOSERP study area eventually be mapped at a scale of 1:50,000, it is estimated that the digitizing of the base maps and two sets of overlays would take from 60 to 90 hours.

7.2 DIGITAL ANALYSIS OF REMOTE SENSING DATA

Consideration of the value of digital analysis of remote sensing data for habitat mapping has indicated that such an approach can be useful and cost-effective. Evaluation of Landsat analogue imagery for habitat mapping has shown that these data may have useful applications in the AOSERP program. Applications for the digital data may be even greater, since digital analysis may allow greater accuracy and more detailed mapping. Computer analysis of digital Landsat data allows a decision to be made for each individual pixel (picture element, representing about 480 square metres on the ground) and is therefore less likely than a human interpreter to incorrectly delineate the boundary of a particular habitat class (other factors being equal).

In a digital analysis, two types of approaches may be used to generate the habitat classes-- supervised and unsupervised. In a supervised study, known features are selected for training purposes. The computer is instructed to select similar spectral signatures throughout the scene of interest. This process is followed for each known class. Supervised classifications are usually employed when a researcher has an in-depth knowledge of the habitat classes. However, if any class has been overlooked during training, that class will not be included in the analysis. In addition, supervised methods are usually very time-consuming since they require the researcher to exactly locate the known test sites in the digital data from aerial photographs or maps. There is no guarantee that the sites will be located accurately, thus jeopardizing the results of the analysis.

The second approach in digital analysis is known as unsupervised classification. In this mode, the researcher picks an arbitrary area for training that appears to be a homogeneous class. The computer divides the study area into a specified number of spectral classes and the researcher then determines how the specific spectral classes relate to habitat types. For the AOSERP study area, it may be advisable to use this unsupervised approach.

The digital analysis of aerial photographs may make use of the methodology described above for the digital analysis of Landsat data. An aerial photograph of any scale is first digitized automatically, using the system described for the geocoding of maps (Section 7.1), and a digital file is thus created containing spectral information from the aerial photograph. Then this digital file is ready for computer analysis or visual display on a system such as the Image 100. Statistical or quantitative analysis may be carried out on these data, using similar software routines to those already derived for Landsat data. These files of classified data from the aerial photography may be combined with or overlaid on other types of digital data, such as those from a corresponding area on Landsat or on a geocoded base map. These classified polygons from the aerial photograph will, because of the larger scale of the photo, be much more detailed than the classified polygons from Landsat data for corresponding areas. In areas where such detailed information is required, then, a researcher may first access the Landsat file to see the area in broad classifications of habitat; having chosen the area which he wishes to examine in greater detail, he then may access the digital file for the aerial photography coverage, and should he want to, may have this information overlaid on the corresponding topographic map.

Estimates of the sensitivity of digital analysis of aerial photographs at any particulr scale cannot accurately be made at this point without carrying out a demonstration project comparing the digital analysis with visual interpretation of the same photographs. However, it may be said on the basis of scientific findings that the digital analysis will likely produce more detailed classifications than the visual interpretation, but these will likely be less accurate. Digital analysis at this point can only assess spectral characteristics of habitat types as seen on the aerial photograph, and cannot assess such other important variables as integration of land types as a human interpreter can and which are necessary for accurate interpretation.

Table 10 presents an evaluation of the potential usefulness of digital Landsat data and digital aerial photographs at two scales, for ecological habitat mapping and for ecological monitoring in the AOSERP study area. The ranking system used in Table 10 is the same as that described in Sections 5 and 6, and the same qualifications apply to the results as stated in the previous discussions. The ranks are not based on results of actual analysis of digital data for the AOSERP study area, since it was not within the terms of reference of the contract to do such analysis. Rather they are based on results reported in the scientific literature, and on the previous experience of those involved in the analysis with similar data products and applications.

The ecological parameters considered as important for mapping and monitoring are the same as those described in previous sections, and fall into five major categories: Vegetation, Terrain and Soils, Hydrology, Land Use and Wildlife. It has been assumed that the two air photo scales are large (about 1:15,000) and small (about 1:60,000), and that the most appropriate type of photography for the application has been used (i.e., in most cases it will be FCIR photography, but in some cases it may be colour photography or another type). For the digital Landsat analysis, it has been assumed that digital data from all four spectral bands have been used.

For vegetation mapping and monitoring, it appears that the large scale photos are the most valuable, and the small scale photos nearly as valuable. The Landsat data are also valuable for

Table 10. Evaluation of digital analysis of aerial photographs (two scales) and landsat data for ecological habitat mapping and ecological monitoring.

	Digital Landsat Data	Digitized Small Scale Air Photos	Digitized Large Scale Air Photos
VEGETATION			
Ecological Habitat Mapping			
Distribution			
Plant communities	2	1	1
Species	3	2	2
Height	4	4	3
Density	3	1	1
Wetlands classification	2	1	1
Ecological Monitoring			
Change in vegetation communities	2	1	1
Vegetation disturbance	2	1	1
Success of revegetation/reclamation	2	1	1
Stress in vegetation	3	2	2
VEGETATION TOTAL	23	14	13
TERRAIN AND SOILS			
Ecological Habitat Mapping			
Surficial Geology			
Landforms	2	2	2
Genetic material	4	3	3
Relief	4	3	3
Aspect	4	4	4
Surface expression	3	2	2
Soils	3	3	3

Continued ...

Table 10. Continued.

	Digital Landsat Data	Digitized Small Scale Air Photos	Digitized Large Scale Air Photos
Construction materials	4	3	3
Ecological Monitoring			
Erosion	2	2	2
Terrain failure	3	2	2
Soil moisture irregularities	3	3	3
Topographic changes	4	3	3
TERRAIN & SOILS TOTAL	36	30	30
HYDROLOGY			
Ecological Habitat Mapping			
Location of water courses, lakes	1	1	1
Classification of lakes, streams, etc.	1	1	1
Ecological Monitoring			
Drainage changes	1	1	1
Erosion	1	1	1
Water quality	2	1	1
Conduit irregularities	3	2	2
HYDROLOGY TOTAL	9	7	7
LAND USE			
Ecological Habitat Mapping			
Linear features	1	1	1
Urban areas	1	1	1
Industrial areas	1	1	1
Recreation facilities	2	1	1

Continued ...

Table 10. Concluded.

	Digital Landsat Data	Digitized Small Scale Air Photos	Digitized Large Scale Air Photos
Logging disturbance	1	1	1
Ecological Monitoring			
Linear features	1	1	1
Urban areas	1	1	1
Industrial areas	1	1	1
Recreation facilities	2	1	1
Logging disturbance	1	1	1
LAND USE TOTAL	13	11	11
WILDLIFE			
Ecological Habitat Mapping & Monitoring			
Aquatic habitat			
Emergent vegetation	2	2	1
Stage of Eutrophication	3	3	2
Rapids and spawning areas	3	2	1
Terrestrial habitat			
Vegetation species and/or species association	2	2	1
Successional stages	3	2	1
Juxtaposition of habitat types	2	2	1
Waterfowl on waterbodies	4	4	4
Census of ungulates	4	4	3
Beaver lodges	4	1	1
WILDLIFE TOTAL	27	22	12
TOTAL FOR ALL PARAMETERS	108	84	73

almost all parameters of importance, with the exception of vegetation height. For terrain and soils parameters, the digital analysis of air photos and Landsat appears to be of less value, as many must be evaluated in terms of topographic location as well as spectral characteristics. These include relief, aspect, genetic materials, topographic changes, and to a lesser extent some of the other parameters.

Digital analysis of hydrologic parameters appears to be very valuable in most cases for all three data sets. Value for monitoring conduit irregularities is questionable and water quality can not be mapped as well from Landsat as from airphotos. For land use features, it appears from the table that all three data sets are almost uniformly very valuable for the mapping and monitoring parameters. Only recreation facilities may be less accurately identified from Landsat digital analysis. For wildlife parameters, the value of the three types of digital analysis varies. Generally, these features are relatively small and thus difficult to accurately map or monitor from Landsat (e.g. rapids and spawning areas). In most cases, the value is improved with scale increase, so that the digitized large scale air photos appear to be the most valuable for mapping and monitoring wildlife parameters. Waterfowl cannot be censused with any of the digital methods, and it is not likely that ungulates could be censused even at the large photo scale. Beaver lodges can not be censused with Landsat, but this could be done on the photography.

The overall totals for all parameters (Table 10) indicate only what was expected, that the large scale air photos are the most valuable in general, followed by the small scale air photos, and finally by digital Landsat data. It is the scale difference which is primarily responsible for this result. However, it should be noted for the Landsat data that the evaluation has been much improved over the evaluation presented for analogue interpretation of any of the bands or the colour composite. Although it must be stressed here again that these assigned ranks are subjective, that the evaluation of digital analysis has not been based on actual interpretation of AOSERP study area digital data, and that there are other important variables to be considered, nevertheless these results do indicate a meaningful pattern. Particularly for Landsat data, digital analysis may provide a better capability for mapping and monitoring of ecological habitat in the AOSERP study area than aerial photography or analogue interpretation of Landsat data.

The advantages of Landsat digital data include frequent coverage (every eighteen days), mapping of a study area with less man-time, and very low cost compared to the cost for aerial photography. The disadvantages include the necessity for highly specialized training, sophisticated computer equipment and a relatively low resolution (480 m^2) of Landsat data (Jacques 1977).

Each of these advantages and disadvantages applies to the AOSERP study area. However, a multistage program would utilize the Landsat data to its full capabilities, while taking advantages of the capabilities of small scale and large scale aerial photography. This is discussed in Section 9.

7.3 DISCUSSION OF RESULTS

The first part of this section demonstrated some of the available techniques for automated geocoding of habitat maps. Geocoding of data entailed photographically reducing the map sheets and then scanning them to produce digitized maps. In the effort to produce the most usable map it was necessary to try various aperture settings for the scanning. Although the results were too gross at a 100 micron setting, the 25 and 50 micron settings should prove sensitive enough to produce a usuable digitized map. In addition, several enhancement techniques were employed to demonstrate how the contrast between map information and the background could be improved. Further modifications of these procedures would improve results to provide useful digitized maps.

The full utility of the digitized maps will only be realized if used in conjunction with other digital data such as that from Landsat. For example, if an analysis of digital Landsat was conducted on the Image 100, it would then be possible to register the geocoded base maps by means of a geometric transformation of the Landsat image. In this way the habitat classes as defined by the Landsat analysis could be compared with the class as defined by the interpreted air photos. The number of acres within each polygon could also be easily extracted. Without this accompanying digital remote sensing analysis, the demonstration of the geocoded maps can be of benefit only as an assessment of the digitizing process for future consideration.

The second part of this section has dealt with digital analysis of remote sensing data, both Landsat and aerial photographs. The results of this evaluation are not based on an actual demonstration of the technique, and thus are tentative. However, the evaluation has shown that both Landsat and aerial photography digital data should be of value for mapping and monitoring ecological habitat in the AOSERP study area. More detailed analysis can be carried out with digital data than through visual interpretation of either Landsat or aerial photographs, but it is most important to note that such analysis will likely be less accurate.

There are several advantages to the creation of a computer-based information system utilizing digital remote sensing data. There are great savings in time when analysis is carried out using specially developed software on a computer system, when compared to the time involved for visual interpretation of remote sensing data. Second, quantification of the spectral and classified data is possible. Third, interaction between different types of digital data is relatively easily accomplished (for example, between Landsat data, aerial photography data, and topographic map data). Finally, more detailed classification of habitat may be possible. The disadvantages are mainly involved with lack of accuracy in the classification, and the necessity of tying all the analysis to sophisticated computer equipment and specialized interpreters. However, when both are considered it is likely that the advantages outweigh the disadvantages. Recommendations for further work are presented in Section 9.

8. CONCLUSIONS

There were two major objectives for this project: first, the preparation of Phase 1 Ecological Habitat Maps (1:50,000 scale) for the AOSERP study area; and second, the evaluation of multistage and multispectral remote sensing techniques for ecological habitat mapping and monitoring. A preliminary discussion and partial evaluation of automated ecological mapping was also included.

8.1 PREPARATION OF ECOLOGICAL HABITAT MAPS AND TERRAIN ANALYSIS

A review of ecological classification systems for habitat mapping was carried out and their applicability to mapping from remote sensing imagery assessed. Discussions were held with AOSERP personnel, researchers working in the study area, and other scientists involved in environmental and remote sensing studies, and a classification approach to the ecological habitat mapping was developed (Section 3).

Although there appeared to be an opportunity for ecological mapping (biophysical mapping) in this program, a number of problems made it necessary to use a more direct approach. These included the present limited understanding of the ecosystem's successional dynamics in the AOSERP study area, limited time, absence of directly related ground survey data, and the need to work in the cover type classes. The classification method devised for this study worked well and was suited to enlargement and change due to its "open-ended" design.

Most AOSERP researchers will be assisted in their efforts by using the 1:50,000 scale habitat maps. The vegetation categories in the system used for the mapping correspond very closely to those derived by Stringer (1976) and those required by the AOSERP researchers. Larger scale FCIR imagery and mapping of study areas has also been requested by virtually all of the wildlife researchers, at a scale of about 1:12,000. Some users would rather have colour photography but this feeling is generally based on their limited experience with FCIR photography.

Aquatic habitat was not easily mapped from the 1:60,000 scale photography and it was concluded that large scale mapping and ground surveys would allow data synthesis that should be coded onto the 1:50,000 maps rather than mapped.

As a result of this 1:50,000 reconnaissance mapping of the AOSERP study area, it was possible to provide a terrain analysis, integrating surficial geology and landforms with terrestrial and to a lesser extent aquatic vegetation (Section 4). It should be noted that this terrain analysis is based mainly on knowledge of the areas which have been mapped to date, under this project, i.e. most of the central portions of the study area. Some changes or additions may be necessary after ground checks have been made. The analysis of terrain should serve as a basis for more detailed research into the nature and dynamics of the ecological systems in the AOSERP study area.

The terrain analysis has shown the relationship of the vegetation communities (upland, bottomland and riparian, wetland and succession after disturbance) to the precipitation, temperature, soil moisture and texture, drainage, slope, aspect and parent material in various sites throughout the study area. This will aid the researcher in understanding the relationship between the vegetation and surficial geology overlays for the habitat maps, as well as planning more detailed research into habitat types.

8.2 MULTISPECTRAL AND MULTISTAGE REMOTE SENSING FOR ECOLOGICAL HABITAT MAPPING AND ECOLOGICAL MONITORING

In order that the multispectral and multistage remote sensing techniques be evaluated in a systematic manner for their application to ecological habitat mapping and to ecological monitoring, a number of ecological parameters under five major headings (vegetation, terrain and soils, hydrology, land use and wildlife) were selected and the value of each sensor ranked against these parameters. For the multispectral analysis, all of the remote sensing techniques used in the 1977 remote sensing data acquisition program in the AOSERP study area, plus analogue Landsat imagery, were evaluated. The multistage evaluation considered three scales of FCIR photography and two of thermal imagery (plus Landsat as previously evaluated), and a discussion of dates of data acqusition was also included.

The results of the evaluation indicated that FCIR photography provided the best overall sensor for ecological habitat mapping. Other sensors had application to particular mapping parameters, and in some cases were slightly more valuable than the FCIR photography. For example, FCIR photography was generally best for mapping vegetation-related parameters, the red band was better for some terrain and soils parameters, and colour photography for some of the wildlife parameters. Nevertheless, the FCIR photography was assessed as the most valuable overall; its resolution, and the combination of infrared plus visible reflectance presented in colour make this type of photography easily interpretable while eliminating the haze and attenuation problems associated with the lower visible regions (i.e. the blue band in particular). Some previous studies have rejected FCIR photography because of its colour balance problems (i.e. darkening of the frames toward the edges, and wide colour shifts from one altitude, day, and film batch to another); however, these problems have now essentially been solved using sensimetric and proper metering of energy in the near infrared portion of the spectrum. It should also be noted that FCIR photography in transparency format is less expensive than colour photography.

Thermal imagery was judged useful to a certain degree in many cases, but it is concluded that for ecological mapping and monitoring, it is not a remote sensing tool which should be used on its own. Its value lies rather as a secondary sensor in almost every case where it provides useful information for ecological mapping and monitoring; used in conjunction with FCIR photography and usually at a relatively large scale, it provides valuable information for hydrologic, vegetation, land use and wildlife studies.

Landsat imagery analyzed at its original 1:1,000,000 scale in analogue format has been shown to be a useful tool, and its value lies in providing a broad overview of the study area for rapid small scale mapping of ecological habitat, and for monitoring on a frequent basis. Some problems exist with mapping at this scale directly from the individual bands, mainly due to the very small scale of the imagery. The colour composite band is most useful; it is somewhat comparable to FCIR photography in that it combines the visible and infrared bands and presents them in colour, making the product easily interpretable. Photographic enlargement of Landsat imagery to a scale of 1:500,000 increased the information which could be mapped, and showed that for most ecological parameters the enlarged colour composite band provides the best data.

Multistage analysis of the remote sensors used in the study showed the general difference in the amount and detail of mapped information which may be obtained at different imagery scales, but most important, it showed that it is not always necessary to carry out ecological habitat mapping and monitoring at a large scale. The reconnaissance level mapping which was done with FCIR photographs provides a useful set of baseline ecological data for habitat, and serves as a permanent record of these baseline conditions. Nearly every important parameter may be mapped to a certain and usable extent on this 1:60,000 scale photography. It then remains to utilize larger scale photographs for more detailed mapping, specifically, as determined by research users or from examination of the smaller scale photographs or from ground surveys. A co-ordinated remote sensing program would include all stages of remote sensing data acquisition, from Landsat which is valuable for overview and frequent up-dating of information, to reconnaissance-level FCIR photography for baseline mapping, to large scale photography and thermal imagery for more detailed research, to ground surveys. A recommendation for such a program is presented in Section 9.

8.3 AUTOMATED ECOLOGICAL MAPPING

The analysis in Section 7 was carried out in two parts. The first considered the value and sensitivity of geocoded maps.

The demonstration of the geocoding of the habitat maps was carried out using the CCRS facilities in Ottawa, and concentrated on the surficial geology overlay of NTS sheet 74 E/4 (1:50,000 scale). With some improvements in the methodology used for this geocoding procedure (and later in the equipment used), automatic geocoding of habitat maps has been demonstrated to be a feasible alternative to a manual approach, with significant savings in man-time. When used in conjunction with other digital data (such as that from Landsat), the full utility of the digitized maps would be realized. The sensitivity of these geocoding procedures appears to be very reasonable when the 50-micron scan or smaller is used for creation of computer compatible tapes and various procedures for enhancement of the digitized data are employed.

The second part of this section dealt with digital analysis of remote sensing data, both for Landsat and aerial photographs. The results of this evaluation are not based on an actual demonstration of the technique, and thus are tentative. The evaluation indicated that both Landsat and aerial photography digital data should be of value of mapping and monitoring ecological habitat in the AOSERP study area, and that the digital maps produced will be more detailed, but less accurate than visually interpreted maps.

