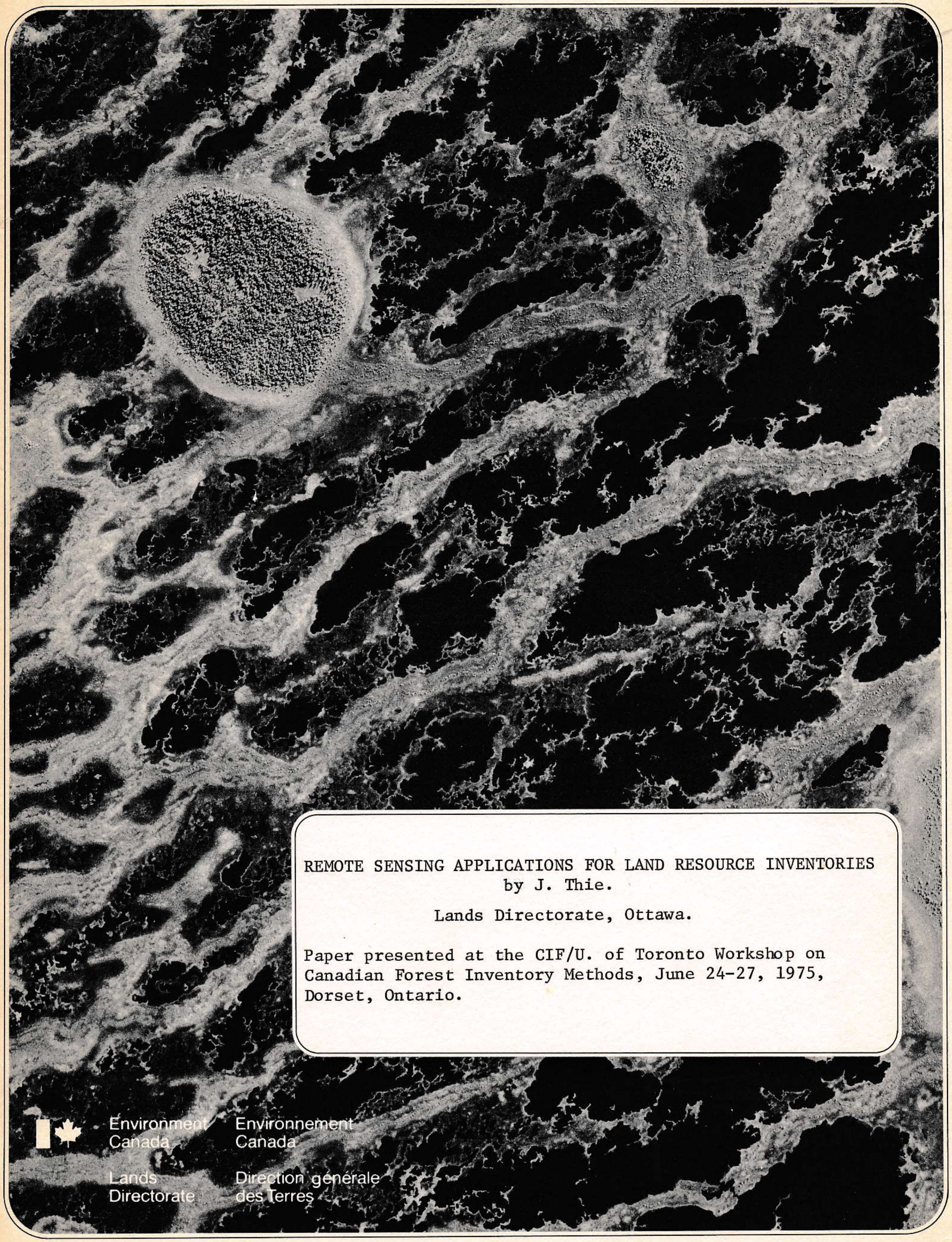

REMOTE SENSING APPLICATIONS FOR LAND RESOURCE INVENTORIES

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REMOTE SENSING APPLICATIONS FOR LAND RESOURCE INVENTORIES

by J. Thie*

1. INTRODUCTION

Managing the resources of the vast landmass of Canada is not an easy task. Without basic information on the natural and human resource base, including present land uses, rational land use planning is virtually impossible. To provide the necessary data base, inventory programs in geological, hydrological, forestry, wildlife, agriculture, climatic and socio-economic fields are necessary at local, provincial and national levels. One such program is the Canada Land Inventory, which provides information on forestry, wildlife, waterfowl, sportfish, recreation and agriculture capability and present land use at a scale suitable for regional planning. This program is confined to the more populated areas, about 1/3 of the land area. This leaves another 2.8 million square miles in the north without an adequate data base.

Since any program based on ground surveying is likely to be prohibitively costly in the areas most covered, any mapping program in the north will rely heavily on remote sensing. Several Canadian organizations, such as Canadian Forestry Service, Forest Management Institute, Canada Centre for Remote Sensing, the Ontario Centre for Remote Sensing, and Terrain Sciences - EMR, have carried out research into the applications of satellite and airborne remote sensing. Many members of the Canadian Institute of Forestry Working Groups on Remote Sensing and Forestry Inventories are playing a leading role in these activities.

Classification systems for mapping descriptions 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 Biophysical land classification system. This development in itself was, to a large extent, made possible by the use of conventional airphoto interpretation techniques. Only in such a way 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., as well as enable us to discriminate better between objects of interest. Repetitive remote sensing adds the dimension of time to the survey. The LANDSAT satellite, orbiting the earth four times daily and covering each part repetitively with an 18 day interval, 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.

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* LANDS DIRECTORATE, Ottawa; This paper is a modified version of an earlier discussion paper presented at the National Workshop to develop an integrated approach to Northern Baseline Inventories, 1974, Toronto.

2. BASIS FOR LAND RESOURCE MANAGEMENT

Environmental resource management is the main aim of provincial and federal resource agencies. To provide information for the proper management of the resources we need inventories, surveys, monitoring and research. In a simplified way three land resource surveys can be groupted into three types:

A National Baseline Study or Inventory:

