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A RAPID RESOURCE INVENTORY FOR CANADA'S NORTH BY MEANS OF SATELLITE AND AIRBORNE REMOTE SENSING

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Purdue University, West Lafayette, Indiana

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ABSTRACT

There is an urgent need in Canada for northern baseline data for resource policy and planning purposes. To evaluate the impact of airborne and satellite remote sensing for Northern Inventories three areas were studied in boreal, arctic and sub-arctic environments. ERTS satellite imagery was found to be very effective for a rapid mapping of bio-physical units and can provide an excellent basis for integration of water and land-based classifications. An operational system for a rapid, broad brush inventory is proposed for Canada, costing in the order of 2-4 dollars per square mile.

INTRODUCTION

Development pressures for Canada's last frontier, the North, are increasing. For a rational planning and management of the resource base, resource planning and management agencies at the provincial and federal levels have found a serious lack of baseline data that allows an integrated and multi-disciplinary approach. Hydro-electric development projects, arctic oil and gas pipelines require decisions related to economic, social and ecological desirability for society and adequate assessments of impact. Biological-physiographical as well as socio-economic data is required. The main benefit of Remote Sensing is in the environmental part of the requirements.

Classification systems for mapping and description of the earth's surface evolved from single discipline oriented systems into integrated ones; from separate soil classifications, vegetation classifications, forest inventories and geomorphological systems into ecologically based ones such as the bio-physical land classification system. This development in itself was, to a large extent, made possible by use of conventional airphoto interpretation techniques. Only by this method could the different elements of ecosystems be effectively integrated, related and mapped.

The development of new remote sensors has added new dimensions to the survey of the environment. Multiband sensor packages aboard aircraft and satellite allow us to measure or map "new" parameters such as surface temperatures, thickness of ice, air pollutants, etc., and to better discriminate between objects of interest. Repetitive remote sensing adds time dimension to the survey and the ERTS satellite, which orbits Canada four times daily covering each part at least every 18 days, can play a significant role in realizing an environment inventory system that will be truly ecologically based, integrating land, water, atmospheric and biological phenomena as well as the interaction with living organisms including man. It is the intention of this study to assess the capabilities of airborne and satellite remote sensing for biological-physiographical data gathering in the north. As low cost and rapidity were considered critical most attention was given to the evaluation of ERTS data.

THE BASIS FOR NORTHERN RESOURCE INVENTORIES

In Canada, the development of a bio-physical classification system was started in 1967, under the auspices of the National Committee on Forest Land. The aim was to differentiate and classify rapidly at a small scale ecologically significant segments of the land surface. (Lacate et al, 1969) It was recognized from the start that such a system should be ecologically based, mapping and describing land surfaces in such a way that value judgements, related to forestry, wild-life, waterfowl, recreation, agricult-ure (if applicable) could be made with little additional effort.

The levels of classification proposed - land region, land district, land system and land type, appear quite adequate and flexible for most resource planning and management requirements as well as for impact prediction. Mapping scales suggested are as follows:

Land Region	1:1 000 000-1:3 000 000
Land District	1: 500 000-1:1 000 000
Land System	1: 125 000-1: 250 000
Land Type	1: 10 000-1: 20 000

One of the weaknesses of the system is the fact that it is a *land* oriented classification system and does *not consider the integration of land and water.* Zoltai attempts this integration using his landscape units in the Manitoba pilot project. Water is an important resource in the North, from a recreational, fishing and wildlife point of view. A northern inventory should pay proper attention to this aspect and integrate land and water classifications into manageable units. While the bio-physical system, because of its ecological basis recognizes environmental changes and describes succession, *more attention to present conditions and man-caused or natural changes should be given.*

In brief an adequate inventory system should:

1. be ecologically based
2. integrate water and land classific-ations.
3. describe present status
4. allow for monitoring of changes (natural or man-induced)
5. map and describe units for multi-disciplinary resource planning and/or management
6. be rapid and inexpensive

STUDY AREAS

To test remote sensing and interpretat-ion techniques under a wide range of climatic and physiographic conditions, three large areas were selected for detailed study. In addition ERTS images for all of Canada were scruti-nized using the Browse Facility of the Canada Centre for Remote Sensing.

Detailed study areas:

1) Playgreen Lake area, Manitoba: an area with a boreal climate, exten-sive peat deposits, paleozoic and precambrian bedrock, glacial till and glacio-fluvial deposits, localized and discontinuous permafrost.

2) The Churchill area, Manitoba: an area characterized by a sub-arctic climate, extensive peat and glacial till deposits and permafrost.

3) The MacKenzie Delta area, N.W.T.: an area with an arctic and sub-arctic climate, extensive (deltaic) deposits, continuous and discontinuous perma-frost.

For each of the study areas a wide range of remotely sensed imagery was provided by the airborne program of the Canada Centre for Remote Sensing. It included multi-band photography, thermal scanning(8-14 μm; 3-5 μm), at various altitudes varying between 5,000 - 35,000 feet A.G.L. recorded at various times of the year. In addition SLAR radar imagery was avail-able for parts of both Manitoba study areas.

RESULTS

Playgreen Lake area: As extensive fieldwork and mapping for soil survey and for site classification and perma-frost was carried out by Tarnocai and Thie, most of the remote sensing imagery was evaluated for this purpose. It was generally found that colour infrared images with scales as small as 1:120 000 provided excellent material for the delineation of permafrost, soils and vegetation types. W12 filters with CC 20B colour compensating filters were very effective in the large organic areas. Permafrost can be mapped within the 90-95% accuracy range. Results for permafrost are discussed in more detail in another paper by Tarnocai and Thie in these proceedings.