The creation of a computer-based information system utilizing digital remote sensing data would allow great time-saving for analysis (compared to the time involved for visual interpretation), quantification of classified data could be easily carried out, interaction between different types of digital data could be accomplished, and more detailed classification of habitat could be done. However, the disadvantages include lack of accuracy in the classification, and the necessity of using sophisticated computer equipment and specialized interpreters for remote sensing analysis. Yet, for a study area as large and generally inaccessible as that of AOSERP, and in which much detailed environmental research is being and will be carried out over the next few years, it is likely that the creation of a computer-based information system would be of great value.

This information system should not be established before an actual demonstration of digital Landsat and aerial photography habitat mapping is completed and reviewed. Then a considerable amount of time will need to be spent in designing the system to ensure compatibility with such systems as the CCRS Image 100, other computer systems and to the proposed earth observation satellite systems which will proliferate over the next few years (Landsat-D, Seasat-A, etc.), and to ensure that the objectives of the researchers in the area will be met. The value of such a system will ultimately be found in automated detection of change in the habitat systems within the AOSERP area, as related to oil sands activity as well as natural change over time.

9. RECOMMENDATIONS

9.1 RECOMMENDATIONS FOR ECOLOGICAL HABITAT MAPPING PROGRAM

In order that the ecological habitat mapping program be completed as originally intended, the following recommendations are made:

1. The coverage of the study area with 1:60,000 scale FCIR photographs should be completed by reflying the areas not covered in July-August 1977. This will permit accurate completion of the vegetation mapping and provide compatible coverage for the entire study area. Obtaining the rest of the multispectral package at the time of these flights is not considered necessary.

2. Ground surveys should be carried out during the 1978 field season to check the accuracy of both the vegetation mapping and the surficial geology mapping. This may be done in areas noted as questionable during the mapping already completed, as well as in "representative" areas in those areas which have not yet been mapped.

3. The remainder of the AOSERP study area should be mapped at a scale of 1:50,000 using the base map plus two overlays as the format, so that a complete set of co-ordinated working maps will be available by the end of 1978 for use by researchers.

4. Consideration should be given to colouring or shading areas of the ecological habitat maps when they are prepared for final presentation, as this will improve their legibility.

5. Aquatic habitat data collection should be carried out during 1978 (using low-level helicopter observations plus ground surveys) to locate and rate predetermined aquatic habitat parameters which may then be coded on the 1:50,000 scale habitat maps, as there is little information on these maps for aquatic habitat at the present time.

9.2 RECOMMENDATIONS FOR REMOTE SENSING PROGRAM FOR ECOLOGICAL MONITORING

The following recommendations are made for a monitoring program in the AOSERP study area, based on remote sensing imagery. In several sections of this report, the concept of a multistage remote sensing program has been introduced, and this is recommended here as follows:

1. Landsat analogue imagery should be obtained every year on a seasonal basis, if available. This could be from spring, summer or fall, and will entail only two sets of imagery to completely cover the study area. All four bands should be obtained, plus the colour composite Band 8. Interpretation of these images should likely be carried out on imagery enlarged to 1:500,000 or 1:250,000 scale, as mapping and analysis will be easier at those scales than at the original scale of 1:1,000,000. These will be used mainly to monitor disturbance due to oil sands development, which can then be compared on a seasonal and annual basis, for a frequent update on environmental disturbance. If Landsat imagery is to be used for habitat mapping vegetation cover type, multidate imagery (summer, fall and winter) is recommended since various vegetation types may be most readily identifiable at different seasons. This is a very inexpensive and rapid method of monitoring a large area such as that of the AOSERP study area. This will involve an expenditure for Landsat data of about $200/date.

2. Reconnaissance level FCIR photographs (1:60,000 scale) should be reflown every three to five years, but preferably once more near the end of the environmental research program. This depends on the need which becomes apparent over the remaining years of the program, but it is likely that it should be done in 1981 or 1982. As was done in 1977, the photographs should be obtained during the peak of foliage development (late July-early August) and should cover the study area completely. This should involve an expenditure of around $40,000.

3. Large scale remote sensing imagery should be obtained for specialized, and more localized research programs. No one recommendation can be made to cover all contingencies, as each facet of the environmental research carried out in the area will have its own very specific requirements for remote sensing, regarding sensor, scale, date and time of data acquisition, data product, etc., and thus no estimate of expenditure is included.

A few examples of such programs are presented here, but this is by no means a complete listing. One example of a detailed localized program which should make use of remote sensing imagery at a larger-than-reconnaissance scale is monitoring of stress in vegetation around the operating oil sands plant sites. It is expected that the effects of airborne pollutants may be seen within five miles of the plants, depending on wind direction and other factors. Thus a remote sensing program should cover sample plots within a radius of up to thirty miles in the direction of prevailing winds. Large scale FCIR photography could be obtained for sample plots along radials from the plant site which are permanently marked and monitored on an annual basis, likely in early August (after the pollutants have had an effect on that year's deciduous foliage and prior to senescence which confuses the identification of vegetation stress).

Permanent plots for biomonitoring could also be set up in other regions within the study area and sampled using very large scale FCIR photography on an annual basis. The photographs would assist in the analysis of ecosystem dynamics and succession, and change due to disturbance, and would also serve as a permanent record of conditions. Complete coverage of each plot might include oblique photographs from four aspects taken from a helicopter. This type of coverage is very expensive, but if the plots are carefully selected the results would be worth the expense in terms of gaining an understanding of the ecosystem dynamics in the AOSERP study area.

Another type of detailed research program which requires large scale remote sensing imagery is that carried out by the wildlife researchers on semi-aquatic mammals, terrestrial birds, etc. in the area. These researchers generally require FCIR photography at a scale of about 1:12,000. They may require a series of study areas totalling perhaps 300 square kilometres to be flown for habitat analyses. This should cost around $2,500.

Thermal imagery in conjunction with colour aerial photography, both at relatively large scales, should be used for water quality studies along the major lakes and drainage courses which may be affected by oil sands development. This imagery should be obtained annually or more frequently to monitor water quality.

In every program in which remote sensing is required, careful assessment must be done prior to deciding on the remote sensing requirements. Cost of the program, the time required to carry out the program, and the quality of the data required are the most important factors. These are influenced by the area of overage, the cost of the remote sensing imagery, the method of analysis and interpretation, the amount of further data processing needed and the required accuracy of the final interpreted product.

9.3 RECOMMENDATIONS REGARDING COMPUTER BASED INFORMATION SYSTEM FOR AOSERP

The final set of recommendations concerns the establishment of a computer-based information system which would store and analyze large amounts of information in a timely fashion, one which seems particularly applicable to the AOSERP study area in which many detailed research programs involving the spatial distribution of habitat are being and will be carried out over the next few years. Before any commitments are made to implement such a system, a test case should be attempted.

1. First, digital analysis of aerial photography at two or three scales should be compared with visual analysis of the same photographs, to accurately evaluate the sensitivity, accuracy and cost effectiveness of both approaches to interpretation, mapping and monitoring in the AOSERP study area and for application to the AOSERP objectives.

2. Second, to obtain improved results in future work, automated geocoding should be modified as follows. Original maps rather than map copies should be used for photo reduction. High contrast transparencies should be generated at a variety of scales until an appropriate scale can be decided upon for maps with small and detailed information. Scanning of the transparencies at additional aperture settings should be carried out. Even though none of the 25 micron files could be read, it is hypothesized that the 25 micron aperture would be appropriate for the geocoding of the habitat maps in the 4" x 5" format size since the 100 micron setting did not appear to produce readable alphanumeric information, and the 50 micron setting produced information of limited readability.

   Additional enhancement methods could be attempted on the Image 100 to gain a better appreciation for the most appropriate techniques that should subsequently be used. In the near future a Versatec plotter with a high contrast plotting capability and a wide paper format will be available for the generation of high quality map data; use of this plotter would likely generate geocoded maps of improved quality. If the geocoded maps are to be added to other digital data sets such as classified remote sensing images and digital animal tracking information, it would be more suitable to have the maps geocoded on the PDS system which is directly interfaced to the Image 100. The PDS is more versatile than the SMD in that it will have a greater variety of aperture settings and an instant quality control capability to check for poorly digitized data.

3. Third, analysis of digital Landsat data should be carried out to accurately assess its applicability to ecological habitat mapping and monitoring in the AOSERP study area. This should include an unsupervised approach to analysis on the Image 100 analysis system, and incorporate a time-variant approach (seasonal, annual) to assess change in the environment.

4. Finally, a demonstration of the interaction between digital aerial photograph data, digital Landsat data, geocoded maps and any other available digital data for the study area (for example, digitized animal tracking data) should be carried out. This would involve comparative interpretations plus overlaying of one data set on another, to demonstrate their application to habitat research in the area.

When these demonstration projects have been assessed, it should then be possible to make a recommendation regarding the feasibility and cost-effectiveness of setting up a computer-based information system for AOSERP.

10. LIST OF REFERENCES

Alberta - A natural history. 1971. W.G. Hardy (ed.) Published by the Patrons. Edmonton, Alta. 343 p.

Alberta Oil Sands Environmental Research Program. 1977. Alberta Oil Sands Environmental Research Program: Operational policy and research goals, revised draft. Edmonton, Alta. 36 p.

American Geological Institute. 1976. Dictionary of geologic terms. Archer Press. New York, N.Y. 472 p.

American Society of Photogrammetry. 1960. A manual of photographic interpretation, 3rd ed. George Banta Co. Inc. Menasha, Wisconsin. 1199 p.

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Winter. n.d. A land use and land cover classification system for use with remote sensor data. Geological Survey Prof. Paper 964, U.S.G.S. 28 p.

Anderson, J.R., E.E. Hardy, and J.T. Roach. 1972. A land-use classification system for use with remote-sensor data. Geological Survey Circular 671. Washington, D.C. 16 p.

Anderson, A.T. and J. Schubert. 1976. ERTS-1 data applied to strip mining. Photogrammetric Engineering & Remote Sensing 42(2): 211-219.

Atlas of Alberta. 1969. Government of Alberta and the University of Toronto Press. Edmonton. 158 p.

Avery, T. Eugene. 1968. Interpretation of aerial photographs, 2nd ed. Burgess Publishing Co. Minneapolis, Minnesota. 324 p.

Bayrock, L.A. 1971. Map 34, Surficial geology, Bitumount N.T.S. 74E, 1:250,000. Research Council of Alberta.

Bayrock, L.A. and T.H.F. Reimchen. 1974. Surficial geology, Waterways N.T.S. 74D, 1:250,000. Alberta Research Council.

Bobba, A.G., J.E. Bruton, and R.P. Bukata. 1976. Landsat-1 identification of groundwater regimes in a Great Lake Basin. Pages 216-230 in Proc. Workshop on Remote Sensing of Soil Moisture and Groundwater. November 8-10, 1976. Toronto, Ontario. 242 p.

Boydell, A.N. 1974. Evaluation of the potential uses of ERTS data for small scale terrain mapping in Canada's North. Pages 329-340 in Proc. International Society of Photogrammetry. Symposium on Remote Sensing and Photo Interpretation. Banff, Alberta, October 1974. 878 p.

Boyle, A.R. and J. Sharp. 1972. Basis of assessment of equipment systems; Chapter 7 in Geographic Data Handling. Vol. 2, R.F. Tomlinson (editor). Ottawa: IGU Commission of Geographical Data Sensing and Processing.

Bureau of Land Management, U.S. Dept. of the Interior. 1976. Wild land vegetation resource inventory: A remote sensing project. Detailed project plan for a joint BLM-NASA-EROS application systems verification test. Washington, D.C.

Canada. Energy, Mines and Resources. 1977. Information bulletin: airborne operation, 3rd ed. Canada Centre for Remote Sensing. Ottawa, Ontario. 112 p.

Canada Soil Survey Committee. 1976. The Canadian system of soil classification. (Draft copy) Agriculture Canada. Ottawa, Ontario. 171 p.

Carder, A.C. 1971. Climate of the Lower Peace River Region. Canada Dept. of Ag. Publ. 1434. 22 p.

Carrigy, M.A. and J.W. Kramers. 1974. Guide to the Athabasca oil sands area. Alberta Research Council. Edmonton, Alberta. 213 p.

Colwell, R.N. 1972. Uses and limitations of multispectral remote sensing. Unpublished presentation to 1972 Alberta Remote Sensing Course. Alberta Remote Sensing Center. Edmonton, Alberta.

Cosgriffe, H.R., J.M. Linne, and M.P. Heyer. 1973. Forest and rangeland resource inventory with small scale color infrared aerial photography. In Aerial Photography in the Plant Sciences and Related Fields. American Society of Photogrammetry. University of Maine. Orono, Maine.

Dabbs, D.L. 1971. Landscape classification of the Peace-Athabasca Delta using air photo techniques. Ph.D. thesis, Dept. Plant Ecol., Univ. Saskatchewan, Saskatoon, Saskatchewan. 350 p.

Dasmann, R.F. 1964. Wildlife biology. John Wiley and Sons, Inc. New York, N.Y.

Daubenmire, R. 1968. Plant communities: A textbook of plant synecology. Harper & Row. New York, N.Y. 300 p.

Dirschl, H.J., D.L. Dabbs, and G.C. Gentle. 1974. Landscape classification and plant successional trends in the Peace-Athabasca Delta. Canadian Wildlife Service Report Series - Number 30. Information Canada. Ottawa, Ontario. 34 p.

Duffy, P.J.B. 1965. A forest land classification for the mixed-wood section of Alberta. Can. Dep. Forest., Pub. No. 1128, 23 p.

Economy, R., D. Goodenough, R. Ryerson, and R. Towles. 1974. Classification accuracy of the Image-100. Pages 278-287 in Proc. 2nd Can. Symp. on Remote Sensing, Univ. of Guelph, April 29-May 1, 1974. 764 p.

Fleming, M.D., J. Berkebile, and R. Hoffer. 1975. Computer aided analysis of Landsat-1 MSS data: A comparison of three approaches, including a modified cluster approach. LARS Information Note 072475. LARS Purdue University, West Lafayette, Indiana.

Frost, R.E. 1945. Identification of granular deposits by aerial photography. Pages 28-37 in HRB Proceedings, Vol. 25.

Fulton, R.J., A.N. Boydell, D.M. Barnett, D.A. Hodgson, and V.N. Rampton. 1974. Terrain mapping in northern environments. Pages 14-60 in Canada's Northlands: Proc. Tech. Workshop, Lands Dir., Envir. Mgt. Serv., Envir. Can., Ottawa, Ontario.

Garner, N.F. 1974. The origin of landscapes. Oxford University Press. New York, N.Y. 734 p.

Gierman, D.M., R.A. Ryerson, G. Moran, and W.A. Switzer. 1975. Remote sensing and the Canada Geographic Information System for impact studies. Pages 235-241 in Proceedings of the Third Canadian Symposium on Remote Sensing, held September 22-24 1975, Edmonton, Alberta. Canadian Aeronautics and Space Institute. Ottawa, Ontario. 516 p.

Goldberg, M., D. Goodenough, and S. Shlien. 1977. Classification methods and error estimation for multispectral scanner data. Pages 125-143 in Proc. 3rd Can. Symp. on Remote Sensing. Sept. 1977. Edmonton, Alberta. 516 p.

Goldberg, M. and S. Schlien. 1977. A four dimensional histogram approach to the clustering of Landsat data. Pages 250-259 in Proc. 1977 Machine Processing of Remotely Sensed Data Symposium.

Gimbarzevsky, P. 1974. Interpretation of ERTS imagery in biophysical surveys. The Canadian Surveyor 28(2):171-176.

Goodenough, D. 1977. The Canada center for remote sensing's image analysis system (CIAS). Pages 227-243 in Proc. Fourth Symp. on Remote Sensing. May 16-18, 1977. Quebec City, Quebec. 816 p.

Goodenough, D. 1976. Image-100 classification methods for ERTS scanner data. Can. Journal of Remote Sensing 2(1):18-29.

Goodenough, D., J. MacDowall and R.A. Ryerson. 1974. Status Report on automatic classification of ERTS imagery of Canada. Pages 733-745 in Proc. International Soc. of Photogrammetry Symposium on Remote Sensing and Photo Interpretation. Oct. 7-11, 1974. Banff, Alberta. 878 p.

Goodenough, D. and S. Shlien. 1974. Results of cover-type classification by maximum likelihood and parallelepiped methods. Pages 135-164 in Proc. Second Canadian Symposium on Remote Sensing. Univ. of Guelph, Ont. April 29-May 1, 1974. 764 p.

Harper, D. 1976. Eye in the sky: Introduction to remote sensing. Canada Science Series. Multiscience Publications Ltd. Information Canada, Montreal, Quebec. 164 p.

Heller, R.C. 1975. Evaluation of ERTS-1 data for forest and rangeland surveillance. USDA Forest Service Research Paper PFW-112. Pacific S.W. Forest & Range Station, Berkeley, California.

Heyland, J.D. 1973. Increase the accuracy of your airborne censuses by means of vertical aerial photographs. Trans. 27th Northeast Fish and Wildlife Conference.

Heyland, J.D. 1972. Vertical aerial photography as an aid in wildlife population studies. In Proc. First Canadian Symposium on Remote Sensing.

Hoffer, R.M., M.D. Fleming, and P.V. Krebs. 1975. Use of computer aided analysis techniques for cover type mapping in areas of mountainous terrain. NTIS-N74-34746, U.S. Dept. of Commerce, National and Technological Information Service.

Holland, W.D. 1976. Biophysical land classification of Banff and Jasper National Parks. Pages 221-237 in Proc. 1st Mtg. Can. Comm. on Ecological (Bio-Physical) Class. Petawawa, Ont. 269 p.

Howarth, P.J. 1976. An evaluation of Landsat imagery for land classification of Eastern Melville Island, N.W.T., Canada. Lands Directorate, Environment Canada. Ottawa, Ontario. 158 p.

Hunt, C.B. 1964. Natural regions of the United States and Canada. W.H. Freeman and Co., San Francisco, Ca. 725 p.

Intercontinental Engineering of Alberta Ltd. (Integ). 1973. An environmental study of the Athabasca Tar Sands. Alberta Environment. Edmonton, Alberta. 112 p.

Jacques, D. 1977. The capabilities of high-flight aerial photography and Landsat multispectral imagery for monitoring coal reclamation activity. Proc. Coal Industry Reclamation Symposium. February 13-16, 1977. Banff, Alberta. 13 p.

Kalensky, Z. 1974. ERTS thematic map from multidate digital images. Pages 767-786 in Proceedings of Symposium on Remote Sensing and Photo Interpretation, International Society for Photogrammetry, Commission VII. October 7-11, 1974. Banff, Alberta. 878 p.

Kirby, C.L., and P.I. Van Eck. 1977. A basis for multistage forest inventory in the boreal forest region. Pages 71-94 in Proc. 4th Can. Symp. on Remote Sensing. May 16-18, 1977. Quebec. 816 p.