> *a study or inventory that is carried out to provide basic environmental data for design of policies and proper resource planning in areas of national and regional concern; using an ecological approach, accommodating weighing of resource alternatives, prediction of impact, selection of implementation studies.*

An Implementation Survey:

> *a study or survey that is carried out to provide specific environmental data needed in addition to baseline data for the proper implementation and refinement of resource plans and policies.*

An Impact Assessment Survey:

> *a study or survey that is carried out in representative benchmark areas selected within implementation study areas with the objective of measuring the actual impact of the resource developments being implemented.*

In Canada, under the auspices of the National Committee on Forest Land, the development of a bio-physical classification system was started to provide baseline data for northern areas. 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, which are related to forestry, wildlife, waterfowl, recreation, agricultural (if applicable) potential could be made with little additional effort. This approach to inventory can be applied to baseline as well as implementation surveys in any part of the country, from wildlands with low use, to extensive and intensive agricultural areas, as well as urban dominated ones.

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.

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. While the bio-physical system, because of its ecological basis recognizes environmental changes and describes succession, more attention to present conditions and man-cuased or natural changes should also be given. Remote sensing could play a major role in eliminating both weaknesses.

3. 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 bio-physical 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, tone and texture (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 already obtained by black and white photography; it adds 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. For example infrared photography helps to detect stress symptoms in plants (disease, moisture, etc.) and in general provides very good discrimination between vegetation types. Different studies have indicated tht 1:120,000 scale colour infrared imagery can provide the equivalent amount of information as 1:60,000 black and white, (Thie, 1971) for bio-physical types of work. The smaller scale can reduce mapping costs for interpretation, while the more synoptic view (about 250 square miles) provides a superior base for land system and district analysis.

Multiband photography can ve 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).

Multi-spectral scanners on board aircraft may be of some use in the future. In theory their advantage is that they can measure the radiation in a very narrow "band" of the electromagnetic spectrum and can therefore optimize the spectral reflectance differences between objects. At present, computer handling and interpretation of data is quite costly, so much so that instruments of this nature are of little operational interest.