Repetitive ERTS coverage was studied for this area. About fourteen ERTS frames in bands 4, 5, 6 or 7 were taken by the satellite with less than 25% cloud cover between July 1972 and January 1974. This material showed positively the capabilities of ERTS to monitor man-induced and natural environmental change. For instance, the progress of the dredge digging the 8-mile channel, part of Manitoba's Northern Hydro electric power development scheme, could be measured (band 7). As well, the expanse of the dredge spill mapped (band 4,5). The construction of new roads, hydro transmission lines, salvage cuttings before inundation could be mapped. In this area which is part of Lake Winnipeg, Churchill and Nelson Rivers diversion scheme, water conditions will change due to inundations, dams and new channels.

On ERTS imagery, based on shape and reflectence, lakes can be grouped into units that have a strong physiographic and possibly limnologic relationship. (Fig. 1). In fact, they provide an indicator for subdivision of land units and exemplify integration of land and water classifications. Unique lakes, such as Little Limestone Lake, have a distinctly different "signature". Wetland types can be identified readily from satellite: open sedge fens, tamarack fens, black spruce bogs, peatplateaus, etc. The infrared bands allowed monitoring of surface moisture conditions. Winter images are effective for estimating tamarack stand densities in fens. Also, winter images showed an interesting difference between pine and spruce stands, which are difficult to separate on summer images (Fig. 2). Even on black and white 1:60 000 photography, this is often not easy to do. Regeneration information in recent burn areas (10-20 years old) shows a level of detail on both summer and winter images that is expected to be of significance to forest management practices.

Churchill Area: Automated as well as visual analysis techniques were used to classify the area. In approximately 1 man day a relatively detailed bio-physical map was prepared from satellite (Fig. 3). Level of detail is such that mapping at the 1:250 000 scale is most appropriate. About 50 percent of the lines were derived from summer images and about 50 percent from winter scenes. The result was checked by an airphoto interpretation of 1:100 000 scale imagery and only minor changes and additions were made, most of which could have been obtained from the ERTS images. The use of colour additive viewing equipment for temporal analysis was attempted, but found to be more laborious and to provide less information than an individual analysis of different winter and summer frames. The visual interpretation technique worked well in the till areas, bedrock controlled areas and the peat deposits of the Hudson Bay lowlands. The importance of winter images increased in the northern boreal till areas where open but continuous tree cover exists. On winter scenes small well drained sand deposits of about 1 km in diameter could be mapped based on vegetation (higher, denser growth).

In three parts of the Churchill area, automated classification from computer compatible satellite tapes was tried using the program developed by Shlien and Goodenough (1973) at the Canada Centre for Remote Sensing. Tapes were radiometrically corrected. Results show that major vegetation types can be mapped successfully. In the subarctic part of this area there is a relatively simple relationship between vegetation (or lack of it) and soils and drainage, whereby different land systems and types could be classified: e.g. frost heaved stone field; well drained peat polygons; saturated but predominately frozen sedge and tamarack sedge fens; ribbed fens, peatplateaus, etc. (Fig. 5). The results are promising for the lowlands area, however, because of the fact that the satellite resolution is about 250'-250' ft. on the ground, the classification on a pixel by pixel basis is too detailed for land system mapping. Data reduction into significant units becomes a necessity; while this can be done by classifying every 2nd, 3rd ...or 10th pixel, it is expected that this only will be really successful if some form of surface pattern recognition can be included. In the boreal parts of the Churchill area, automated classification cannot eliminate the influence of old forest fires and classification accuracies are low. Also it is required that summer and winter spectral data is needed for reasonable results. In this case, visual techniques proved to be faster, less expensive and better adapted to bio-physical land classification. In addition, while satellite maps provide delineation of units; the description of these units will have to be based on photo interpretation and ground truthing.

Computer Classification of the Mackenzie Delta Area, N.W.T.

The area around Richards Island was selected for a study aimed at evaluating the usefulness of an automated classification system for the arctic environment. This area was selected because it provided a wide variety of sites from terrestrial and aquatic ecosystems and, not the least, was ground truthed during the 1972 and 1973 field seasons.

Computer compatible tapes of the data taken by the ERTS in July 30, 1972, were prepared by CCRS. These tapes were then converted to meet the requirements of the LARS system. The statistical multispectral pattern analysis system (LARSYSAA) developed at LARS and described by Fu et al, (1969), was used for the classification.

In this classification 22 classes were identified on the basis of the selected training classes. These 22 classes include all the terrestrial surfaces (vegetated and unvegetated) and water bodies. They were identified according to their spectral responses and spectral indexes as follows: vegetated (classes 1-5, 12 and 14-19); unvegetated (classes 13, 21 and 22): and water bodies (classes 6-11 and 20). Two sets of printouts were then made. On printout 1 (Fig. 6) the terrestrial classes were printed out, but the water bodies were identified with one symbol: on printout 2 (Fig. 7) the water bodies were symbolized and printed out, but the terrestrial classes were combined under one symbol. The ground truth data was then superimposed on these printouts and, the vegetated and water body classes were further divided and other components were identified (see Table 1 and 2).

