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REMOTE SENSING FOR ENVIRONMENTAL MONITORING AND IMPACT ASSESSMENT

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Paper Presented at 1974 Banff Symposium - I.S.P., Commission VII.

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ABSTRACT

Monitoring of ecosystem dynamics is a key element in the development of strategies and methodologies for the most effective management of natural resources and in the development and implementation of measures to protect the environment. Remote sensing has been found to have a number of significant advantages and is being developed to serve the Canadian environmental needs. Remote sensing from ERTS, NOAA and from aircraft combined with selected field observations have provided an operational system for the monitoring and description of ecosystems as well as the assessment of environmental impact and effectiveness of control measures. A system for low cost, long term environmental monitoring for a large hydroelectric development in northern Canada is described.

RESUME

La surveillance de la synamique des écosystèmes est une condition essentielle à la création de méthodes et de moyens permettant une gestion plus efficace des ressources naturelles, et à l'élaboration et à l'application de mesures de protection de l'environnement. On a découvert que la télédétection était avantageuse à plusieurs points de vue; on a amélioré présentement les techniques afin de répondre aux besoins du Canada en matière d'environnement. La télédétection par satellites ERTS et NOAA, et par avions, associée des méthodes particulières d'observation sur le terrain a permis de compter sur un système utilisable pour la surveillance et la description de l'écosystème ainsi que pour l'évaluation de l'efficacité des mesures de lutte contre la pollution et de leur répercussion sur l'environnement. On y décrit un système à faible prix de revient, permettant la surveillance à long terme de l'environnement, pour un important aménagement hydroélectrique dans le nord du Canada.

ZUSAMMENFASSUNG

Die laufende Überwachung der Dynamik von ökologischen Systemen nimmt eine Schlüsselstellung ein in der Entwicklung der Strategie und Methodik für ein maximal wirksames Management der Naturschätze und in der Entwicklung und Anwendung von Umweltschutzmaßnahmen. Es hat sich gezeigt, daß die Fernerkundung eine Reihe wesentlicher Vorteile bietet; deshalb wird ihre Entwicklung im Dienste der kanadischen Umwelterfordernisse besonders vorangetrieben. Die Fernerkundung aus ERTS- und-NOAA Satelliten und aus Flugzeugen ist in Verbindung mit ausgewählten Bodenbeobachtungen zu einem funktionierenden System für die Überwachung und Beschreibung ökologisher Systeme ausgebaut worden, welches auch der Beurteilung der Wirksamkeit von Kontrollmaßnahmen und ihres Einflusses auf die Umwelt dient. Es wird ein kostengünstiges Langzeit-Umweltüberwachungssystem für ein großes Wasserkraftwerkprojekt im Norden Kanadas beschrieben.

INTRODUCTION

The present rate of population growth and the use of our natural resources and living space have made man realize the limits of our planet. Development and growth seem unavoidable and natural resource planning based on ecological concepts is needed. With ecologically based resource management we can hope to maximize long range benefits, social as well as economic, without unduly harming our life-sustaining ecosystems.

Essential to such planning and management is knowledge about ecosystems. Only with this knowledge and the study of the impact of man's past activities can we expect to predict the impact of our planned actions. Without this knowledge the evaluation of resource alternatives becomes ineffective and the expected benefits may prove to be too costly. The development of any region, whether in the economic, social or cultural sphere, is dependent upon the totality of the natural and human resources of that region. Its productivity is dependent, not upon the capabilities of soil and climate alone or upon the capabilities of living organisms alone, but upon specific relationships between living organisms and the total environment (Hills, 1970).

In the past, airborne remote sensing has been found to be a most effective tool for the description and mapping of natural ecosystems (Thie, 1972, Johnson, 1970). Remote sensing in the ultra violet, visible, thermal and microwave parts of the electromagentic spectrums has been correlated with many ecosystem parameters which are essential for describing and understanding these systems. New sensors which add new parameters are continuously being developed. For example, in Canada the Sensor Working Group stimulates the development of, among others, correlation spectrometers, a laser fluorosensor, Lidar, spectroscopic devices, and a soil moisture meter (MacDowall, 1973). It is however obvious that ground truthing remains a key to being able to properly describe ecosystem elements.

Ecosystems are very dynamic, their elements and their interrelationships are ever-changing. To really understand these, repetitive surveys have to be carried out on hourly, weekly, monthly, yearly or multi-yearly basis. In fact without understanding the dynamics of natural changes of the environment, it will be impossible to adequately assess the impact of man's activities on the environment.

The survey of the natural dynamics of a large area, certainly in Canada, is only possible by means of remote sensing from aircraft and satellites in combination with selective ground truthing. While aircraft remote sensing provides more detailed information, the conduct of frequently repeated airborne surveys over all of Canada is politically as well as financially not feasible. Satellite remote sensing with its low resolution and regular 18-day cycle provides a reasonable alternative, although it should always be used in combination with aircraft and ground truth data.

MONITORING OF NATURAL ENVIRONMENTAL CHANGE

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. Airborne and satellite remote sensing may help to identify, classify and describe the building blocks of our environment. Ecosystems can be defined as any area of nature that includes living organisms and non-living substances to produce an exchange of materials between living and non-living parts (Odum, 1961). The non-living parts of an ecosystem are collectively known as 'physiography', consisting of both landform and climate. Plants, animal and human communities comprise the living portions of the ecosystems (Hills, 1970). Because of the relative stability landform features are frequently used to classify ecosystems.