Kirby, C.L., D. Goodenough, D. Day, and P. Van Eck. 1975. Landsat imagery for Banff and Jasper National Parks inventory and management. Pages 207-226 in Proc. 3rd Can. Symposium on Remote Sensing, Sept. 22-24, 1975. Edmonton, Alta. 516 p.

Krajina, V.J. n.d. Biogeoclimatic zones of British Columbia. MacMillan Bloedel. Vancouver, B.C.

Lacate, D.S. 1969. Guidelines for bio-physical land classification. Can. Forest. Service, Dep. Fisheries and Forestry. Pub. No. 1264. Ottawa, Ont. 61 p.

Langley, P.G. 1971. Multistage sampling of earth resources with aerial and space photographs. Pages 129-142 in Monitoring Earth Resources from Aircraft and Spacecraft, R. N. Colwell. Forestry Remote Sensing Lab. University of California. 170 p.

La Roi, G.H. 1967a. Taiga. Pages 151-169 in Alberta, a natural historv. W.G. Hardy (ed.), Published by the Patrons. Edmonton, Alberta. 343 p.

Lee, Y.J. 1975. Reliability of estimating clear-cut and uncut and mature timber areas using Landsat imagery. Pages 265-272 in Proc. 3rd Canadian Symposium on Remote Sensing. Sept. 22-24, 1975. Edmonton, Alta. 516 p.

Legge, A.H. et al. 1974. Development and application of an ecologically based remote sensing legend system for the Kananaskis, Alberta, (Remote Sensing Test Corridor (Subalpine) Forest Region). Inter. Soc. Photogrammetry. October 1974. Banff, Alta. 47 p.

Lueder, D.R. 1959. Aerial photographic interpretation - principles and applications. McGraw Hill, New York, N.Y. 47 p.

Lombard North Group. 1973. An environmental impact assessment of the Shell Canada Limited development plan for Lease C-13, Athabasca Tar Sands. June 4, 1973. Calgary, Alberta.

Lombard North Group. 1974. Environmental study. Amoco Canada Tar Sands lease, Gregoire Lake area, Alberta. Lombard North Group. Calgary, Alberta. 158 p.

MacConnell, W.P. and P. Stoll. 1969. Evaluating recreational resources of the Connecticut River. Photogrammetric Engineering 35(7): 686-692.

Manual of Remote Sensing. 1975. Vol. 1: Theory, instruments and techniques. F.J. Janza (ed.). American Society of Photogrammetry. Falls Church, Va. 867 p.

McCarthy, M.M. 1972. Monitoring levels of existing environmental impact utilizing remote sensing techniques. Pages

1385-1409 in Proc. Eighth International Symposium on Remote Sensing - Volume 2. University of Michigan, Ann Arbor, Michigan. October 2-6, 1972. 1540 p.

McPherson, R.A. and C.P. Kathol. 1977. Surficial geology of potential mining areas in the Athabasca Oil Sands Region - Quaternary Geoscience Ltd. Alberta Research Council. Open File Report 1977-4. 177 p.

Michalyna, W., and R.G. Eilers. 1973. Effects of various soil properties and management practices on infrared scan and panchromatic imagery from Portage la Prairie, Manitoba. Can. Jour. Soil Science 53: 445-457.

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

Miller, V.C. 1961. Photogeology. McGraw-Hill. New York, N.Y. 248 p.

Miller, W.L. 1974. The economic impact of remote sensing data as the source of nonpoint pollution monitoring and control. LARS information Note 041674. Purdue University, West Lafayette, Indiana. 11 p.

Mollard, J.D. n.d. Landforms and surface materials of Canada. A stereoscopic airphoto atlas and glossary, 3rd ed. Regina, Sask. various pagings.

Moss, E.H. 1959. Flora of Alberta. Univ. Toronto Press. 546 p.

Moss, E.H. 1932. The vegetation of Alberta. IV--The poplar association and related vegetation of Central Alberta. J. Ecol. 20:380-415.

Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21: 493-567.

National Aeronautics and Space Administration (NASA). 1976. Landsat data users handbook. Goddard Space Flight Centre. Greenbelt, Maryland.

National Aeronautics and Space Administration (NASA). 1975. Proceedings of the NASA Earth Resources Survey Symposium, held June 1975 in Houston, Texas, Volume I. Lyndon B. Johnson Space Centre. Houston, Texas. 598 p.

North, M.E.A. 1976. A plant geography of Alberta. Dept. of Geography, University of Alberta, Edmonton, Alberta. 147 p.

Olson, C.E. Jr. 1977. Pre-visual detection of stress in Pine forests. Pages 933-944 in 11th International Symposium on Remote Sensing of Environment. April 1977, Ann Arbor, Michigan. 1688 p.

Paul, C.K. 1977. Remote sensing of environmental impact of land use activities. Pages 363-378 in Proceedings of the Eleventh International Symposium on Remote Sensing of Environment, held April 25-29, 1977. Environmental Research Institute of Michigan. Ann Arbor, Michigan. 1668 p.

Pfister, R.D. 1977. Ecological classification of forest land in Montana and Idaho. Pages 329-358 in Proc. Ecological Classification of Forest Land in Canada and Northwestern USA. Vancouver, B.C. 395 p.

Pierce, T.W. and J. Thie. 1976. Biophysical land classification in the Environmental Management Service, Dept. of the Environment. Pages 55-58 in Proc. 1st Mtg. Can. Comm. on Ecological (Bio-physical) Land Class. Petawawa, Ontario.

Ray, R.G. 1960. Aerial photographs in geologic interpretation and mapping. Geological Survey Publications Paper 373. U.S. Government Printing Office. Washington, D.C. 48 p.

Ross, G.A. 1970. Airphoto interpretation in route location and materials survey. Fifth Nevada and Highway Conference. Reno, Nevada. March 18, 1970. 13 p.

Rowe, J.S. 1972. Forest regions of Canada. Dept. of Environment, Can. Forest Service, Pub. No. 1300. Ottawa, Ontario. 172 p.

Salomonson, V.V. 1973. Water resources. Pages 126-137 in Symp. on Significant Results Obtained from Earth Resources Technology Satellite-1. Greenbelt, Maryland, March 5-9, 1973. 179 p.

Scarpace, F.L., R.P. Madding, and T. Green. 1975. Scanning thermal plumes. Photogrammetric Engineering and Remote Sensing 41(10): 1223-1231.

Scarpace, F.L., R.E. Wade, and L.T. Fisher. 1974. The use of ERTS imagery for lake classification. Pages 259-272 in Proc. of Symp. on Remote Sensing and Photo Interpretation, International Society for Photogrammetry, Com. VII, October 7-11, 1974. Banff, Alberta. 878 p.

Scherz, J.P. J.F. Van Domelen, K. Holtje, and W.L. Johnson. 1974. Lake eutrophication as indicated by ERTS satellite imagery. Pages 247-258 in Proc. of Symp. on Remote Sensing and Photo Interpretation, International Society for Photogrammetry, Com VII, October 7-11, 1974. Banff, Alberta. 878 p.

Schick, C.C. and K.R. Ambrock. 1974. Waterfowl investigations in the Athabasca Tar Sands Area. Can. Wildlife Serv. Unpubl. rep. 34 p.

Shanholtzer, G., and L.D. Alexander. 1975. The application of Landsat data to habitat mapping in site and route selction studies. Pages 438-494 in Proceedings of the Fall Convention of the American Society of Photogrammetry, held October 1975. Phoenix, Arizona. 891 p. American Society of Photogrammetry. Falls Church, Virginia.

Shlien, S. and D. Goodenough. 1974. Quantitative methods of processing the information content of ERTS imagery for terrain classification. Pages 237-265 in Proc. Second Canadian Symposium on Remote Sensing. Univ. of Guelph, Ontario. April 29-May 1, 1974. 764 p.

Steiner, D., and A.E. Salerno. 1975. Remote sensor data systems, processing and management. Pages 611-803 in R.G. Reeves (ed.), Manual of Remote Sensing. American Society of Photogrammetry. Falls Church, Va. 2144 p.

Stohr, C.J., and T.R. West. 1974. Delineation of sinkholes using thermal infrared imagery. LARS Information Note 032574. Purdue University, West Lafayette, Indiana. 143 p.

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

Syncrude Canada Ltd. 1975. Baseline environmental studies of Ruth Lake and Poplar Creek. Environmental Research Monograph. 1975-3. 120 p.

Syncrude Canada Ltd. 1974a. Regional hydrogeological study, McMurray Oil Sands Area, Alberta. Environmental Research Monograph 1976-5. October 1974. 41 p.

________ 1974b. Remote sensing and the Athabasca Tar Sands, an overview. Syncrude Canada Ltd., Environmental Research Monograph 1974-1. 47 p.

Syncrude Canada Ltd. 1973a. The habitat of Syncrude Tar Sands lease #17, an initial evaluation. Syncrude Canada Ltd., Environmental Research Monograph 1973-1. 40 p.

________ 1973b. The hydrology of lease 17: A report of studies completed in the year 1973. Environmental Research Monograph 1975-2. 44 p.

Tanguay, M.G., and J.Y. Chagnon. 1972. Thermal infrared imagery at the St. Jean-Vianney landslide. Pages 387-402 in Proc. 1st Can. Symp. on Remote Sensing. February 1972, Ottawa. 764 p.

Thie, J. 1976. Evaluation of remote sensing techniques for biophysical ladn classification in the Churchill Area, Manitoba. Unpubl. M.Sc. thesis, Dept. Soil Science, Univ. of Manitoba, Winnipeg. 89 p.

Thie, J., and G. Ironside (eds.). 1976. Ecological (biophysical) land classification in Canada. Proc. 1st Mtg. Can. Comm. on Ecological (Biophysical) Land Class. May 25-28, 1976. Petawawa, Ont. 269 p.

Thie, J., and C. Wachmann. 1974. Remote sensing for environmental monitoring and impact assessment. Pages 301-316 in Proc. ISP Comm. VII Symp. Remote Sensing and Photo Interpretation. October 7-11, 1974. Banff, Alberta. 878 p.

Walmsley, M.E., and J. van Barnweld. 1977. Biophysical land classification techniques: The application to ecological classification of forest land in British Columbia. Pages 42-120 in Proc. Ecological Classification of Forest Land in Canada and Northwestern USA. Vancouver, B.C. 395 p.

Weber, F.P. 1971. Applications of airborne thermal remote sensing in forestry. Pages 75-88 in Applications of remote sensors in forestry. Inter. Union of Forest Research Organizations. Druckhaus Rombach, Freiburg, West Germany. 189 p.

Williams, R.S. Jr., and W.D. Carter, (eds.). 1976. ERTS-1: A new window on our planet. Geological Survey Professional Paper 929. U.S. Government and Printing Office. Washington, D.C. 362 p.

Wobber, F.J., C.E. Weir, T. Leshendok, and W. Beeman. 1975. Coal refuse site inventories. Photogrammetric Engineering and Remote Sensing 41(9): 1163-1171.

Wride, M.C., and K. Baker. 1977. Thermal imagery for census of ungulates. Pages 1091-1100 in Proc. 11th Symp. on Remote Sensing of Environment. Ann Arbor, Michigan. April 1977. 1688 p.

Zoltai, S.C., F.C. Pollett, J.K. Jeglum, and G.D. Adams. 1975. Developing a wetland classification for Canada. In Forest soils and land management. Pages 479-511 in Proc. 4th North America Soils Conf. Laval, Quebec. August 1973. B. Bernier and C.H. Winget (eds.). Les Presses de L'Univ. Laval.

11. APPENDICES

11.1 Glossary of Surficial Geology Terms

abandoned shoreline: former contact between the land and a pre-existing water body, may be identified by the presence of beach deposits and former beach ridges.

active floodplain: portion of a river valley adjacent to the river channel, deposited during the present stream's regime and covered with water when the river overflows its banks during flood stages.

apron: (CSSC) a relatively gentle slope at the foot of a steeper slope, and formed by materials from the steeper, upper slope.

beach ridges: discontinuous linear mounds of beach material (primarily sands and coarser sediments) heaped up by wave action; often occur in a series of parallel curving ridges.

bedrock: (CSSC) consolidated solid rock exposed at the surface of the earth or overlain by unconsolidated material.

blanket: (CSSC) a mantle of unconsolidated materials thick enough to mask minor irregularities in the underlying topography but which still conforms to the underlying relief.

colluvial: (CSSC) non-sorted to poorly sorted massive to moderately well stratified sediments ranging in size from clay to boulders and blocks, having reached their present position by direct, gravity induced movement.

crag and tail: streamlined ridge or hill paralleling the direction of ice movement; usually consisting of a knob containing resistant bedrock material (crag) and an elongate tail of till or weaker bedrock.

deflated: (modified CSSC) the modification of the surficial debris through the sorting out, lifting and removal of loose, dry, fine grained particles by the turbulent eddy action of the wind.

drumlin: streamlined hill or ridge composed of glacial till paralleling the direction of ice movement; generally steepest toward one side, with other slopes being considerably more gentle.

eolian: (modified CSSC) medium to fine sand and coarse silt that has been transported through the turbulent eddy action of the wind; generally well sorted, poorly compacted, massive to weakly cross-bedded.

eroded (channelled): sloping surface crossed by a series of intermittent channels, active channels, or abandoned channels.

escarpment: steeply sloping face commonly encountered along entrenched river channels, and along abrupt terminations to highlands.

esker: long narrow sinuous ridge of rudely stratified sands and gravels marking the course of a former subglacial drainage channel.

extensively eroded by post depositional processes: used primarily to discriminate areas extensively modified by fluvial processes from those only moderately eroded since deposition.

failing: (CSSC) modification of surfaces by the formation of tension fractures or by large consolidated or unconsolidated masses moving slowly downslope, i.e. slumps.

fan: (modified CSSC) cone shaped alluvial deposit possessing a perceptible gradient from apex to toe; formed where a stream runs out onto a level plain or meets a slower stream. The reduction in gradient decreases the stream's carrying capacity resulting in partial deposition of its load. Sediment includes massive and crudely stratified coarse, medium and fine grained debris.

fluvial: (modified CSSC) sediments transported and deposited through the action of running water. Generally includes stratified, moderately well sorted, rounded gravels and sands, with minor amounts of silt and clay.

fluvial bar: mass of sand, gravel or alluvium deposited on the bed of a stream.

fluvial terrace: slightly inclined level surface bounded by a steeply ascending slope on one side, and steeply descending slope on the other. Marks the former position of a river meander.

glacial: (modified CSSC) produced or deposited as a result of glacier ice exerting strong control upon the mode of origin of the materials or mode of operation of the process.

glacial fluting: large furrow cut by the abrading action of debris contained within the ice; often appears as a series of elongate parallel ridges and depressions aligned in the direction of ice flow.

glaciofluvial: (modified CSSC) deposit formed by the interaction of ice and running water; usually refers to features deposited either directly in front of or in contact with glacier ice.

glaciolacustrine: (CSSC) used where there is evidence that lacustrine materials were deposited in contact with glacial ice.

gullied: (modified CSSC) sloping surface crossed by a series of parallel to subparallel, steep sided and narrow drainage channels.

hummocky: (CSSC) complex sequence of slopes extending from somewhat rounded depressions or kettles of various sizes to irregular or conical knolls or knobs.

inclined: (CSSC) a sloping unidirectional surface with a generally constant slope not broken by marked irregularities. Slopes are between 1^{o} and 35^{o}.

kame: conical hill or ridge usually composed of stratified sands and gravels formed in contact with glacial ice.

kame terrace: terracelike body of stratified sand and gravel deposited between a valley glacier and the adjacent valley wall, or between two glacial lobes.

karst modified: (CSSC) modification of overlying unconsolidated materials by collapse resulting from solution of underlying carbonate rocks.

kettle: steep sided bowl-shaped depression in glaciofluvial, glaciolacustrine or glacial till deposits, usually bounded by an abrupt convex break of slope; formed as partially or wholly buried blocks of ice melted.

kettled: (CSSC) deposit or feature modified by depressions formed by melting ice blocks.

lacustrine: (CSSC) sediment generally consisting of either stratified fine sand, silt and clay deposited in the lake bed or moderately well-sorted and stratified sand and coarser materials that are beach and nearshore sediments, transported and deposited by wave action.

level: (modified CSSC) a flat or very gently sloping unidirectional surface with a generally constant slope of less than 1^{o}.

local relief: the average difference in elevation between the high and low points of features on the land surface.

meander scar: crescentic depression within a stream valley formed by lateral planation of the stream.

meltwater channel: vally (often steep sided) created by the downcutting of a stream whose source of water was from the melting of glacial ice and snow.

meltwater channel sediments: mainly stratified sands, silts and clays deposited within a recognizable channel of a meltwater stream.

modifying process: (modified CSSC) includes a variety of geological processes that have modified or are currently modifying genetic materials and their surface expression.

morainal (glacial till): (modified CSSC) sediment generally consisting of well-compacted non-stratified material of varied particle size which has been transported by a glacier and deposited without modification by intermediate agents.

organic deposits: peat deposits derived from both sphagnum mosses and sedges and varying from thin localized deposits (less than 1 metre) to thick deposits completely masking the character of underlying sediments.

outwash bar remnants: mounds of partially stratified sands and gravels deposited as fluvial bars in meltwater streams.

outwash bench: slightly inclined level surface bounded by a sharp break in slope; consists of stratified sands and gravels deposited in a former outwash plain or meltwater channel.

outwash plain: a level to undulating plain composed of material washed out from glacier ice by meltwater streams; material varies in particle size and is usually stratified.

outwash terrace: slightly inclined level surface bounded by a sharp break in slope, consists of stratified material deposited in a former outwash plain or meltwater channel.

oxbow lake: a crescent-shaped lake formed in an abandoned river bend which has become separated from the main stream by a change in the course of the river.

ridged: (modified CSSC) an elongate sharp crested upland surface with steep sides; ridges may appear parallel, subparallel or intersecting.

<u>rolling</u>: (CSSC) a very regular sequence of moderate slopes extending from rounded sometimes confined concave depressions to broad rounded convexities producing a wave-like pattern of moderate relief.

<u>sand dune</u>: a mound or ridge of windblown (eolian) sand which may be stabilized through vegetation encroachment.

<u>sand hill</u>: a large, often irregular shaped deposit of windblown sand rising above the surrounding land surface.

<u>sinkhole</u>: a funnel-shaped circular to elongate depression in the land surface communicating with a subterranean passage developed by solution, usually in a limestone region.

<u>slump</u>: material that has slipped down from higher slopes moving as a unit or several subsidiary units, usually exhibiting backward rotation on a horizontal axis parallel to the slope which it descends.

<u>surface expression</u>: (modified CSSC) the form (assemblage of slopes) and pattern of forms assumed by the uppermost layer of the overburden.

<u>terraced</u>: relatively flat, horizontal, or gently inclined surface bounded by a steeply ascending slope on one side and by a steeper descending slope on the opposite side; results in steplike topography along valley walls.