On Figure 6 the terrestrial classes are based on the surface cover, i.e. the different tundra vegetation types and unvegetated surfaces. Because of the close relationship between vegetation and the subsurface components of the ecosystem, the landform, parent material and soil can be interpreted by human interpreters using the ground truth data and other studies. A very close correlation was found between the ground truth data and the classes identified by the computer. Grouping of classes was necessary in transitional areas, e.g. marginal wetlands along lake shores and other wetlands and unvegetated areas covering a wide variety of situations.

It was surprising to see that the classification of water bodies (Fig. 7) in the delta correlated so closely with the ground truth data. These water bodies are noted for the wide variety of water types containing various amounts of suspended sediment, and ranging from fresh water to sea water in an everchanging fashion. A few lakes near the sea shore were classified as sea water and this caused some concern until it was learned that, due to the nature of these lakes, different waters (fresh and sea water) were stratified and did not mix. If the lake is a shallow one, it would have the same signature as sea water (personal communication from N. Snow, F.R.B.). In addition it was found that the fresh MacKenzie River water did not mix homogeneously with the salty water of the Beaufort Sea. Instead, bodies of both waters remained unmixed at the interface: i.e. isolated bodies of fresh water were found in salt water and vice versa (see Figure 7).

Based on this study the automated,

computer classification of arctic ecosystems (terrestrial and aquatic) together with ground truth data and interpretation can provide a great deal of information which could be extremely useful for inventories and environmental monitoring or identification of areas affected by pollution, e.g. oil spills due to pipeline rupture and sedimentation caused by construction of roads and pipelines.

DISCUSSION

Airborne Remote Sensing: Interpretation of aerial photographs has been a common practice for most operational inventories, e.g. soils, landforms, forestry, crops, land use, etc. In the field of land classification the photo interpretational inference techniques and extrapolations from selective field sampling has proven quite successful. In the Manitoba biophysical pilot project an area of about 5,500 square miles was mapped and described in less than 1 man-year (Zoltai et al 1970). The work was done by the interpretation of black and white photographs at a scale of about 1:63,000.

The important information stored on an image, and used for classification, is relief, shape, texture and tone (or "signature"). Relief and shape especially contain valuable information for inferring conditions which cannot be "seen" directly; tone and texture help to differentiate between objects.

Airborne remote sensing cannot significantly add to the relief information; only a small amount to shape information. The main value lies in the fact that it can increase the contrast of surface features and may make certain parameters visible which we cannot see with our eyes or by conventional photography. Different studies have indicated that 1:120,000 scale colour infrared imagery can provide the equivalent amount of information as 1:60,000 black and white (Thie, 1971). This smaller scale can reduce mapping cost for interpretation, while the more synoptic view (about 250 square miles) provides a superior base for land system and direct analysis.

Multiband photography can be valuable for land and water classification systems. It would enable the simultaneous use of water penetration film (colour or blue green) and land vegetation film filter combinations (colour; colour IR with different filters).

Multispectral scanners on board aircraft may be of some use in the future. At present, computer handling and interpretation of data is quite costly, so that instruments of this nature appear to be of little operational interest. Single channel or dual channel scanners especially in the thermal infrared of the spectrum, however seem advantageous to include in a sensor package. It allows mapping of temperatures to about 0.5°C during the day and night. Repetitive flights with such instruments can be used to describe and measure the temperature regime of land types over time (frost pockets, exposure influence) and help approximate microclimate over large areas at low cost.

The value of side looking radar imagery for land classification purposes is still somewhat uncertain. Experience with this material in this study showed little promise for the mapping and systems; cultural features such as farm fields and buildings, transmission lines, etc. could be mapped with success. A number of new sensors are being developed, like the HISS radar (Holgraphic Ice Surveying System) and soil moisture meter. If both systems are successful they will be able to add important quantitative data. The Laser fluorosensors presently under development, can be used for bathymetric surveys in shallow water areas, fish tracking, oil slicks and dyes on water. Also LIDAR; optical probing of the atmosphere with a high-power laser source can add significantly to a limnological or atmospheric survey. (MacDowall, Lapp 1973).

Satellite Remote Sensing

The satellites that should be considered for the use in the north are the earth observation satellites like ERTS and its successors and some of the weather satellites like NOAA. Both can be received directly by the Canadian Receiving Station in Prince Albert, Saskatchewan. The characteristic difference between the two types occurs is in scale, resolution and frequency of orbit. ERTS resolution is about 90 meters, and there is an 18 day interval between coverages. NOAA with a 900 meter resolution covers all of Canada twice daily (day and night time).

The resolution and scale of ERTS is quite suited for mapping at the Land Region, District and Land system mapping of the bio-physical classifications. In fact, the major problem encountered in the study areas was to reduce the amount of data in significant larger complexes. Repeated imaging of the same area throughout the growing season, winter and over a number of years will help assess and define the dynamics of our environment. This is an aspect which has been missing even in most ecologically based surveys though vegetation succession may have been described. Seasonal imaging will help in relating phenological phenomena, disease development, moisture stress symptoms, snow-melt and ice movements to other physiographic parameters like landforms, soil, relief, exposure, water, etc. Winter images proved to be of particular importance for the delineation of land system; snow cover and low sun angles enhance relief and land form information. Also snow cover provides composite signatures of vegetation types that are based on tree height, stand density and composition. Summer images tend to show the predominant influence of stand composition. Another easy application is the monitoring of the freezing of water bodies and river systems. Even in mid-winter part of northern rivers, like the Churchill River, and northern lakes, like South Indian, show open water leads. These may be significant from the wildlife and certainly, fish point of view.