Single channel or dual channel scanners especially in the thermal infrared range of the spectrum seem advantageous to include in a sensor package. They allow mapping of temperatures to about $0.5^{o}C$ during 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. It can also be used for the detection of ground water discharge areas, incipient forest fires, and water pollution or lake surface temperatures.

The value of side looking radar imagery for land classification purposes is still somewhat uncertain. Experience with this material in Manitoba (Thie, 1974) showed little promise for the mapping of land 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).

4. SATELLITE REMOTE SENSING

The satellites that should be considered for use are the earth observation satellites like LANDSAT-1 and 2 and their 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 differences between the two types are in scale, resolution, as well as frequency of orbit. The LANDSAT satellites have a 4 channel multispectral scanner which registers in the Green, Red and two near-infrared bands of the spectrum. The NOAA satellite provides, in addition to this, thermal IR scanning.

4.1 SCALE AND RESOLUTION

The scale of imagery produced from LANDSAT is 1:1,000,000. Photographic enlargements to 1:250,000 and even 1:125,000 provide good quality imagery for interpretation and mapping.

The Bio-physical land classification system suggests mapping scales for its different levels 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

The resolution and scale of LANDSAT seems quite suited for mapping at the first three levels. Considering that on the computer compatible tapes from LANDSAT, the minimum resolution of 1 pixel, represents 77-57m on the gorund, even some use for land type mapping can be expected. As was experienced in land classification in the Churchill and Mackenzie area, (Thie, Tarnocai, 1974), LANDSAT provides very detailed information from computer tapes and the major problem encountered was to reduce this amount of data into significant larger, complexed units. This can be done by using human or automated interpretation techniques. At present the human based ones are more effective, certainly for bio-physical types of classifications. The scale of the NOAA imagery is extremely small; one picture covers about half of Canada. The resolution is very much poorer than LANDSAT, however high contrast phenomena can be monitored effectively: snow and ice, large burn areas in winter, etc.

4.2 REPEATED COVERAGE:

The NOAA satellites cover Canada every day; LANDSAT-1 and 2 have an 18-day interval between passes over the same area. For the high north, successive coverage up to five days can occur. 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 phenologican phenomena, disease development, moisture stress symptoms, snowmelt, and ice movements to other physiographic parameters like landforms, soil, relief, exposure, water, etc. Winter images can enhance particular surface phenomana, e.g. snow cover and low sun angles enhance relief and fracture interpretation.

It is obvious that rapid and more gradual changes that occur on the surface of the earth can be monitored from satellite in a gross way. This includes natural phenomena like forest fires (frequency of occurance, 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-caused 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 artificially 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.

The present operational availability of LANDSAT is demonstrated in Figure 1. On this computer print-out all the locations in Canada that are repeatedly imaged by the satellite are shown. Each number identifies the number of good quality cloud free images that are available for the period July 1972 to October 1974. All land areas are covered at least once, while most areas, considerably more frequently, up to 13 times.

A combination of NOAA and LANDSAT satellite monitoring is specially attractive for fast change high contrast phenomena like snowmelt, ice reconnaissance and surface temperature patterns. The daily coverage by NOAA compliments the less frequent higher resolution of LANDSAT images. The NOAA imagery may also be of much value for delineating 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 imagery may add regional climatic parameters.

4.3 LAND WATER INTERFACE

The synoptic view from satellite has shown very clearly the relationships that exist between physiography of the "land" area and water signatures.

A very strong correlation is apparent between lake and shoreline shape, water reflectance (in the Green and Red bands) and the surrounding land areas. This relationship is often so strong that water information can be used to infer parent materials and shorelines conditions from turbidity information and lake shapes. In fact, based only on lakes (providing a fairly large number occur in a mapsheet) a general physiographic map can be drawn in many areas. Landscape units or even land systems that appear to be uniform physiographically could in a number of instances be subdivided based on spectral reflectance of water. Regional limnology and regional lake inventories can benefit from satellite. As well the satellite will assist future inventory teams to integrate land and water classifications.