<u>undulating</u>: (modified CSSC) a regular sequence of gentle slopes extending from rounded, sometimes confined concavities to broad rounded convexities to produce a wave-like pattern of local relief.

<u>veneer</u>: (CSSC) thin layer of unconsolidated materials too thin to mask the minor irregularities of the underlying unit surface.

11.2 A Preliminary list of fish fauna endemic to the major habitat types in the AOSERP Study Area. (Species are ranked in order of economic or scientific importance.)

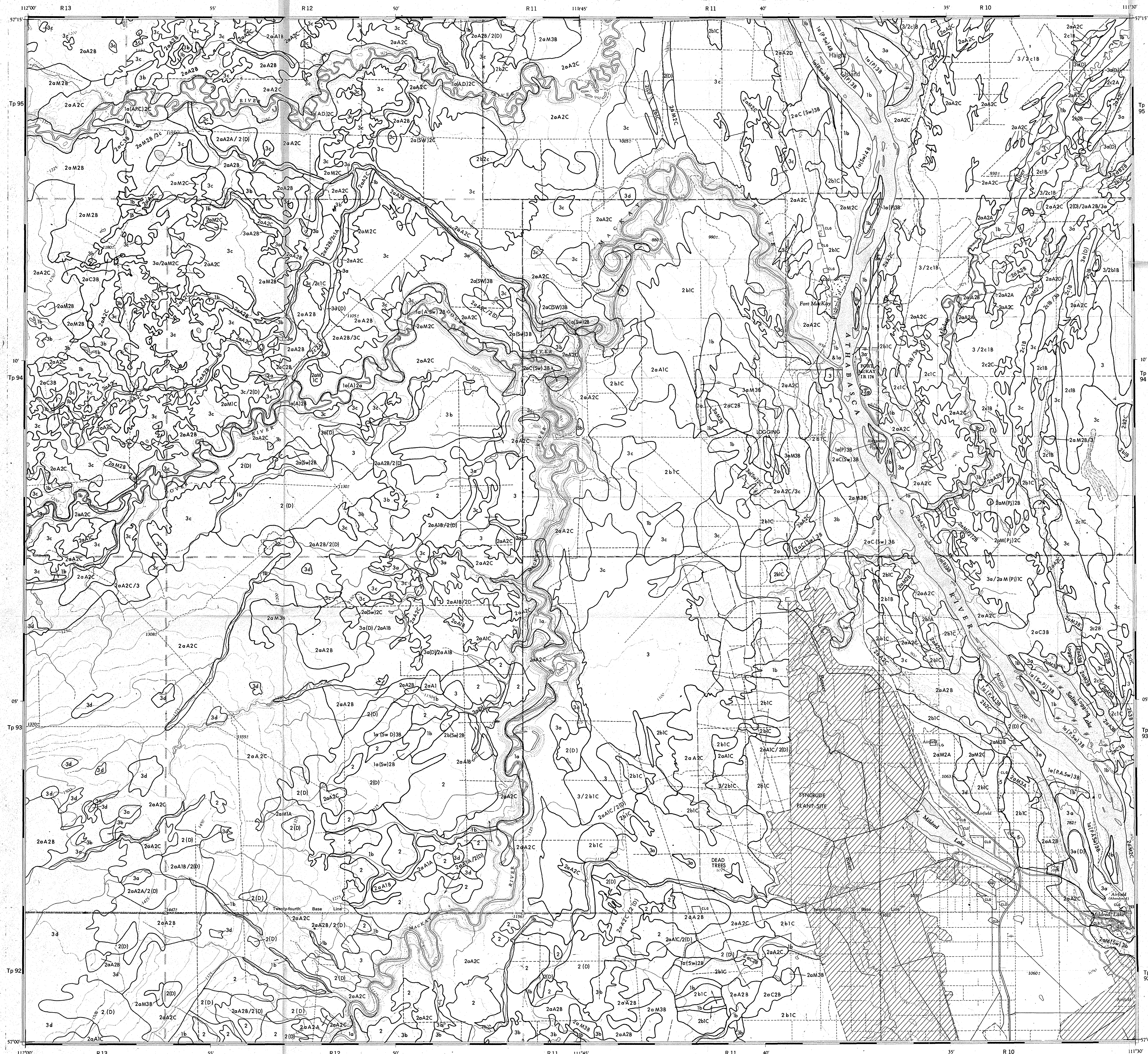
Species	Lakes	Large Rivers[1]	Tributary Streams
Lake trout (*Salvelinus namaycush*)	+		
Arctic grayling (*Thymallus arcticus*)		+	+
Walleye (*Stizostedion vitreum*)	+	+	
Rainbow trout (*Salmo gairdneri*)[2]		+	
Dolly Varden (*Salvelinus malma*)[2]		+	
Lake whitefish (*Coregonus clupeaformis*)	+	+	
Mountain whitefish (*Prosopium williamsoni*)		+	+
Northern pike (*Esox lucius*)	+	+	+
Goldeye (*Hiodon alosoides*)		+	
Yellow Perch (*Perca flavescens*)	+	+	
Lake cisco (*Coregonus artedii*)	+	+	
Longnose sucker (*Catostomus catostomus*)	+	+	+
White sucker (*Catostomus commersoni*)	+	+	+
Burbot (*Lota lota*)	+	+	
Brook stickleback (*Culaea inconstans*)	+	+	+
Spoonhead sculpin (*Cottus ricei*)		+	
Slimy sculpin (*Cottus cognatus*)	+	+	+
Longnose dace (*Rhinichthys cataractae*)		+	
Pearl dace (*Semotilus margarita*)		+	
Lake chub (*Couesius plumbeus*)		+	
Flathead chub (*Hybopsis gracilis*)		+	
Emerald shiner (*Notropis antheroides*)		+	
Spottail shiner (*Notropis hudsonius*)		+	
Fathead minnow (*Pimephales promelas*)			+

[1] includes fauna of Athabasca River

[2] rare in study area

12. AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta
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 Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters Upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigation into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather, a Feasibility Study
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant
14.	HE 2.4	Athabasca Oil Sands Historical Research Design (3 volumes)
15.	ME 3.4	Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Alberta Oil Sands Region Stream Gauging Data
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Evaluation of Organic Constituents
21.		AOSERP Second Annual Report, 1976-77
22.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 4.2.1	Review of Dispersion Models and Possible Applications in the Alberta Oil Sands Area
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area



VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar, aspen poplar, white spruce, willow, alder, paper birch
b. DECIDUOUS SHRUB	willow, alder, dwarf birch, immature aspen, paper birch
2. UPLAND COMMUNITIES	
UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites, aspen poplar, tall willow, alder, balsam poplar, paper birch
a. WHITE SPRUCE – ASPEN FOREST (2aA aspen; 2aM mixed; 2aC coniferous)	white spruce, aspen, jack pine
b. MIXED CONIFEROUS	black spruce, jack pine, white spruce
c. JACK PINE	jack pine, black spruce, white spruce, aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES	
UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes, low scattered shrubs, tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI–OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses, sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs, sphagnum mosses
4. BURN	
5. NON–VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols

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

Height Class (m)

- 1 0 - 10
- 2 11 - 20
- 3 21 - 30
- 4 31+

Crown Cover

- A open
- B medium
- C dense

FORT MacKAY

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

MAGNETIC DECLINATION 25°56′ EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.5′

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978

74 E 4

FORT MACKAY

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

Miles 1 0 1 2 3 Milles
Metres 1000 500 0 1000 2000 3000 4000 Mètres
Yards 1000 500 0 1000 2000 3000 4000 Verges

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

MAGNETIC DECLINATION 25°56′ EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.5′

SURFICIAL GEOLOGY AND LANDFORMS

Standard: $A^{b}_{c}d, e\ f$ where,

A - genetic material
b - qualifying descriptor (not always used)
c - surficial expression
d - specific landform information (not always used)
e - local relief
f - modifying process (not always used)

Composite Area:
= both components present in approximate proportions.
– first component more abundant than second

GENETIC MATERIAL

C Colluvial
E Eolian
F Fluvial
L Lacustrine
M Morainal
R Bedrock
U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

QUALIFYING DESCRIPTOR

G Glacial

LANDFORM

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

SURFACE EXPRESSION

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

LOCAL RELIEF

1 less than 10 meters
2 10 - 50 meters
3 51 - 150 meters
4 over 150 meters

MODIFYING PROCESS

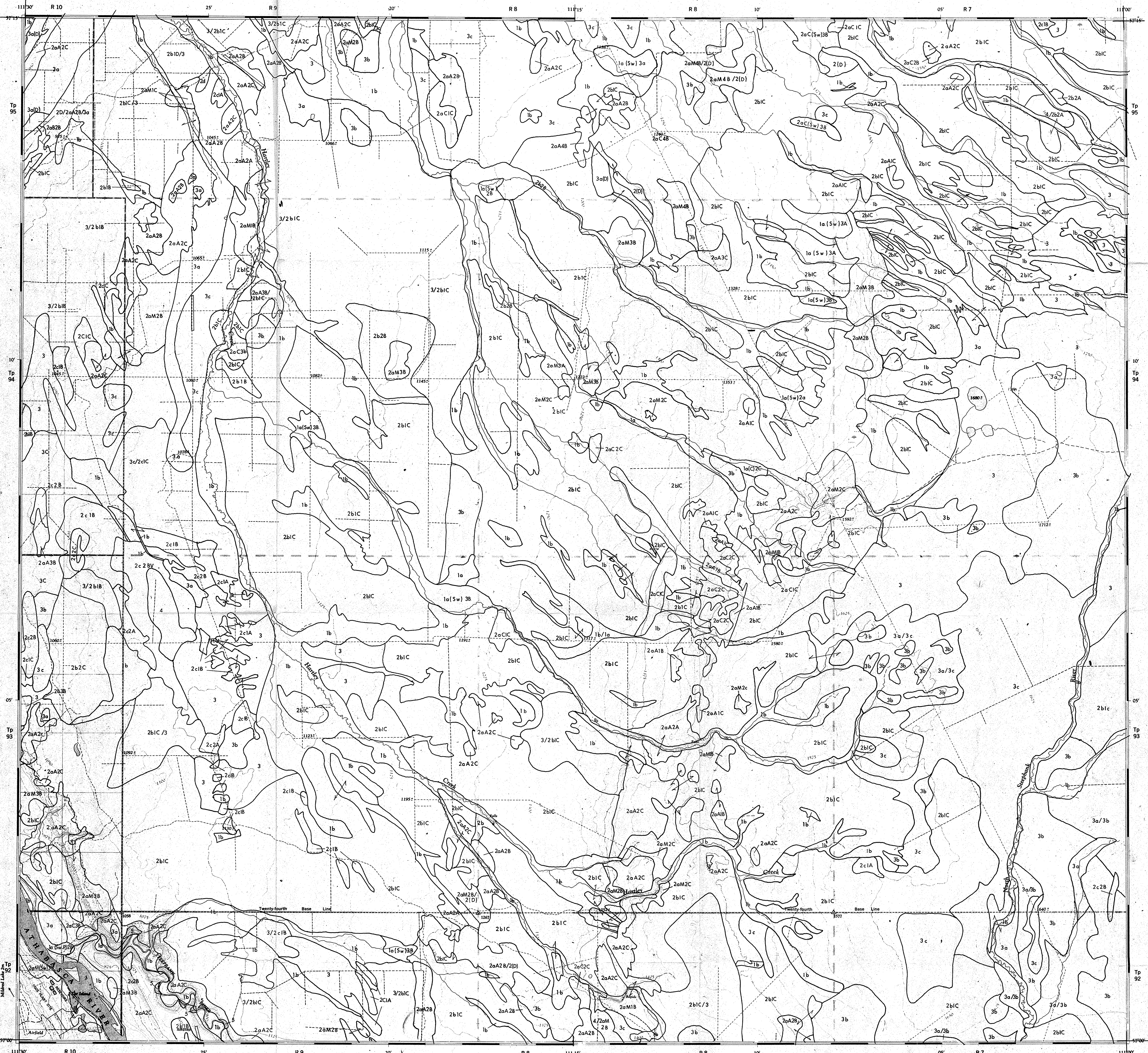
D deflated
E eroded (channelled)
F failing
H kettled
K karst modified
V gullied

SYMBOLS

kettle
drumlin
wetlands
esker
fluting
sinkhole
slump
dune
gullied
abandoned shoreline, beach ridges
crag and tail
glacial meltwater channel
escarpment (indicated downslope direction)

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978



VEGETATION LEGEND

		POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1.	BOTTOMLAND & RIPARIAN COMMUNITIES	
	a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar, aspen poplar, white spruce, willow, alder, paper birch
	b. DECIDUOUS SHRUB	willow, alder, dwarf birch, immature aspen, paper birch
2.	UPLAND COMMUNITIES	
	UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites, aspen poplar, tall willow, alder, balsam poplar, paper birch
	a. WHITE SPRUCE – ASPEN FOREST (2aA aspen; 2aM mixed; 2aC coniferous)	white spruce, aspen, jack pine
	b. MIXED CONIFEROUS	black spruce, jack pine, white spruce
	c. JACK PINE	jack pine, black spruce, white spruce, aspen
	d. UPLAND OPEN	grasses, low herbs and shrubs
3.	WETLAND COMMUNITIES	
	UNDIFFERENTIATED (Complex)	
	a. FEN COMMUNITIES	sedges, rushes, low scattered shrubs, tall shrubs
	b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
	c. SEMI–OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses, sedges, rushes
	d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs, sphagnum mosses
4.	BURN	
5.	NON–VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols

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

Height Class (m)

- 1 0 - 10
- 2 11 - 20
- 3 21 - 30
- 4 31+

Crown Cover

- A open
- B medium
- C dense

HARTLEY CREEK

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

MAGNETIC DECLINATION 25°44′ EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.4′

Building	Bâtiment	
School	École	
Post Office	Bureau de poste	P
Church	Église	
Horizontal control point	Point géodésique	
Astronomical monument	Repère astronomique	
R.C.M.P. Detachment	Poste de la G.R.C.	
Intermittent stream	Cours d'eau intermittent	
Intermittent lake	Lac intermittent	
Marsh or Swamp	Marais ou marécage	
Tundra polygons	Sols polygonaux	
Tundra ponds	Étangs de toundra	
Icefield or Glacier	Champ de glace ou glacier	

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY

MARCH, 1978

HARTLEY CREEK

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

MAGNETIC DECLINATION 25°44' EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.4'

SURFICIAL GEOLOGY AND LANDFORMS

Standard: $A^{b}_{c}d, e\ f$ where,

- A - genetic material
- b - qualifying descriptor (not always used)
- c - surficial expression
- d - specific landform information (not always used)
- e - local relief
- f - modifying process (not always used)

Composite Area:

= both components present in approximate proportions.
– first component more abundant than second

GENETIC MATERIAL

- C Colluvial
- E Eolian
- F Fluvial
- L Lacustrine
- M Morainal
- R Bedrock
- U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

SURFACE EXPRESSION

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

QUALIFYING DESCRIPTOR

- G Glacial

LANDFORM

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

LOCAL RELIEF

- 1 less than 10 meters
- 2 10 - 50 meters
- 3 51 - 150 meters
- 4 over 150 meters

MODIFYING PROCESS

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

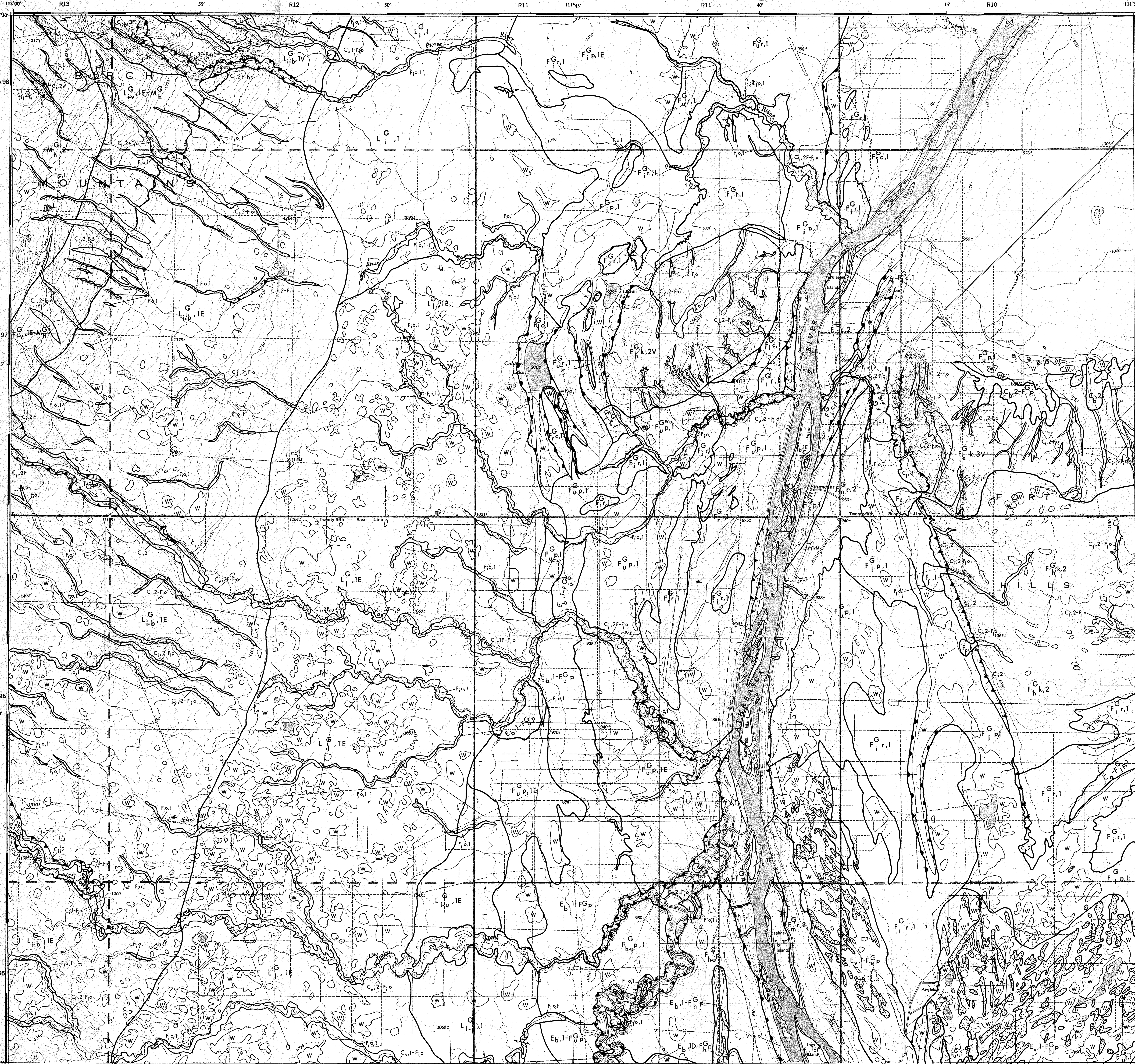
SYMBOLS

kettle
esker
sinkhole
dune
abandoned shoreline, beach ridges
glacial meltwater channel
drumlin
fluting
slump
gullied
crag and tail
escarpment (indicated downslope direction)
wetlands

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978.