It is obvious that rapid and more gradual changes occurring on the surface of the earth can be monitored from satellite in a gross way. This includes natural phenomena like forest fires (frequency of occurrence, areas burned, habitat destroyed), regeneration in disturbance areas, fluctuations in surface moisture (saturation of wetlands, flooding, etc), changes in waterbodies (freezing, thawing, fluctuation in water levels and size, turbidity and suspended sediments).

It is expected that such information will be very valuable in approximating the dynamic aspects of the ecological building blocks.

Monitoring of man-induced changes could add significantly to sensitivity ratings of "land types" to such changes. Satellite has shown examples of SO_2 damage, shoreline erosion and increased turbidity as result of artifically higher water levels in lakes, the effect of logging activities on waterbodies, road construction and drainage; dredge spills; urban expansion and other land use changes.

A combination of NOAA and ERTS satellite monitoring is specially attractive for fast change high contrast phenomena like snowmelt, ice reconnaissance and surface temperature patterns. The daily coverage by NOAA complements the less frequent high resolution ERTS. The NOAA imagery may also be of much value for defining the bio-physical land regions. These regions are defined by a distinctive regional climate as expressed by vegetation. The temperature information and the extremely small scale of this satellite may add regional climatic parameters.

Land water interface: The synoptic view from satellite has shown clearly the relationships that exist between physiography and water signatures. A very strong relation is apparent between lake and shoreline shape, water reflectance and the surrounding land areas. This information can be analysed in a visual way, in which shapes, size, patterns and signature can be mapped or in an automated way that allows a classification based on very slight spectral differences. Based on spectral reflectance of water bodies, land systems that appear to be uniform physiographically could be subdivided. In total, ERTS will enable a future inventory team to integrate land and water classifications into a meaningful system.

LAND CLASSIFICATION

As we mentioned before the ERTS scale and resolution is quite suitable for reconnaissance type of surveys. This study showed that especially in arctic and sub-arctic areas, satellite can be a very effective mapping tool.

Most land systems at a 1:250 000 scale (even at a 1:125 000 scale) can be readily drawn from satellite images. This is also the case for large (organic) wetland areas in the boreal zone. Vegetation in both cases is a good indication of ecosystems and relatively few disturbances (fires) that distract from these have occurred. In the boreal zone, with its forest cover, an often broken precambrian physiography and its complex fire history, mapping from ERTS cannot be as easily achieved. Land systems delineation by means of visual techniques is more complicated and results less accurate. Combination of winter and summer images have to be used to increase accuracy in most cases. No significant work with automated classification has been done yet. It is too early to say that these could improve classification considerably. The land-water relations discussed before showed quite conspicuously in parts of boreal zone and could be successfully used as a source for land-water delineation. The satellite can recognize significant patterns occurring in the distribution of parent materials if they are expressed by vegetation.

It should be made clear that while satellite imagery can assist in mapping of significantly different land systems, the description of the land systems will have to be based on a description of land types (ecosystems). For the analysis and description of these building blocks: airphoto interpretation is essential and cannot be replaced.

COST CONSIDERATION

In Table 3, the approximate cost of northern surveys are identified based on work done by Zoltai, (1971), Jurdant (1974) and the authors. It is clear that most of the monies (80%) required are absorbed by the field program. However, if costs are lowered by a reduction in fieldwork, lower quality information results. Cost is based on the fact that for most of Canada's north, 1:68 000 scale black and white photography is available. Therefore, the cost related to additional airborne remote sensing becomes operational. Although selected or complete reflying of many areas may be desirable for detailed conventional surveys. Cost surveys using conventional black and white imagery, selected airborne sensing and photo interpretation can produce inventory data for about 6 to 21 dollars per square mile, depending upon amount of field work. The cost for the ERTS based system is in the order of 3-6 dollars per square mile (9-18 million dollars for Canada's north). The information provided will be better than the low cost conventional type of survey, partly because a number of dynamic phenomena can be described from ERTS.

April, 1974, in Toronto, the "Workshop on Northern Baseline Data Needs" defined Canada's urgent need for a *rapid broad brush* type of survey. The use of satellite remote sensing in combination with selective airborne sensing would be a powerful rapid and low cost method for this purpose. Consider Manitoba for example where an area of about 164,000 square miles could be surveyed in approximately 3-4 years time for about $500,000 dollars.

AN OPERATIONAL SYSTEM

Satellite imagery can provide a basic operational tool for a rapid resource inventory in combination with existing black and white photography and supported by selected airborne sensing.

Based on experiences with satellite data as illustrated in this paper the following procedure is suggested:

1. *The formation of a team composed of one ecologist, one pedologist-geomorphologist and one limnologist. If the ecologist lacks a wildlife background, a wildlife biologist may have to be added to the team.*

2. *Existing satellite data should be used to delineate (preliminary) land districts and broad land systems (1:250 000 scale). Use should be made of repetitive imagery and enhancement techniques.*

3. *Based on satellite data analysis (2), areas should be selected for airborne sensing, photo interpretation and field work.*

4. *Based on field work, selected areas (land types) should be described.*

Based on Temporal satellite data, dynamic phenomena should be included.