4.4 LAND CLASSIFICATION

As was mentioned before the LANDSAT scale and resolution is quite suitable for reconnaissance types of surveys. Work with LANDSAT in Northern Manitoba showed that especially in arctic and subarctic areas, satellite imagery 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 in large (organic) wetland areas in the boreal zone. Vegetation in both zones is a good indication of the distribution and extent ecosystems and relatively few disturbances (like) fires appear to have occurred. In the boreal zone, with its forest cover, broken precambrian physiography (in Manitoba, that is) and its complex fire history , mapping from LANDSAT cannot be as easily achieved. Land systems delineation by means of visual techniques is more complicated and results less accurate. Combinations 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 the boreal zone and could be successfully used as a source for land-water delineation.

It should be made clear that while satellite imagery can assist in delineating 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 and field studies are essential and cannot be replaced.

5. HUMAN versus AUTOMATED INTERPRETATION TECHNIQUES

Up to now human interpretation techniques are superior for the analysis of airborne as well as satellite Remote Sensing Data for Bio-physical Land Classification in most parts of Canada. Automated interpretation is still in its childhood and is not expected to produce methodology that will eliminate a human interface within the next 3 years. It is obvious however, that computer compatible tapes from satellites store considerably more information than black and white or colour images produced from them. For instance, the 64 "density levels" of the tape can only be translated into 10-12 grey tones on a black and white print or transparency for the same band. Effective use of all this information will require a computer at some stage. However, in addition to "signature", shape is critical for delineation and identification of land system.

No satisfactory techniques to analyze, by computer, shape information stored in images, have been developed yet. For land classification work a man-computer interface will therefore remain essential. Again in relatively simple areas like the Hudson Bay lowlands and some areas of the Arctic, automated classification can be very successful.

Human interpretation can be aided by special enhancement type of equipment such as colour additive viewers, colour density slicers or even simple diano and agfacontour slicing techniques. While these instruments and techniques have their place, their value should not be over-emphasized. Some of them (colour additive viewer, agfacontour, diazo) allow temporal overlays of satellite imagery that can be attractive for time-change studies.

Human interpretation of aerial photographs will, for a long time, to my feeling, form the most essential component of bio-physical surveys.

6. COST CONSIDERATIONS

Presently the Airborne Remote Sensing Unit of the Canada Centre provides multiband sensing for experimental and development projects on a subsidized price. On a commercial basis the price would be close to the $40.00 per sensor line mile, depending of course, on sensor package, location, size of area, etc. In an operational project this would mean about $20,000 for a high altitude super-wide angle coverage, including some lower level flights for an area of 5,000 square miles.

As at present, most of northern Canada is covered by black and white 1:63,000 scale photography. It is thought to be financially unattractive to refly complete mapsheets. It would, however, be very effective to fly selected parts with airborne remote sensing possibly on a repetitive basis. The combination of satellite, old black and white small scale photography, and recent airborne multiband remote sensing is considered an attractive package. The charges for satellite imagery are minimal.

If we look at the results of the Manitoba pilot project, it is clear that acceptable mapping can be accomplished for about $43,000 per mapsheet. (R.C. Goulden, J. Thie, 1970). Therefore an expense of $20,000 to obtain completely new airborne Remote Sensing coverage appears unrealistic.

Most of the costs involved in a northern survey are for fieldwork and mapping purposes. It is, therefore, unlikely that the use of satellite and airborne Remote Sensing will reduce cost by more than 25%, if at all. However, the end result, the description, approximation of ecosystems could be improved significantly.

7. A POTENTIAL OPERATIONAL APPLICATION

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 if the following approach is taken.

A. *Carry out a rapid general type of mapping using as main tools LANDSAT, selected airphoto interpretation and selected field work.*

B. *Carry out with a more detailed regular type of bio-physical mapping in areas of high priority.*

Based on experience 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, and airphoto interpretation, 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 LANDSAT 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 LANDSAT (relatively speaking).