74 E 5



BITUMOUNT

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

Miles 1 — 0 — 1 — 2 — 3 Milles
Metres 1000 — 500 — 0 — 1000 — 2000 — 3000 — 4000 Mètres
Yards 1000 — 500 — 0 — 1000 — 2000 — 3000 — 4000 Verges

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

MAGNETIC DECLINATION 26°15' EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.5'

Roads:	Routes:	
hard surface, all weather	pavée, toute saison	more than 2 lanes / plus de 2 voies; 2 lanes / 2 voies
hard surface, all weather	pavée, toute saison	less than 2 lanes / moins de 2 voies
loose surface, all weather	de gravier, toute saison	2 lanes or more / 2 voies ou plus; less than 2 lanes / moins de 2 voies
loose surface, dry weather	de gravier, période sèche	
cart track	de terre	
trail or portage	sentier ou [illegible]	
Railway, normal gauge, single track	Chemin de fer, voie unique (écartement normal)	siding / voies d'évitement; station / gare
Horizontal control point, with elevation	Point géodésique, avec cote	454 △
Bench mark, with elevation	Repère de nivellement, avec cote	BM 157 →
Spot elevation; precise, approximate	Point coté; précis, approximatif	.450 .450 ±

Building	Bâtiment	Church	Église
School	École	Post Office	Bureau de poste
Cemetery	Cimetière		
Mine or Open cut	Mine ou fosse à ciel ouvert		
Lighthouse	Phare		
Power transmission line	Ligne de transport d'énergie		
River with bridge	Rivière avec pont		
Stream, intermittent or dry	Cours d'eau intermittent, ou à sec		
Lake intermittent, indefinite	Lac intermittent, rive imprécise		
Marsh or Swamp	Marais ou marécage		
Depression contours	Courbes de cuvette		

SURFICIAL GEOLOGY AND LANDFORMS

Standard: $A^{b}_{c}d, e\,f$ where,

A - genetic material
b - qualifying descriptor (not always used)
c - surficial expression
d - specific landform information (not always used)
e - local relief
f - modifying process (not always used)

Composite Area:

= both components present in approximate proportions.
- first component more abundant than second

GENETIC MATERIAL

- C Colluvial
- E Eolian
- F Fluvial
- L Lacustrine
- M Morainal
- R Bedrock
- U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

SURFACE EXPRESSION

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

QUALIFYING DESCRIPTOR

- G Glacial

LANDFORM

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

LOCAL RELIEF

1. less than 10 meters
2. 10 - 50 meters
3. 51 - 150 meters
4. over 150 meters

MODIFYING PROCESS

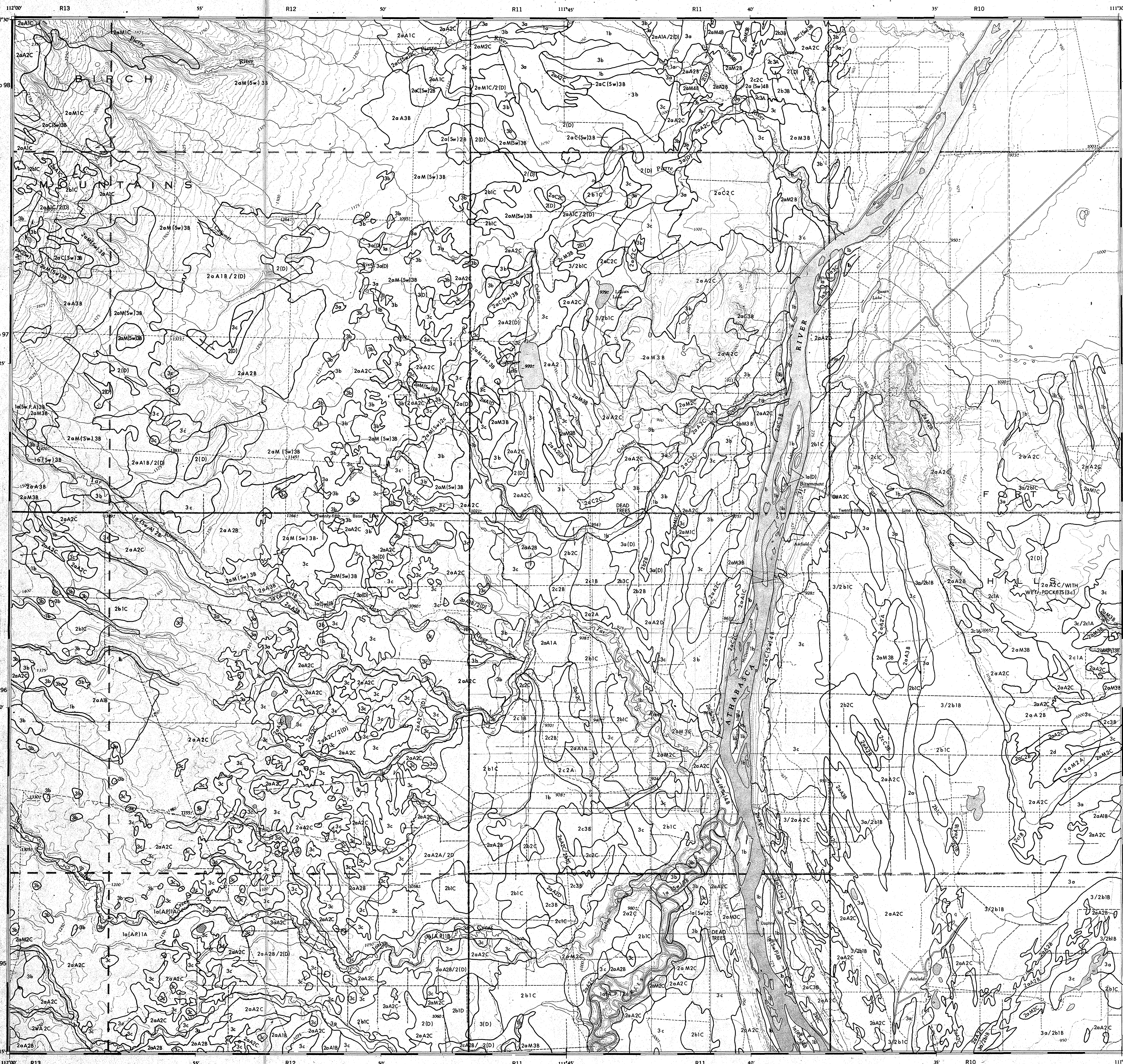
- D deflated
- E eroded (channelled)
- F failing
- H kettled
- K karst modified
- V gullied

SYMBOLS

kettle
esker
sinkhole
dune
abandoned shoreline, beach ridges
glacial meltwater channel
drumlin
fluting
slump
gullied
crag and tail
escarpment (indicated downslope direction)
wetlands

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978



VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar, aspen poplar, white spruce, willow, alder, paper birch
b. DECIDUOUS SHRUB	willow, alder, dwarf birch, immature aspen, paper birch
2. UPLAND COMMUNITIES	
UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites, aspen poplar, tall willow, alder, balsam poplar, paper birch
a. WHITE SPRUCE – ASPEN FOREST (2aA aspen; 2aM mixed; 2aC coniferous)	white spruce, aspen, jack pine
b. MIXED CONIFEROUS	black spruce, jack pine, white spruce
c. JACK PINE	jack pine, black spruce, white spruce, aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES	
UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes, low scattered shrubs, tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI-OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses, sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs, sphagnum mosses
4. BURN	
5. NON-VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols	Height Class (m)	Crown Cover
(Pj) jack pine	1 0 - 10	A open
(Sw) white spruce	2 11 - 20	B medium
(P) poplar	3 21 - 30	C dense
A aspen	4 31+	
(Sb) black spruce		
(T) tamarack		
(W) willow		
(Q) aquatic vegetation undifferentiated		
C conifer		
(D) deciduous shrub		
O open		

BITUMOUNT

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

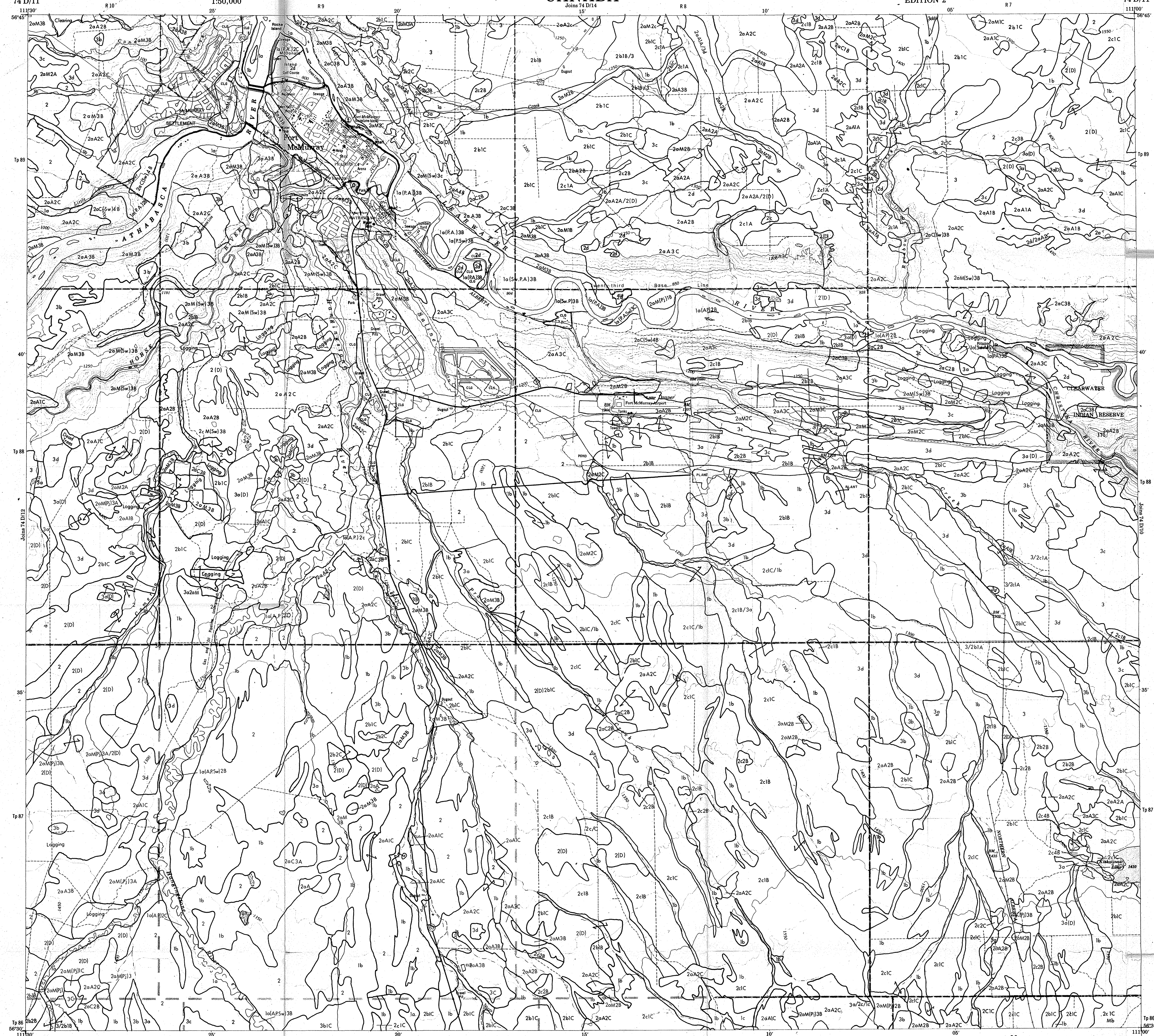
MAGNETIC DECLINATION 26°15′ EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.5′

Building — Bâtiment	Church — Église
School — École	Post Office — Bureau de poste
Cemetery — Cimetière	
Mine or Open cut — Mine ou fosse à ciel ouvert	
Lighthouse — Phare	
Power transmission line — Ligne de transport d'énergie	
River with bridge — Rivière avec pont	
Stream, intermittent or dry — Cours d'eau intermittent, ou à sec	
Lake intermittent, indefinite — Lac intermittent, rive imprécise	
Marsh or Swamp — Marais ou marécage	
Depression contours — Courbes de cuvette	

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978

74 D/11 — CANADA — 1:50,000 — EDITION 2 — 74 D/11



VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar, aspen poplar, white spruce, willow, alder, paper birch
b. DECIDUOUS SHRUB	willow, alder, dwarf birch, immature aspen, paper birch
2. UPLAND COMMUNITIES	
UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites, aspen poplar, tall willow, alder, balsam poplar, paper birch
a. WHITE SPRUCE – ASPEN FOREST (2aA aspen, 2aM mixed, 2aC coniferous)	white spruce, aspen, jack pine
b. MIXED CONIFEROUS	black spruce, jack pine, white spruce
c. JACK PINE	jack pine, black spruce, white spruce, aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES	
UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes, low scattered shrubs, tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses, sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs, sphagnum mosses
4. BURN	
5. NON-VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols	Height Class (m)	Crown Cover
(Pj) jack pine	1 0 10	A open
(Sw) white spruce	2 11 20	B medium
(P) poplar	3 21 30	C dense
A aspen	4 31+	
(Sb) black spruce		
(T) tamarack		
(W) willow		
(Q) aquatic vegetation undifferentiated		
C conifer		
(D) deciduous shrub		
O open		

FORT McMURRAY
ALBERTA
WEST OF FOURTH MERIDIAN - OUEST DU QUATRIÈME MÉRIDIEN

Scale 1:50,000 Échelle

Miles 1 — 0 — 1 — 2 — 3 Milles
Metres 1000 — 0 — 1000 — 2000 — 3000 — 4000 Mètres
Yards 1000 — 0 — 1000 — 2000 — 3000 — 4000 Verges

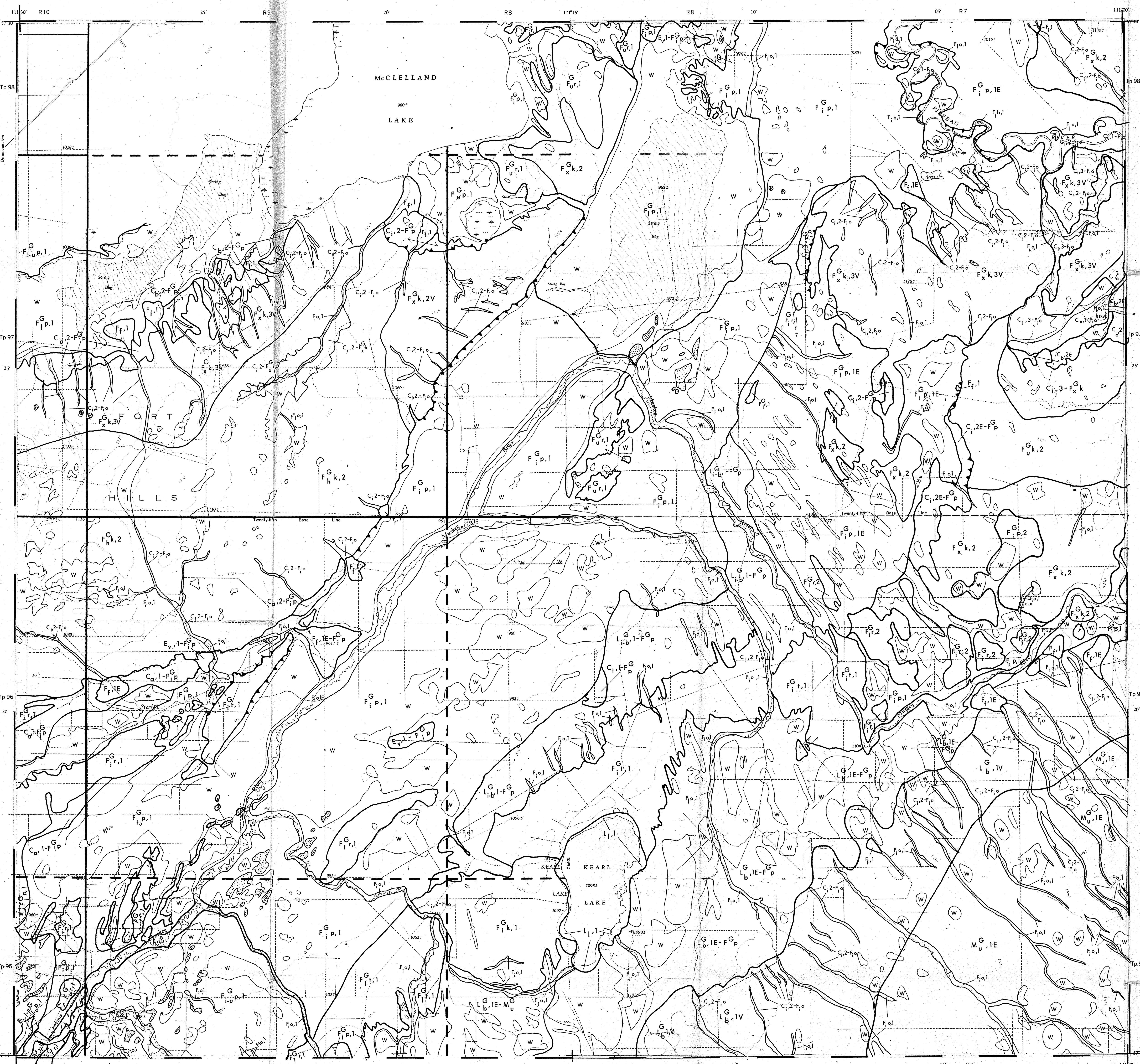
Roads:	Routes:		
hard surface, all weather	pavée, toute saison	dual highway / 2 chaussées séparées	more than 2 lanes / plus de 2 voies
hard surface, all weather	pavée, toute saison	2 lanes / 2 voies	less than 2 lanes / moins de 2 voies
loose or stabilized surface, all weather	gravier aggloméré, toute saison	2 lanes or more / 2 voies ou plus	less than 2 lanes / moins de 2 voies
loose surface, dry weather and unclassified streets	de gravier, temps sec et rues hors classe		
cart track	de terre		
trail or cut line	sentier ou percée		

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927
Transverse Mercator Projection

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978

74 E 6



SURFICIAL GEOLOGY AND LANDFORMS

Standard: $A^{b}_{c}d, e\ f$ where,

A · genetic material
b · qualifying descriptor (not always used)
c · surficial expression
d · specific landform information (not always used)
e · local relief
f · modifying process (not always used)

Composite Area:

= both components present in approximate proportions.
– first component more abundant than second

GENETIC MATERIAL

C Colluvial
E Eolian
F Fluvial
L Lacustrine
M Morainal
R Bedrock
U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