5. *Results extrapolated using satellite where possible.*

6. *Final maps to be prepared on ERTS mosiacs.*

7. *Total cost about 15-30k per 5,000 square miles.*

8. *A detailed survey can be carried out simultaneously in high priority areas. However it will have to be mainly based on airphoto interpretation whereby strongly reducing the role of ERTS (relatively speaking).*

9. *Continuous updating of conditions using ERTS, as well as monitoring effect of management and planning decisions.*

Points 1 - 6 could be completed in a period of 3 - 4 years; 8 would require significant more time, 10 - 20 years while 9 should be done continuously in areas of rapid change.

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TABLE 1 Description of classes for Figure 1.

Symbol	Class No.	Description of Class	Vegetation Type	Landform	Material	Soil
I	5	Marsh (1) (very wet)	Carex and floating aquatic	Fluvial Plain	Alluvial, sand and clay loam	Gleysol
Z	4	Marsh (2) (wet)	Carex, willows and some floating aquatic	Fluvial Plain	Alluvial, sand and clay loam	Gleysol
▪	3	Marsh (3)	Dense Carex and willow	Fluvial Plain	Alluvial, sand and clay loam	Gleysol
/	1	Peatland	Ledum-Betula glandulosa and mosses	Dominantly polygons	Fen and sphagnum peat	Organo Cryosol
F 4 Y	16, 17 18 19	Other small wetlands along lake shores and peatlands	Complex of Carex, willow and aquatic	Fluvial and lacustrine Plain and Peatland	Sand, clay and peat	Gleysol and Organo Cryosol
H O	15 14	Shallow lake or pond	Aquatic and some Carex-willow	Fluvial and lacustrine Plain and Peatland	Sand, clay	Gleysol
–	2	Upland	Shrubby tundra (Betula g., Salix, ericaceous)	Marine or veneer of morainal over Marine	Sand and fine sand	Turbic Cryosol and Static Cryosol
. O	13, 21 22	Unvegetated shoreline, sandbars, shallow water	Unvegetated	Fluvial and lacustrine plain	sand and clay	Gleysol
J	12	Partly vegetated shoreline, drained lake beds	Sparsely vegetated Carex and willows	Fluvial and lacustrine plain	sand and clay	Gleysol, Organo Cryosol, Turbic Cryosol
M	6, 7, 8, 9, 10, 11, 20	Water bodies of river channels, lakes, lagoons and bays				

TABLE 2 Description of classes for Figure 2.

Symbol	Class No.	Description of Class
O	7, 8	Mackenzie water - rich in suspended sediments
I	10	Shallow water - dominantly shallow lakes, bays and lagoons
4	6	Very shallow water and sandbars
J	11	Lakes
M	9	Sea water
Z	20	Wetlands - marshes and peatlands
–	1, 2, 3, 4, 5, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22	Land

TABLE 3 COST ANALYSIS NORTHERN RESOURCE INVENTORY

	Cost per 10 000 square miles	
	Conventional Survey	ERTS base Survey
TOOLS		
Base maps	-	-
Aerial photographs	1 k	1 k
Airborne sensing	0-40 k	0-5 k
ERTS imagery	1 k	1 k
METHOD		
Fieldwork	40-140 k	20-40 k
Photo-interpretation	10-15 k	2-10 k
REPORT		
Maps	) 10-20 k	8-10 k
Description	)	
	$62-217 k	$32-65 k
Total cost for Canada's North	$18-61 million	$9-18 million
per square mile	$6-22	$3-6

Figure 1

A lake interpretation from ERTS (1424-17082; 20 September 1973) in the Playgreen Lake study area. The delineation is based on shoreline configuration, water distribution and water reflectance. The continuous lines identify major physiographic regions. Broken lines delineate different water signatures that appear to have relations with physiographic sub-units. While most of the reddish colours are related to suspended sediment levels, few of these near E are shallow waters.