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

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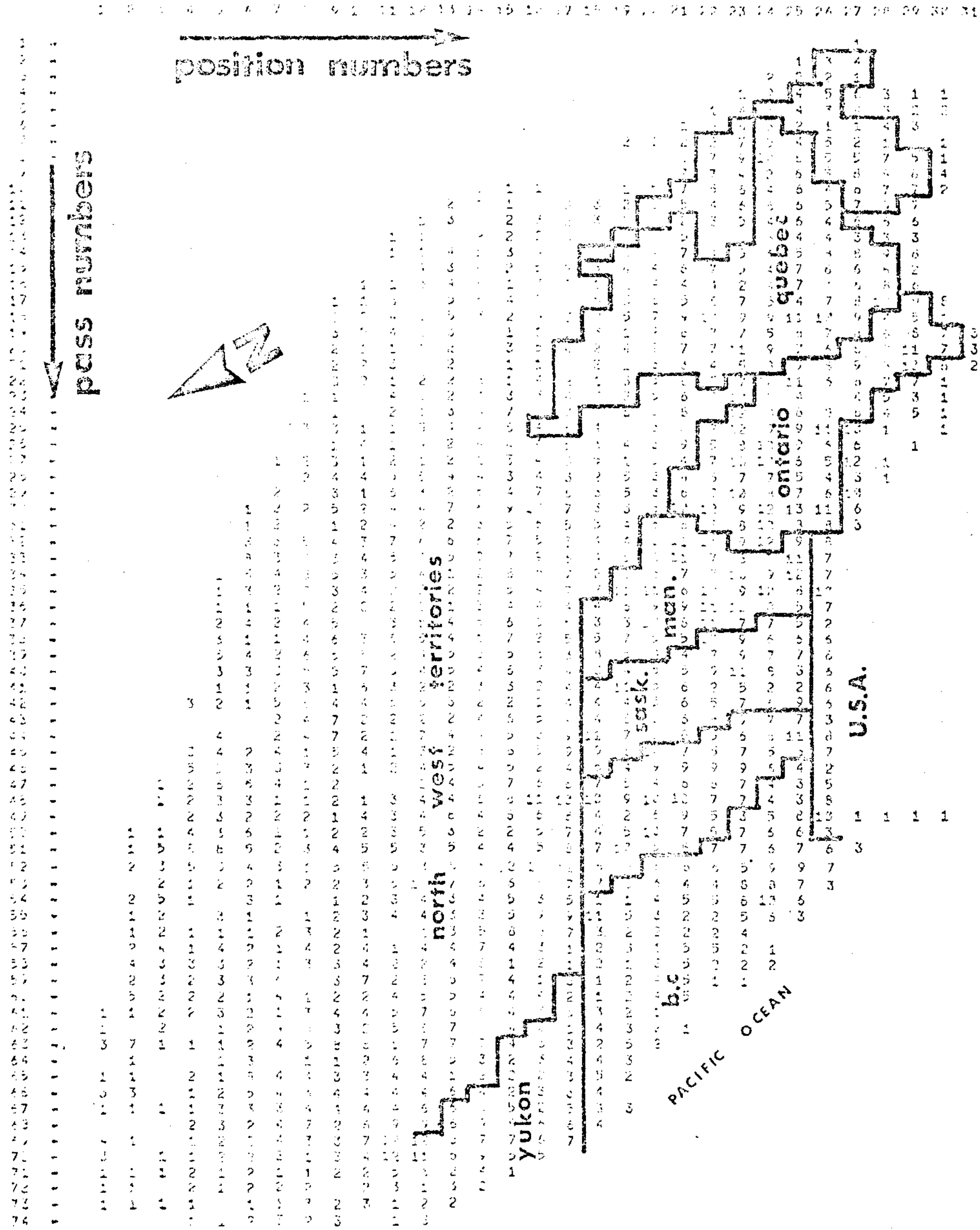

FIG. 1: Frequency count of LANDSAT-1 imagery in Canada with 25% cloud over or less taken between July '72 and October '74. Because of the overlap between passes (45% in the south increasing to 80% in the north) effective coverage frequency can be 2x greater (in the south) or more than the number indicated. (Thie & Wachmann, 1974).