SURFACE EXPRESSION

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

QUALIFYING DESCRIPTOR

G Glacial

LANDFORM

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

LOCAL RELIEF

1 less than 10 meters
2 10 50 meters
3 51 150 meters
4 over 150 meters

MODIFYING PROCESS

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

SYMBOLS

kettle
esker
sinkhole
dune
abandoned shoreline, beach ridges
glacial meltwater channel
drumlin
fluting
slump
gullied
crag and tail
escarpment (indicated downslope direction)
wetlands

KEARL LAKE

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

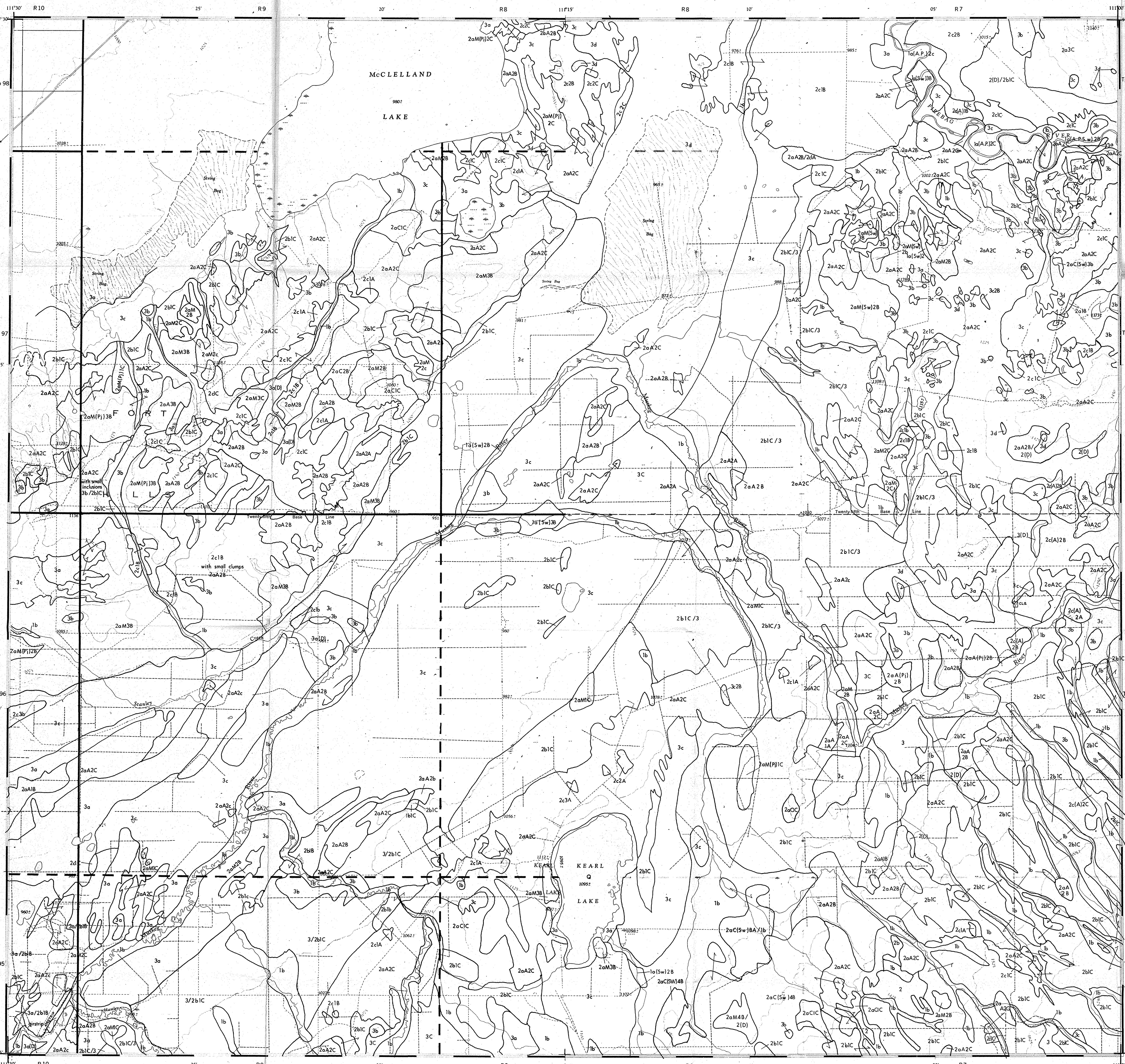
Transverse Mercator Projection
North American Datum 1927

MAGNETIC DECLINATION 25°54′ EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.5′

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978

74 E 6



VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar, aspen poplar, white spruce, willow, alder, paper birch
b. DECIDUOUS SHRUB	willow, alder, dwarf birch, immature aspen, paper birch
2. UPLAND COMMUNITIES	
UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites, aspen poplar, tall willow, alder, balsam poplar, paper birch
a. WHITE SPRUCE – ASPEN FOREST (2aA aspen; 2aM mixed; 2aC coniferous)	white spruce, aspen, jack pine
b. MIXED CONIFEROUS	black spruce, jack pine, white spruce
c. JACK PINE	jack pine, black spruce, white spruce, aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES	
UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes, low scattered shrubs, tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI–OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses, sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs, sphagnum mosses
4. BURN	
5. NON–VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols	Height Class (m)	Crown Cover
(Pj) jack pine	1 0 - 10	A open
(Sw) white spruce	2 11 - 20	B medium
(P) poplar	3 21 - 30	C dense
A aspen	4 31+	
(Sb) black spruce		
(T) tamarack		
(W) willow		
(Q) aquatic vegetation undifferentiated		
C conifer		
(D) deciduous shrub		
O open		

KEARL LAKE

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

Miles 1 0 1 2 3 Milles
Metres 1000 500 0 1000 2000 3000 4000 Mètres
Yards 1000 500 0 1000 2000 3000 4000 Vergès

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

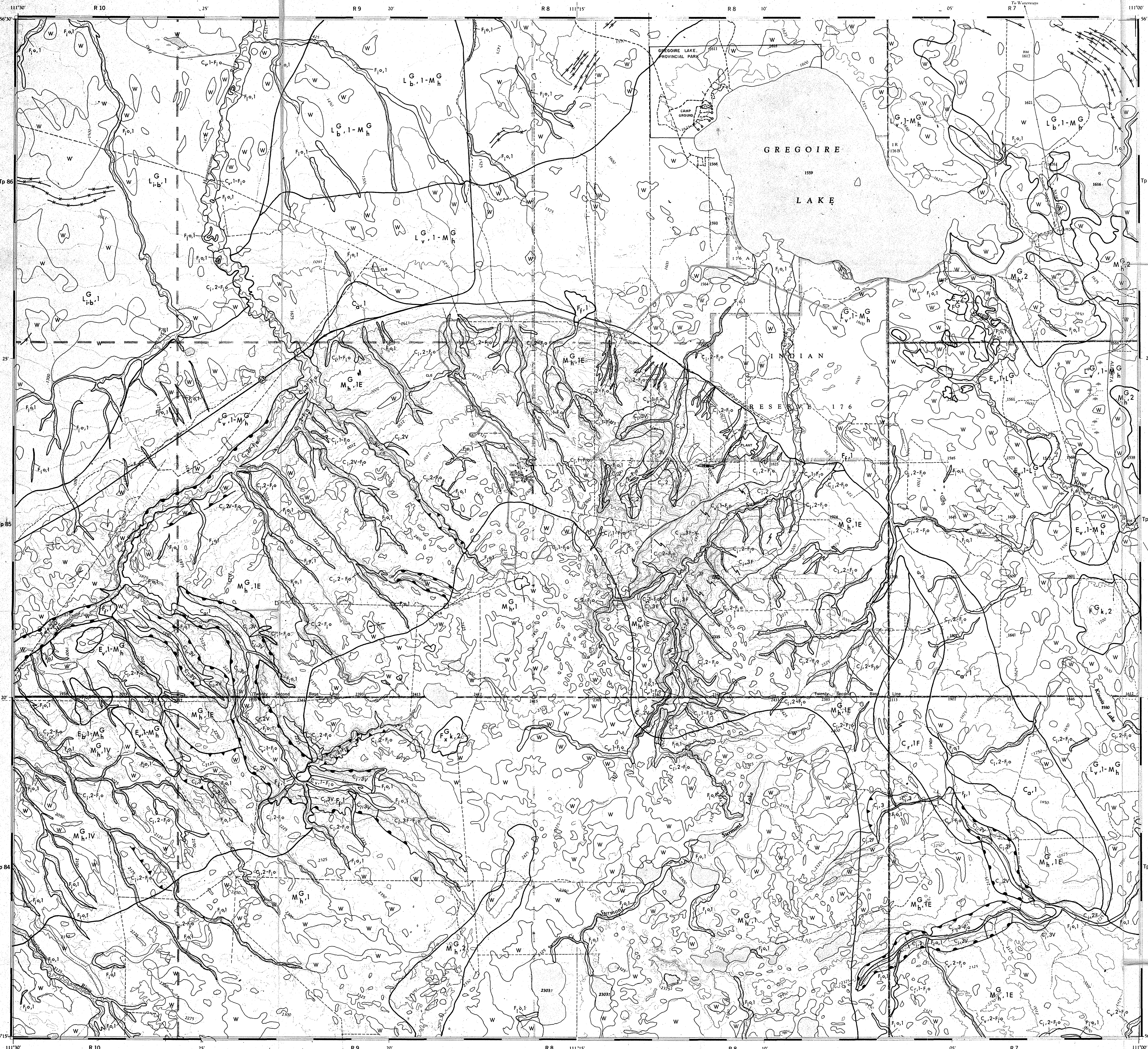
Transverse Mercator Projection
North American Datum 1927

MAGNETIC DECLINATION 25°54' EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.5'

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY

MARCH, 1978



GREGOIRE LAKE

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

SURFICIAL GEOLOGY AND LANDFORMS

Standard: A $^{b}_{c}$ d, e f

where,
A - genetic material
b - qualifying descriptor (not always used)
c - surficial expression
d - specific landform information (not always used)
e - local relief
f - modifying process (not always used)

Composite Area:
= both components present in approximate proportions.
- first component more abundant than second

GENETIC MATERIAL

C Colluvial
E Eolian
F Fluvial
L Lacustrine
M Morainal
R Bedrock
U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

QUALIFYING DESCRIPTOR

G Glacial

LANDFORM

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

LOCAL RELIEF

1 less than 10 meters
2 10 - 50 meters
3 51 - 150 meters
4 over 150 meters

SURFACE EXPRESSION

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

MODIFYING PROCESS

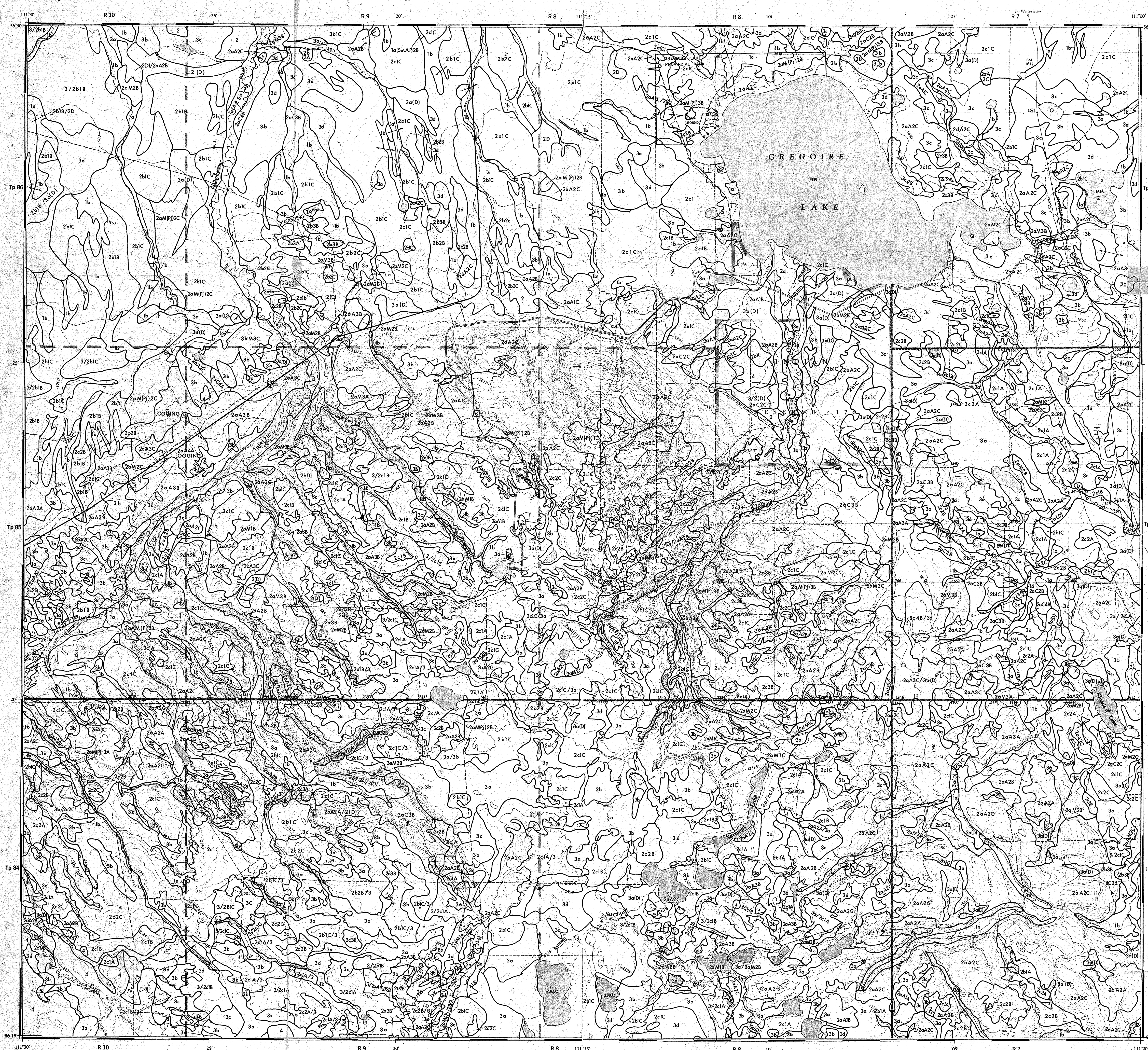
D deflated
E eroded (channelled)
F failing
H kettled
K karst modified
V gullied

SYMBOLS

kettle
esker
sinkhole
dune
abandoned shoreline, beach ridges
glacial meltwater channel
drumlin
fluting
slump
gullied
crag and tail
escarpment (indicated downslope direction)
wetlands

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978



VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar aspen poplar white spruce willow alder paper birch
b. DECIDUOUS SHRUB	willow alder dwarf birch immature aspen paper birch
2. UPLAND COMMUNITIES	
UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites aspen poplar tall willow alder balsam poplar paper birch
a. WHITE SPRUCE – ASPEN FOREST 2aA aspen 2aM mixed 2aC coniferous	white spruce aspen jack pine
b. MIXED CONIFEROUS	black spruce jack pine white spruce
c. JACK PINE	jack pine black spruce white spruce aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES	
UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes low scattered shrubs tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI-OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs sphagnum mosses
4. BURN	
5. NON-VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols	Height Class (m)	Crown Cover
(Pj) jack pine	1 0 - 10	A open
(Sw) white spruce	2 11 - 20	B medium
(P) poplar	3 21 - 30	C dense
A aspen	4 31+	
(Sb) black spruce		
(T) tamarack		
(W) willow		
(Q) aquatic vegetation undifferentiated		
C conifer		
(D) deciduous shrub		
O open		

GREGOIRE LAKE
ALBERTA
WEST OF FOURTH MERIDIAN

SCALE 1:50,000

1 ½ 0 1 2 3 Miles
1000 500 0 1000 2000 3000 4000 Metres
1000 500 0 1000 2000 3000 4000 Yards

Roads:
hard surface, all weather .... more than 2 lanes / Dual
hard surface, all weather .... 2 lanes / Route No 18
loose surface, all weather .... 2 lanes or more
loose surface, all weather .... less than 2 lanes
dry weather ....
cart track; trail, or cut line ....
Railways:
normal gauge, multiple track .... Station
normal gauge, single track .... Stop / Siding
abandoned or under construction
underpass, overpass ....
Tunnel; Drawbridge ....
Power line; Telephone line ....

Boundaries:
international, with monument ....
provincial ....
county or district ....
township or parish ....
township or parish, unsurveyed ....
section line ....
park, reserve, etc ....
Horizontal control point, with elevation ... 582
Bench mark, with elevation .... BM 3025
Spot elevation; precise, approximate ... 4582 737±
Historical site; Cemetery C
Mine or open cut; Quarry ....
Sand or gravel pit ....

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

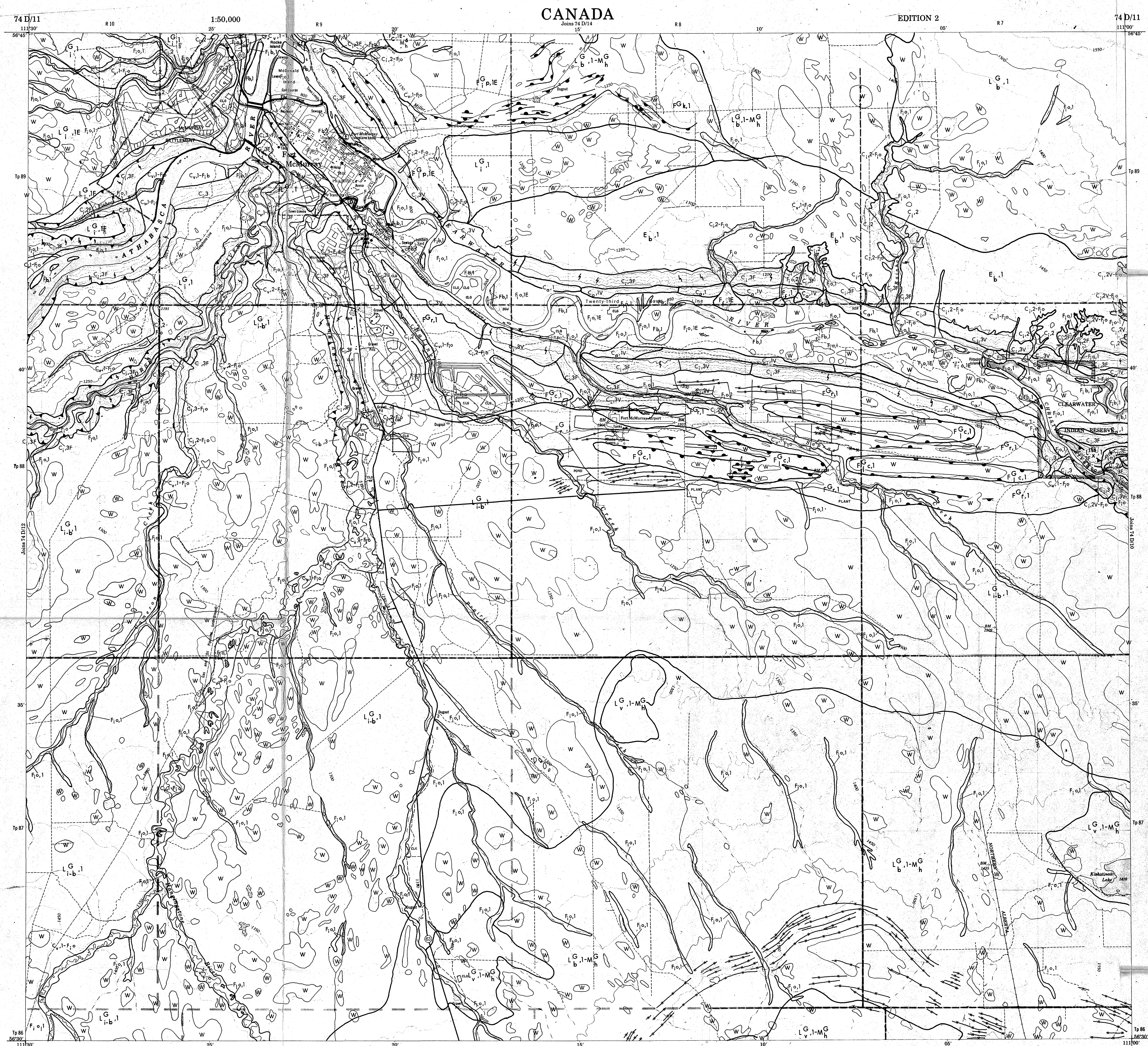
Copies may be obtained from the
Map Distribution Office,
Dept. of Mines and Technical Surveys,
Ottawa.