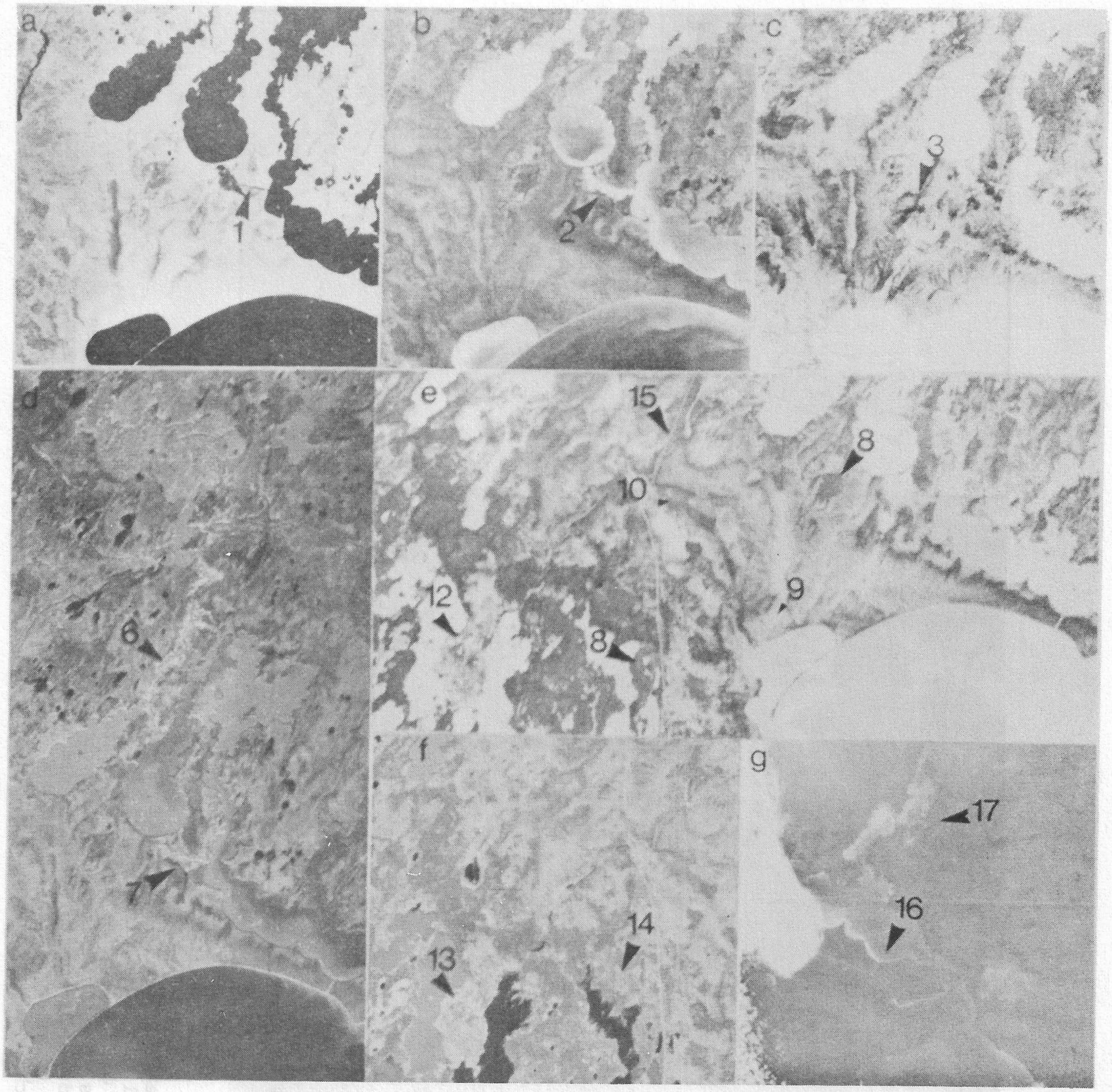

Figure 2

A series of ERTS photographs in the Playgreen Lake area. Picture (a) (ERTS band 7; July 28, 1973) shows the channel that is being dredged to connect two lakes (1). Image (b) shows band 5 of the same date, the extent of dredge spoil (2) on the land can be delineated; note that on image (d) September 20, 1973, the area covered has increased (7). Around 6 clearings are visible along a channel where flooding may take place. The clearing for the so called two mile channel is also visible on this image. Photo (g) taken on June 21, 1973, shows the start of a turbidity plume at the mouth of this future channel (16): man-caused or natural? Photo (c) taken April 8, 1973, shows the spring melt of snow; water has accumulated in many of the few wetlands (dark areas e.g. 3). Direction of drainage is clearly visible. Photo (e) (cl, 18 December 1973) shows the value of winter images; jack pine is (8) significantly different from spruce dominated cover types (dark green e.g. 10), also Tamarack densities (9) come out well. This colour composite of bands 5, 6, 7 provides good separation between hardwoods (14) and conifers. Twelve and 13 show regeneration patterns in burned over areas; 15 gives the location of recently built hydro transmission lines.

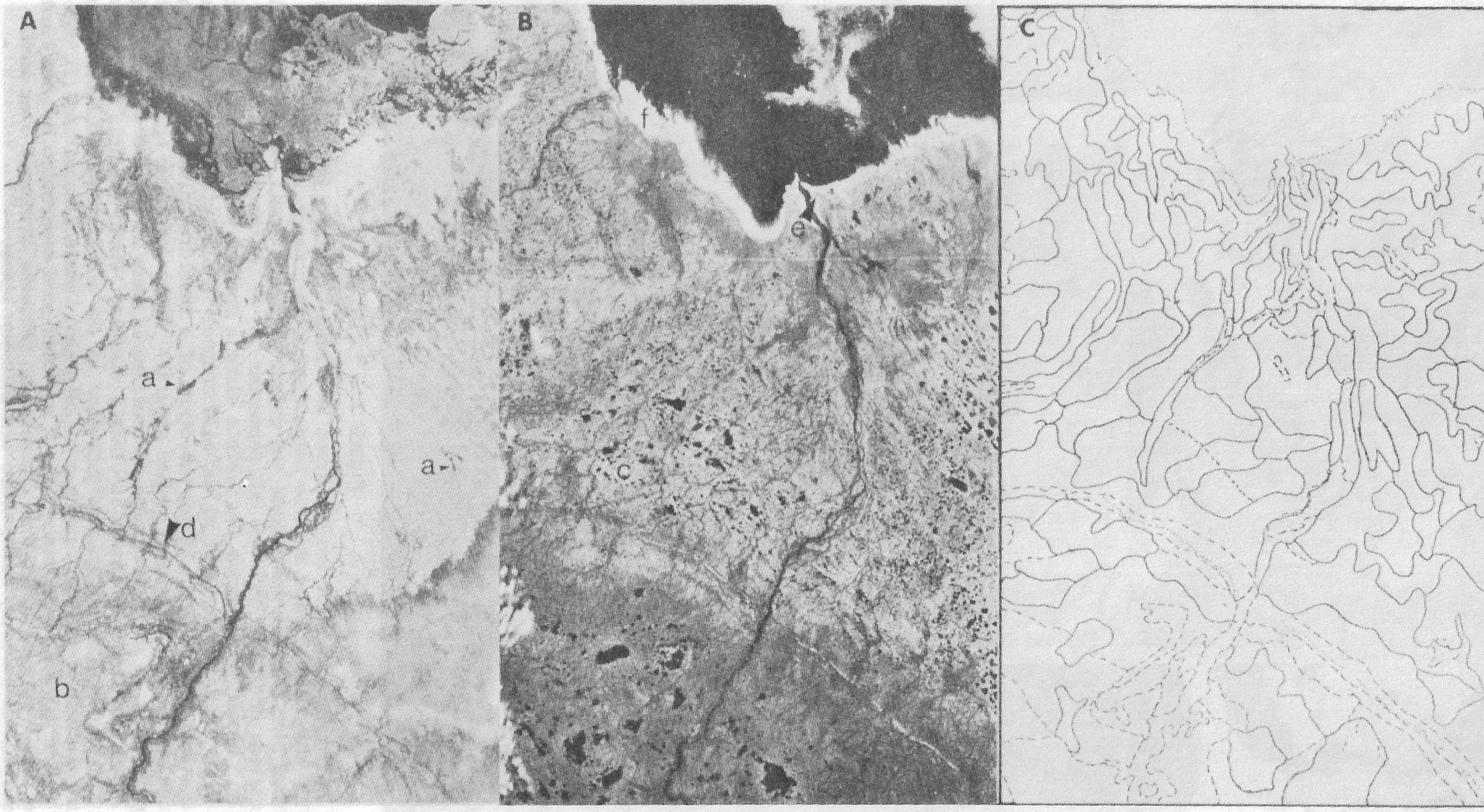

Figure 3

A sample of early winter (A) and summer (B - July 27, 1973) ERTS images, band 5, for the Churchill area and a delineation of land systems based on visual interpretation techniques. Continuous lines were obtained from summer images; broken lines from winter images. The winter images enhances coniferous vegetation (**a**) that correlates with sand and gravel deposits. Note the old marine beaches at (d) and the semi-open black spruce forest around (b); light tones (C) of the lichen dominated areas; the town of Churchill (e) and marine flats (f).