House; Building ....
School ....
Church; Church with spire ....
Post Office .... P
Radio Station ....
Tower; Chimney .... 120'
Well; Tank ....
Cutting ....
Embankment ....
Cliff ....
Contours:
elevation 250 225
depression 250 225
approximate 250 225

Foreshore flats ....
Lighthouse ....
Wharf or pier; Breakwater ....
Levee or dyke ....
Rocky reef ....
Swamp or marsh ....
Inundated land, seasonal ....
Intermittent lake, stream ....
Indefinite shoreline, stream ....
Rapids, large, small; Bridge ....
Ditch or flume ....
Icefield or Glacier ....
Wooded area; unclassified, scrub
Vineyard; Orchard ....

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978



Joins 74 D/6

FORT McMURRAY
ALBERTA
WEST OF FOURTH MERIDIAN - OUEST DU QUATRIÈME MÉRIDIEN

Scale 1:50,000 Échelle

Roads:	Routes:		
hard surface, all weather	pavée, toute saison	dual highway / 2 chaussées séparées	more than 2 lanes / plus de 2 voies
hard surface, all weather	pavée, toute saison	2 lanes / 2 voies	less than 2 lanes / moins de 2 voies
loose or stabilized surface, all weather	gravier aggloméré, toute saison	2 lanes or more / 2 voies ou plus	less than 2 lanes / moins de 2 voies
loose surface, dry weather and unclassified streets	de gravier, temps sec et rues hors classe		
cart track	de terre		
trail or cut line	sentier ou percée		

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927
Transverse Mercator Projection

SURFICIAL GEOLOGY AND LANDFORMS

Standard: $A^{b}_{c}d, e\,f$ where,

A genetic material
b qualifying descriptor (not always used)
c surficial expression
d specific landform information (not always used)
e local relief
f modifying process (not always used)

Composite Area:

= both components present in approximate proportions.
- first component more abundant than second

GENETIC MATERIAL

C Colluvial
E Eolian
F Fluvial
L Lacustrine
M Morainal
R Bedrock
U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

SURFACE EXPRESSION

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

QUALIFYING DESCRIPTOR

G Glacial

LANDFORM

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

LOCAL RELIEF

1 less than 10 meters
2 10 50 meters
3 51 150 meters
4 over 150 meters

MODIFYING PROCESS

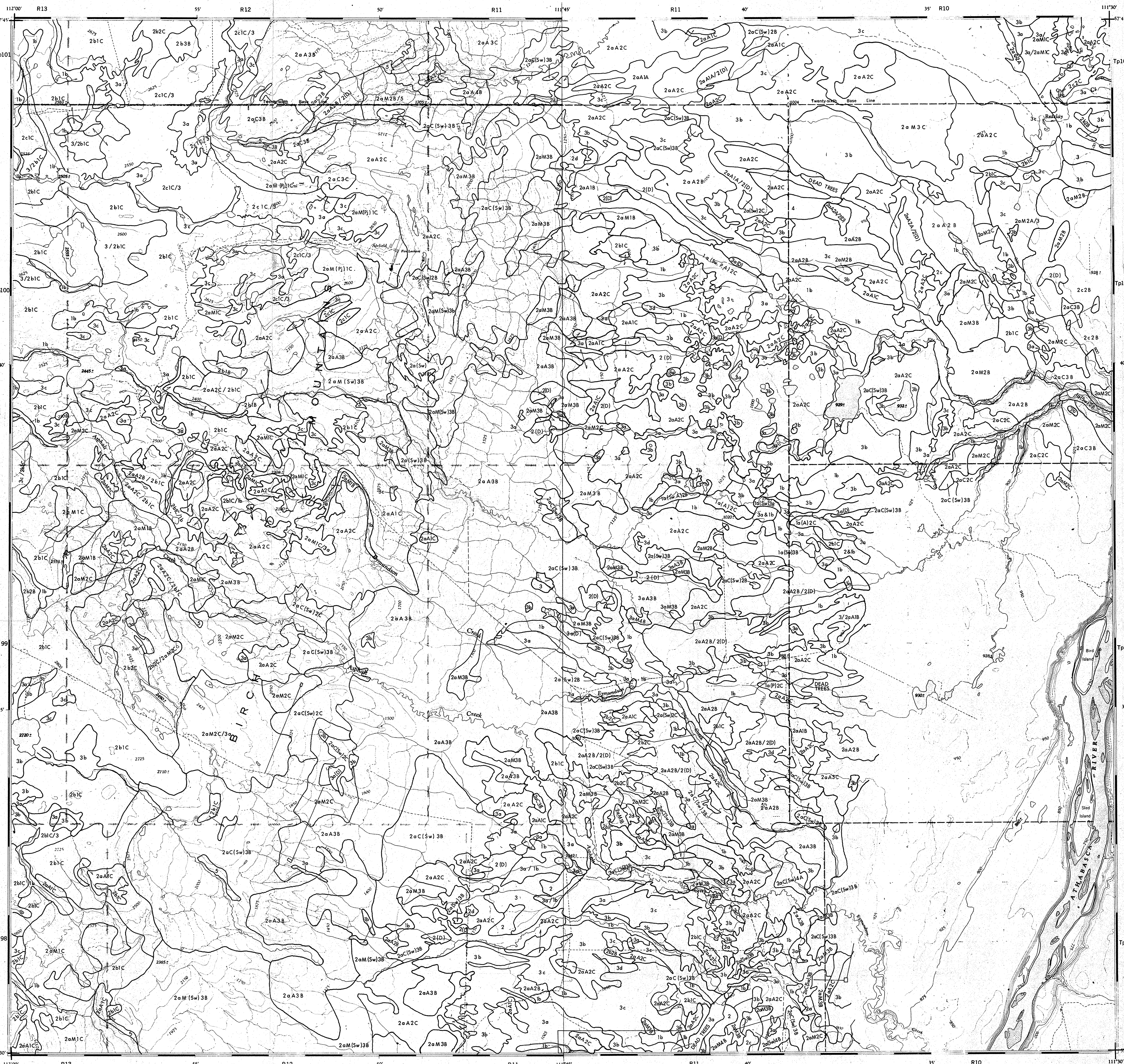
D deflated
E eroded (channelled)
F failing
H kettled
K karst modified
V gullied

SYMBOLS

kettle
drumlin
wetlands
esker
fluting
sinkhole
slump
dune
gullied
abandoned shoreline, beach ridges
crag and tail
glacial meltwater channel
escarpment (indicated downslope direction)

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978



VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar aspen poplar white spruce willow alder paper birch
b. DECIDUOUS SHRUB	willow alder dwarf birch immature aspen paper birch
2. UPLAND COMMUNITIES UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites aspen poplar tall willow alder balsam poplar paper birch
a. WHITE SPRUCE – ASPEN FOREST 2aA aspen 2aM mixed 2aC coniferous	white spruce aspen jack pine
b. MIXED CONIFEROUS	black spruce jack pine white spruce
c. JACK PINE	jack pine black spruce white spruce aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes low scattered shrubs tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI–OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs sphagnum mosses
4. BURN	
5. NON–VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols

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

Height Class (m)

- 1 0 - 10
- 2 11 - 20
- 3 21 - 30
- 4 31+

Crown Cover

- A open
- B medium
- C dense

ASPHALT CREEK

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

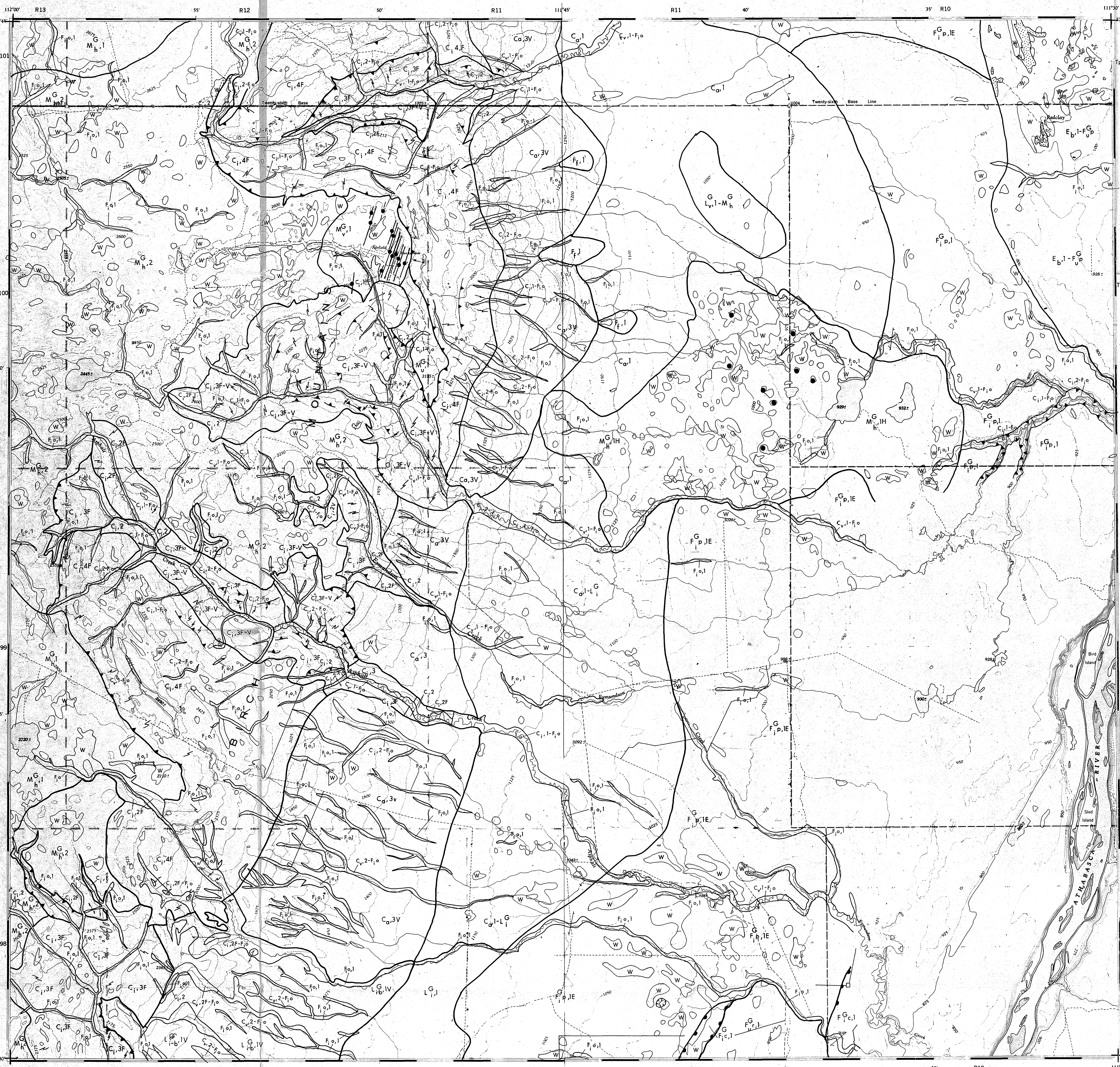
Miles 1 0 1 2 3 Miles
Metres 1000 500 0 1000 2000 3000 4000 Mètres
Yards 1000 500 0 1000 2000 3000 4000 Verges

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level
Transverse Mercator Projection
North American Datum 1927
MAGNETIC DECLINATION 26°33' EAST AT CENTRE OF MAP 1964
Annual change decreasing 4.6'

ÉQUIDISTANCE DES COURBES 25 PIEDS
Élévations en pieds au-dessus du niveau moyen de la mer
Projection transverse de Mercator
Réseau géodésique nord-américain unifié 1927
DÉCLINAISON MAGNÉTIQUE AU CENTRE DE LA FEUILLE EN 1964: 26°33' EST
Variation annuelle décroissante 4.6'

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978



ASPHALT CREEK

ALBERTA

WEST OF FOURTH MERIDIAN

SCALE 1:50,000 ÉCHELLE

CONTOUR INTERVAL 25 FEET
Elevations in Feet above Mean Sea Level

Transverse Mercator Projection
North American Datum 1927

MAGNETIC DECLINATION 26°33′ EAST
AT CENTRE OF MAP 1964
Annual change decreasing 4.6′

ÉQUIDISTANCE DES COURBES 25 PIEDS
Élévations en pieds au-dessus du niveau moyen de la mer

Projection transverse de Mercator
Réseau géodésique nord-américain unifié 1927

DÉCLINAISON MAGNÉTIQUE AU CENTRE
DE LA FEUILLE EN 1964 : 26°33′ EST
Variation annuelle décroissante 4.6′

SURFICIAL GEOLOGY AND LANDFORMS

Standard: $A^{b}_{c}d, e\,f$ where,

A - genetic material
b - qualifying descriptor (not always used)
c - surficial expression
d - specific landform information (not always used)
e - local relief
f - modifying process (not always used)

Composite Area:
= both components present in approximate proportions.
— first component more abundant than second

GENETIC MATERIAL

C Colluvial
E Eolian
F Fluvial
L Lacustrine
M Morainal
R Bedrock
U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

QUALIFYING DESCRIPTOR

G Glacial

LANDFORM

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

LOCAL RELIEF

1 less than 10 meters
2 10 - 50 meters
3 51 - 150 meters
4 over 150 meters

SURFACE EXPRESSION

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

MODIFYING PROCESS

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

SYMBOLS

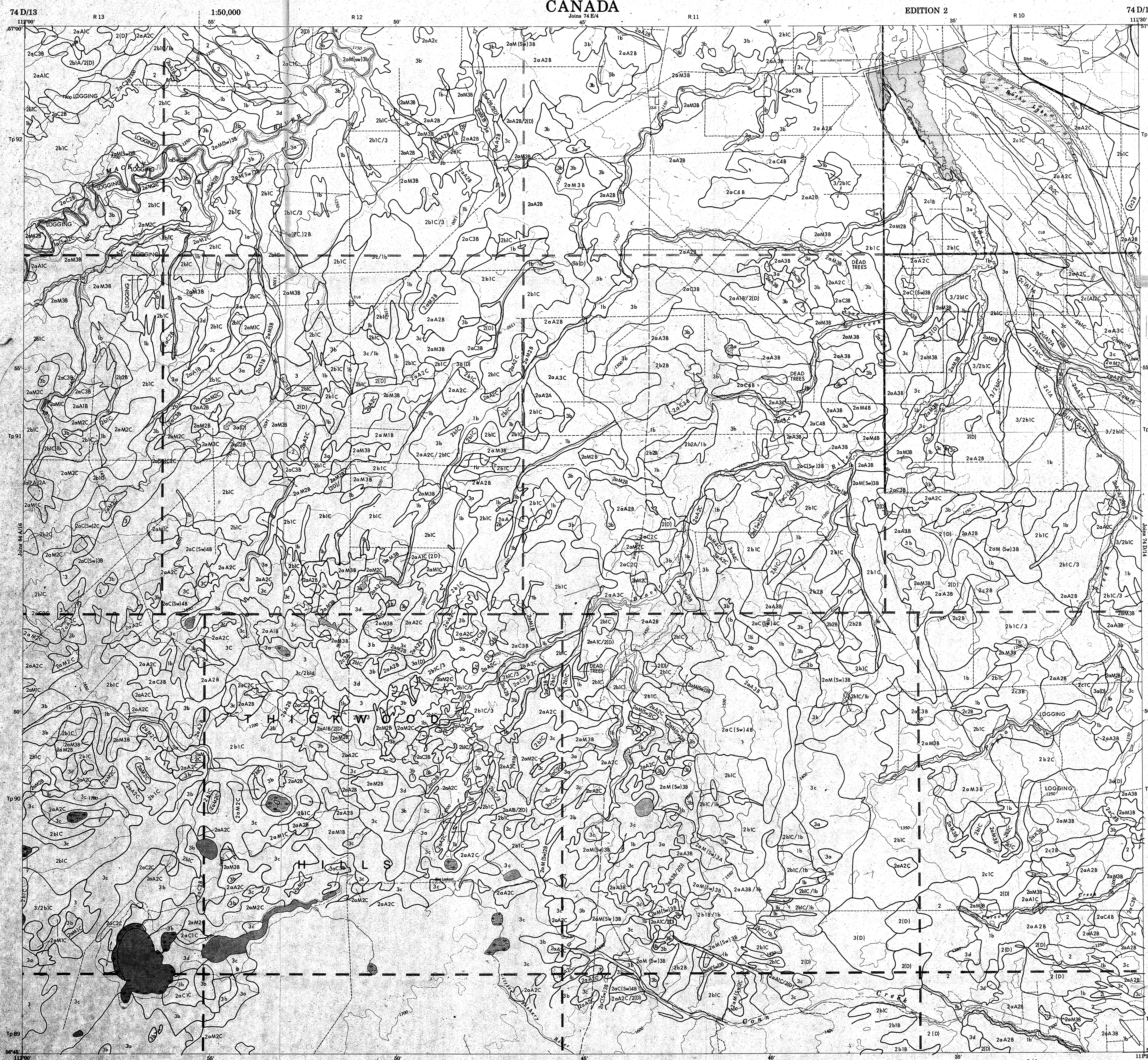
kettle
esker
sinkhole
dune
abandoned shoreline, beach ridges
glacial meltwater channel
drumlin
fluting
slump
gullied
crag and tail
escarpment (indicated downslope direction)
wetlands