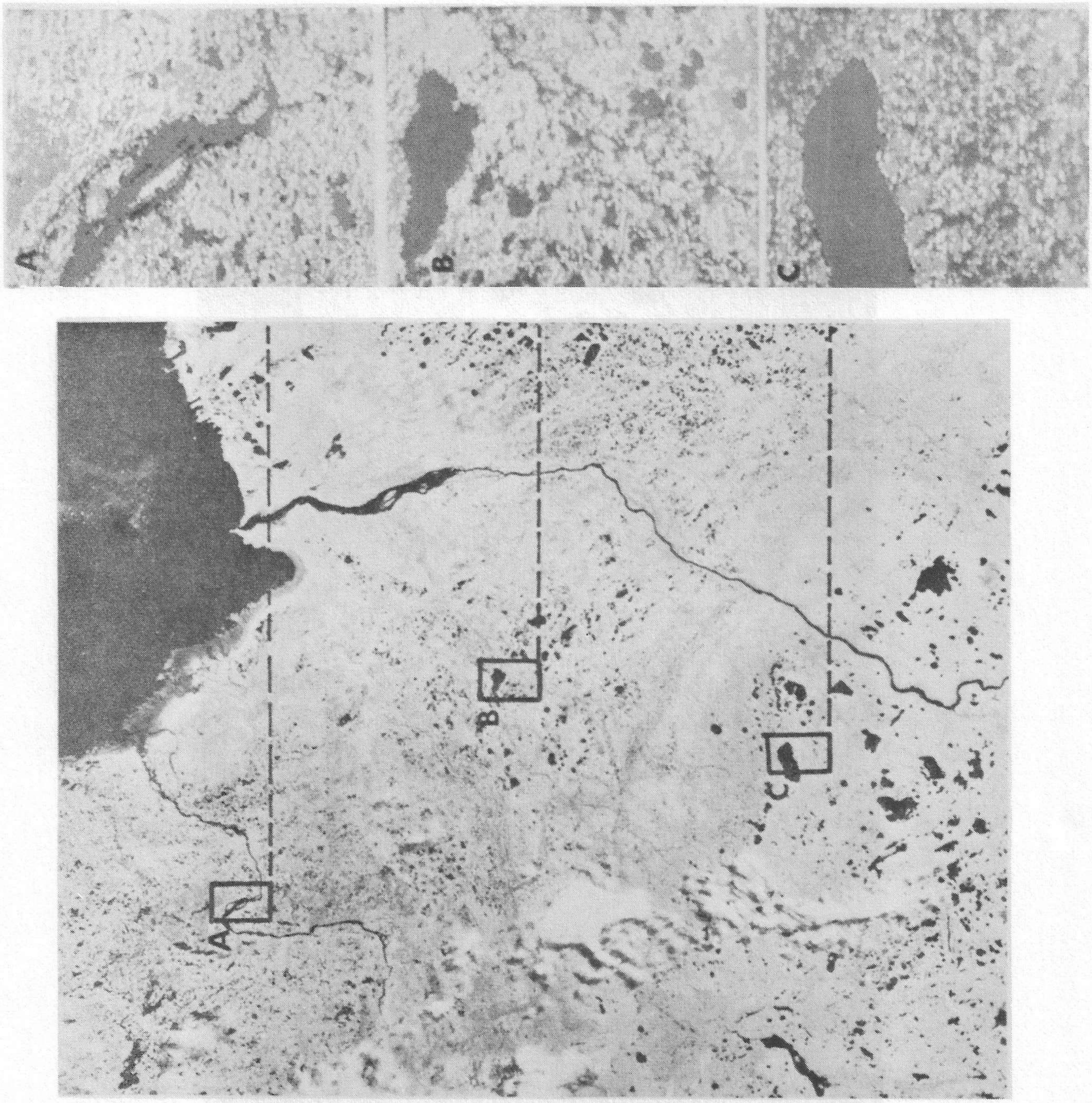

Figure 4

Three areas are identified on a band 7 image of ERTS. The areas are classified using the multispectral analyser display at CCRS: Red are frost heaved stone fields and till areas, dark blue is water, light blue are predominantly peat polygone areas; pink identifies patterned fen type wetlands; green means spruce on peat (AC) and on peat and sand (B).

Figure 5

Computer classification of the terrestrial environment of the Richards Island area.

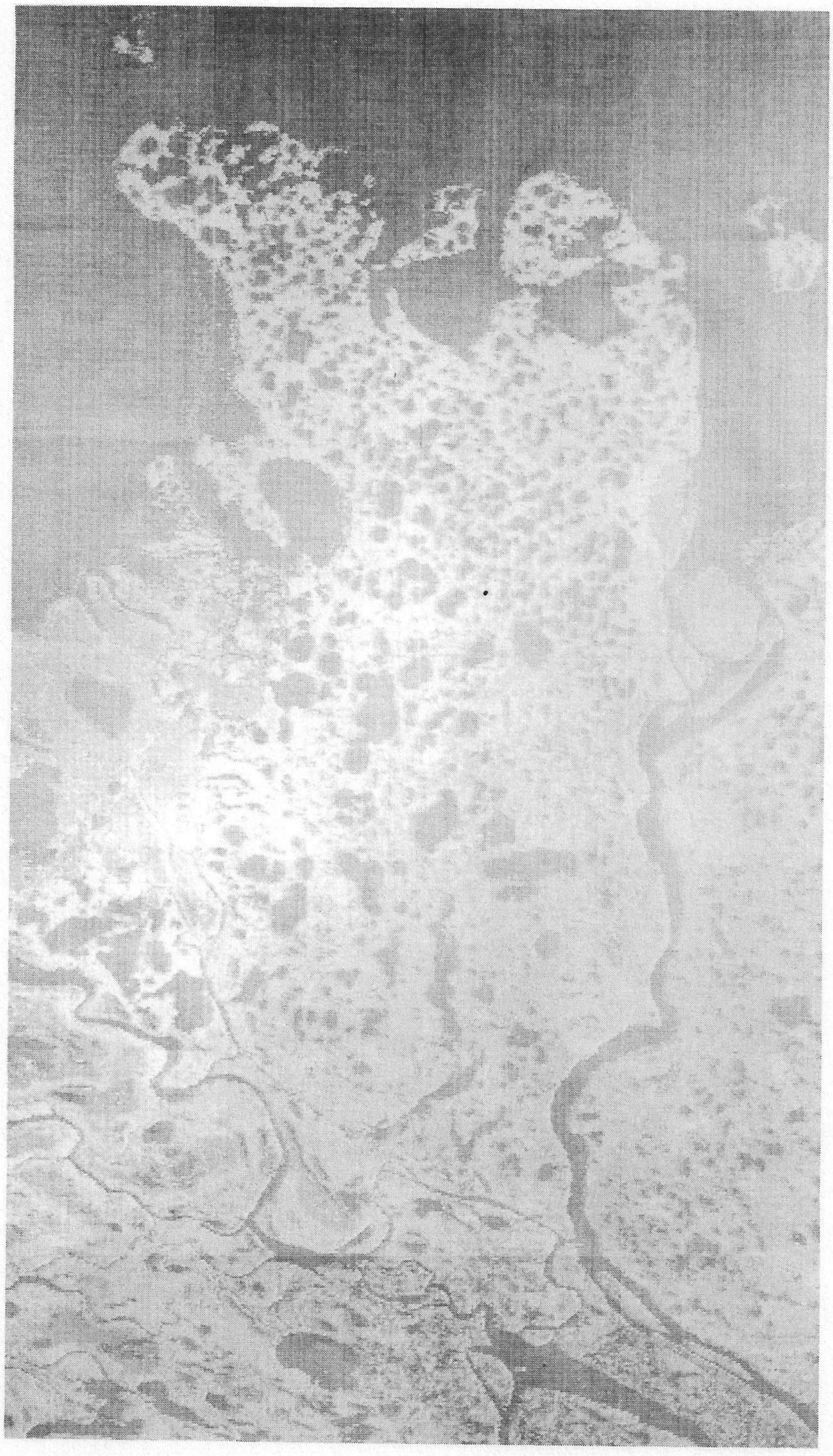

Figure 6

Computer classification of the aquatic environment of the Richards Island area.