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978

CANADA

74 D/13 1:50,000 EDITION 2



RUTH LAKE

ALBERTA

WEST OF FOURTH MERIDIAN - OUEST DU QUATRIÈME MÉRIDIEN

Scale 1:50,000 Échelle

VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar, aspen poplar, white spruce, willow, alder, paper birch
b. DECIDUOUS SHRUB	willow, alder, dwarf birch, immature aspen, paper birch
2. UPLAND COMMUNITIES	
UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites, aspen poplar, tall willow, alder, balsam poplar, paper birch
a. WHITE SPRUCE – ASPEN FOREST (2aA aspen; 2aM mixed; 2aC coniferous)	white spruce, aspen, jack pine
b. MIXED CONIFEROUS	black spruce, jack pine, white spruce
c. JACK PINE	jack pine, black spruce, white spruce, aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES	
UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes, low scattered shrubs, tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI-OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses, sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs, sphagnum mosses
4. BURN	
5. NON-VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols

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

Height Class (m)

- 1 0 - 10
- 2 11 - 20
- 3 21 - 30
- 4 31+

Crown Cover

- A open
- B medium
- C dense

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927
Transverse Mercator Projection

alberta canada
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR:
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978

74 D/14 | 1:50,000 | CANADA | EDITION 2 | 74 D/14

Joins 74 E/3

Joins 74 D/11

WOOD CREEK

ALBERTA

WEST OF FOURTH MERIDIAN - OUEST DU QUATRIÈME MÉRIDIEN

Scale 1:50,000 Échelle

Miles 1 0 1 2 3 Milles
Metres 1000 0 1000 2000 3000 4000 Mètres
Yards 1000 0 1000 2000 3000 4000 Verges

VEGETATION LEGEND

	POSSIBLE COMPONENTS VISIBLE ON FALSE COLOUR INFRARED PHOTOGRAPHY
1. BOTTOMLAND & RIPARIAN COMMUNITIES	
a. BOTTOMLAND & RIPARIAN FOREST	balsam poplar, aspen poplar, white spruce, willow, alder, paper birch
b. DECIDUOUS SHRUB	willow, alder, dwarf birch, immature aspen, paper birch
2. UPLAND COMMUNITIES	
UNDIFFERENTIATED (Usually Complex)	deciduous shrub on burned over sites, aspen poplar, tall willow, alder, balsam poplar, paper birch
a. WHITE SPRUCE – ASPEN FOREST (2aA aspen, 2aM mixed, 2aC coniferous)	white spruce, aspen, jack pine
b. MIXED CONIFEROUS	black spruce, jack pine, white spruce
c. JACK PINE	jack pine, black spruce, white spruce, aspen
d. UPLAND OPEN	grasses, low herbs and shrubs
3. WETLAND COMMUNITIES	
UNDIFFERENTIATED (Complex)	
a. FEN COMMUNITIES	sedges, rushes, low scattered shrubs, tall shrubs
b. BLACK SPRUCE BOG FOREST	black spruce, sphagnum mosses
c. SEMI-OPEN BLACK SPRUCE, TAMARACK BOG FOREST	black spruce, tamarack, sphagnum mosses, sedges, rushes
d. LIGHTLY FORESTED TAMARACK AND OPEN MUSKEG	tamarack, black spruce, low shrubs, sphagnum mosses
4. BURN	
5. NON–VEGETATED	recent slides, slumps with sparse vegetation (unclassified)

Symbols	Height Class (m)	Crown Cover
(Pj) jack pine	1 0 - 10	A open
(Sw) white spruce	2 11 - 20	B medium
(P) poplar	3 21 - 30	C dense
A aspen	4 31+	
(Sb) black spruce		
(T) tamarack		
(W) willow		
(Q) aquatic vegetation undifferentiated		
C conifer		
(D) deciduous shrub		
O open		

Produced, 1970, by the SURVEYS AND MAPPING BRANCH, DEPARTMENT OF ENERGY, MINES AND RESOURCES. Updated from aerial photographs taken in 1967. Culture check 1970. Printed 1973.

Copies may be obtained from the Canada Map Office, Department of Energy, Mines and Resources, Ottawa, or your nearest map dealer.

Roads:	Routes:		
hard surface, all weather	pavée, toute saison	dual highway / 2 chaussées séparées	more than 2 lanes / plus de 2 voies
hard surface, all weather	pavée, toute saison	2 lanes / 2 voies	less than 2 lanes / moins de 2 voies
loose or stabilized surface, all weather	gravier aggloméré, toute saison	2 lanes or more / 2 voies ou plus	less than 2 lanes / moins de 2 voies
loose surface, dry weather and unclassified streets	de gravier, temps sec et rues hors classe		
cart track	de terre		
trail or cut line	sentier ou percée		

This Provisional Map is equivalent to a standard map in accuracy of content.

Some names on this map are not yet official. Corrections or additions are invited by the Surveys and Mapping Branch.

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927
Transverse Mercator Projection

Cette carte provisoire équivaut une carte régulière au point de vue précision de l'information.

Certains noms inscrits sur cette carte ne sont pas encore officiels. La Direction des levés et de la cartographie saurait gré au public de lui signaler corrections et additions.

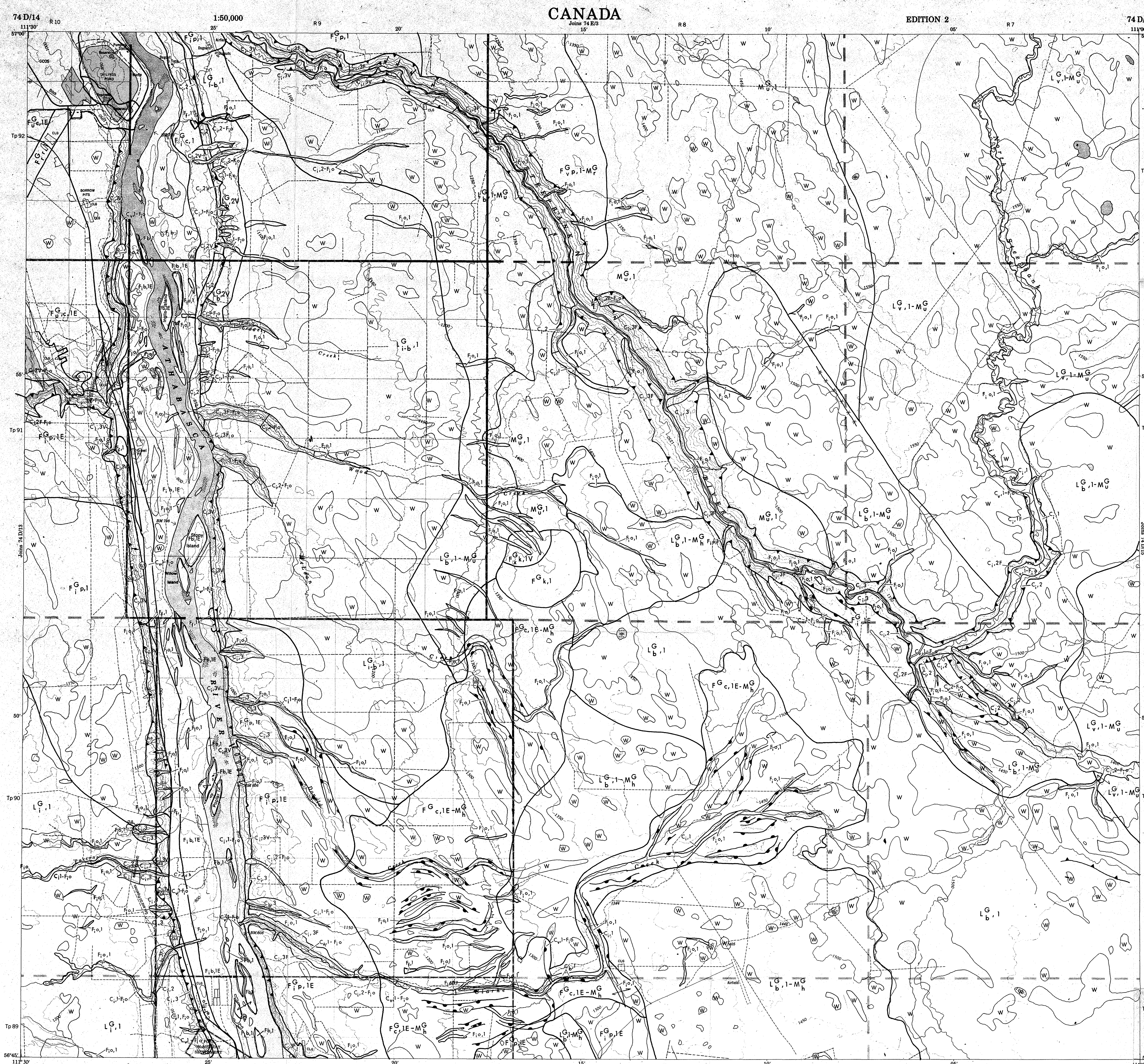
ÉQUIDISTANCE DES COURBES 50 PIEDS
Élévations en pieds au-dessus du niveau moyen de la mer
Système de référence géodésique nord-américain, 1927
Projection transverse de Mercator

Établie en 1970, par la DIRECTION DES LEVÉS ET DE LA CARTOGRAPHIE, MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES. Mise à jour à l'aide de photographies aériennes prises en 1967. Vérification des ouvrages en 1970. Imprimée en 1973.

Ces cartes sont en vente au Bureau des Cartes du Canada, ministère de l'Énergie, des Mines et des Ressources, Ottawa, ou chez le vendeur le plus près.

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978



WOOD CREEK
ALBERTA
WEST OF FOURTH MERIDIAN - OUEST DU QUATRIÈME MÉRIDIEN

Scale 1:50,000 Échelle

Produced, 1970, by the SURVEYS AND MAPPING BRANCH, DEPARTMENT OF ENERGY, MINES AND RESOURCES. Updated from aerial photographs taken in 1967. Culture check 1970. Printed 1973.

Copies may be obtained from the Canada Map Office, Department of Energy, Mines and Resources, Ottawa, or your nearest map dealer.

Roads:	Routes:		
hard surface, all weather	pavée, toute saison	dual highway / 2 chaussées séparées	more than 2 lanes / plus de 2 voies
hard surface, all weather	pavée, toute saison	2 lanes / 2 voies	less than 2 lanes / moins de 2 voies
loose or stabilized surface, all weather	gravier aggloméré, toute saison	2 lanes or more / 2 voies ou plus	less than 2 lanes / moins de 2 voies
loose surface, dry weather and unclassified streets	de gravier, temps sec et rues hors classe		
cart track	de terre		
trail or cut line	sentier ou percée		

This Provisional Map is equivalent to a standard map in accuracy of content.

Some names on this map are not yet official. Corrections or additions are invited by the Surveys and Mapping Branch.

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927
Transverse Mercator Projection

Cette carte provisoire équivaut une carte régulière au point de vue précision de l'information.

Certains noms inscrits sur cette carte ne sont pas encore officiels. La Direction des levés et de la cartographie saurait gré au public de lui signaler corrections et additions.

ÉQUIDISTANCE DES COURBES 50 PIEDS
Élévations en pieds au-dessus du niveau moyen de la mer
Système de référence géodésique nord-américain, 1927
Projection transverse de Mercator

Établie en 1970, par la DIRECTION DES LEVÉS ET DE LA CARTOGRAPHIE, MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES. Mise à jour à l'aide de photographies aériennes prises en 1967. Vérification des ouvrages en 1970. Imprimée en 1973.

Ces cartes sont en vente au Bureau des Cartes du Canada, ministère de l'Énergie, des Mines et des Ressources, Ottawa, ou chez le vendeur le plus près.

SURFICIAL GEOLOGY AND LANDFORMS

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

Composite Area:
- = both components present in approximate proportions.
- − first component more abundant than second

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

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

QUALIFYING DESCRIPTOR
- G Glacial

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

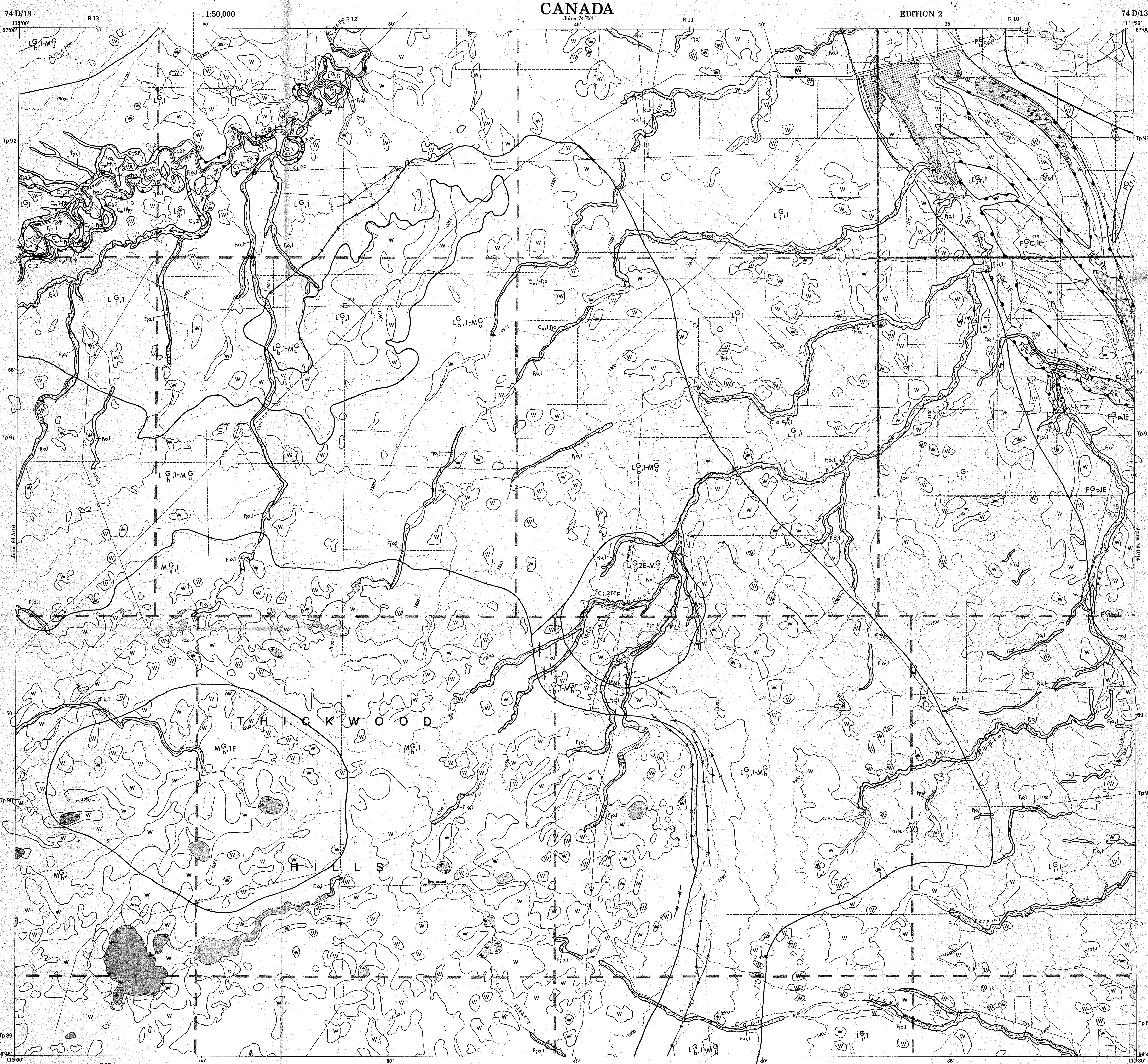
LOCAL RELIEF
- 1 less than 10 meters
- 2 10 50 meters
- 3 51 150 meters
- 4 over 150 meters

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

SYMBOLS
- kettle
- esker
- sinkhole
- dune
- abandoned shoreline, beach ridges
- glacial meltwater channel
- drumlin
- fluting
- slump
- gullied
- crag and tail
- escarpment (indicated downslope direction)
- wetlands

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD., CALGARY
MARCH, 1978



RUTH LAKE

ALBERTA

WEST OF FOURTH MERIDIAN - OUEST DU QUATRIÈME MÉRIDIEN

Scale 1:50,000 Échelle

Miles 1 0 1 2 3 Milles
Metres 1000 0 1000 2000 3000 4000 Mètres
Yards 1000 0 1000 2000 3000 4000 Verges

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927
Transverse Mercator Projection

Roads:
hard surface, all weather (more than 2 lanes; Dual)
hard surface, all weather (2 lanes; Route No)
loose surface, all weather (2 lanes or more)
loose surface, all weather (less than 2 lanes)
dry weather
cart track; trail, or cut line

Railways:
normal gauge, multiple track (Station)
normal gauge, single track (Stop; Siding)
abandoned or under construction
underpass, overpass
Tunnel; Drawbridge
Power line; Telephone line

Boundaries:
international, with monument
provincial
county or district
township or parish
township or parish, unsurveyed
city or town
park, reserve, etc
Horizontal control point, with elevation . . . △ 582
Bench mark, with elevation . . . BM 3025
Spot elevation; precise, approximate . . . 4582 .757±
Historical site; Cemetery
Mine or open cut; Quarry
Sand or gravel pit

House; Building
School
Church; Church with spire
Post Office
Radio Station
Tower; Chimney
Well; Tank
Cutting
Embankment
Cliff
Contours:
elevation
depression
approximate

Foreshore flats
Lighthouse
Wharf or pier; Breakwater
Levee or dyke
Rocky reef
Swamp or marsh
Inundated land, seasonal
Intermittent lake, stream
Indefinite shoreline, stream
Rapids, large, small; Bridge
Ditch or flume
Icefield or Glacier
Wooded area; unclassified, scrub
Vineyard; Orchard

SURFICIAL GEOLOGY AND LANDFORMS

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

Composite Area:
= both components present in approximate proportions.
– first component more abundant than second

GENETIC MATERIAL

C Colluvial
E Eolian
F Fluvial
L Lacustrine
M Morainal
R Bedrock
U Undifferentiated, parent material undistinguishable due to organic cover (refer to vegetation map)

SURFACE EXPRESSION

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

QUALIFYING DESCRIPTOR

G Glacial

LANDFORM

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

LOCAL RELIEF

1 less than 10 meters
2 10 - 50 meters
3 51 - 150 meters
4 over 150 meters

MODIFYING PROCESS

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

SYMBOLS

kettle
esker
sinkhole
dune
abandoned shoreline, beach ridges
glacial meltwater channel
drumlin
fluting
slump
gullied
crag and tail
escarpment (indicated downslope direction)
wetlands

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

OVERLAY INFORMATION PREPARED FOR
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
BY
INTERA ENVIRONMENTAL CONSULTANTS LTD. CALGARY
MARCH, 1978