During the last decade only have there been attempts in Canada to survey and provide resource data in a multidisciplinary and integrated fashion--the Canada Land Inventory System and the Bio-physical Land Classification System (Lacate et al, 1970) are examples of this. However, in addition to these integrated surveys, single disciplinary resource monitoring will still be required. For adequate monitoring of environmental phenomena at least monthly or seasonal surveys are needed over large areas. In Canada very few regularly repeated airborne surveys have been carried out and ERTS-1 imagery is the only source of information which has been gathered with reasonable frequency (18-day interval) and resolution (about 80 meters on the ground). ERTS covers all areas; data is provided rapidly for areas that are of immediate interest and a file of information is built up for areas which may be of future concern. Many of the following discussions are therefore related to ERTS-1 applications which are usually combined with selected airborne surveys.

The bio-physical land classification system is an ecological survey which uses the relatively stable landforms as a basis for ecosystem mapping. Such a survey provides information related to the ecological limitations and is a prerequisite to integrated resource management (Jurdant et al, 1974). Four different levels are identified in the system: land region, land district, land system and land type. ERTS remote sensing can contribute to the mapping, description and monitoring of these units as it builds up a file of information on environmental dynamics covering large areas on the earth's surface; the data may include snow cover, snow melt, freezing and thawing of lakes, phenology of vegetation, etc. Such information, collected over a period of time, may assist in the delineation of areas with ecologically significant uniform climate. For example, the melting of snow and lake ice (Fig. 1) correlates strongly with land region (ecoregion) boundaries which were obtained after extensive field work. These climatically defined larger units (mapping scale usually 1:1,000,000 or smaller) can be broken down into the next level (land district; scale of mapping 1:500,000 to 1:1,000,000) on ERTS imagery. While satellite imagery can help in the mapping of land systems, the description of 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 at the present time. In areas where relatively simple relationships exist between vegetation and soils and where little disturbances have occured, such as by fire, satellite mapping of land systems may become effective. Such areas include Arctic and sub-Arctic environments, as well as large wetlands. In the more complex areas, such as the Boreal zone of the Precambrian Shield, most mapping and monitoring will have to be carried out on airborne imagery (Thie et al, 1974).

Considering the continuous change which takes place in the environment it is clear that a proper description of the environment should include change phenomena. The ERTS shows a potential to provide some of this data, in spite of its relatively low resolution, for example the formation and melting of aufeis or icings. Aufeis represents temporary, above ground storage of ground water discharged during winter; aufeis as small as 100 m^2 can be identified (Van Everdingen, 1974). An aufeis development and melting is shown in Fig. 4 E, F. In Fig. 2 E, F, the changing conditions in a carex fen type wetland which is surrounded by raised drumlins show spring meltwater storage and late summer conditions.

Repetitive airborne surveys of selected ecosystems using multiple sensor combinations are important for the description of the more dynamic ones. Comparison of photographs which were taken within a ten-year and a twenty-year interval made it possible to determine the rate of melting of perennially frozen peat landforms as a function of time, and environmental parameters such as climate, drainage, fires, etc. (Thie, 1974). One could expect that forest fires on peat plateaus in the sensitive southermost fringe of the discontinuous permafrost zone would increase the rate of melting, however the study showed no measurable change. These permafrost ecosystems are stable enough to survive fires and possible some human activities.

By using ERTS the mapping of forest fires is a simple task as demonstrated by the Ontario Centre for Remote Sensing (Zsilinszky,1974). Mapping of recently burned-over areas in Northwestern Ontario by means of conventional airborne techniques cost approximately $13,500; ERTS mapping provided the same amount of data for about $500.00. Annual mapping of forest fires can be done for relatively small amounts of money. Considering the number of fires in Canada (1973: 5,087 fires and about 835,000 hectares) this can amount to significant benefits every year.

McQuillan, 1973, describes the benefits of monitoring sea ice for transportation in northern Canada and estimates benefits of about $4 million annually in 1975 which will increase to about $12 million in 1990 if ERTS and NOAA data can be rapidly transmitted to the user, for example to ships. Benefits can be increased to over $100 million annually in 1990 if the remote sensing systems are extended to include ice thickness measuring sensors, a satellite with microwave imaging sensors on board and a satellite data relay system. In any monitoring program using remote sensing we should therefore not only be concerned with the acquisition of data and its interpretation, but also with the design of a system for rapid data transmission to the user.

Monitoring of water conditions from a satellite may be especially promising for the characterization and mapping of water bodies. Water conditions are very dynamic. Different researchers have shown correlation between ERTS digital data and suspended sediment, chlorophyll, turbidity, etc. Ice melt and break-up can be related to current flows (Fig. 4 A, B), while suspended sediments and humic water can be related to surrounding land materials (Fig. 4 C, D).

ENVIRONMENTAL IMPACT ASSESSMENT AND PREDICTION

Base line information which describes the natural conditions of the environment is essential to impact assessment and impact prediction. Without this data change cannot be measured or adequately predicted. For most areas in Canada, the type of base line information which is needed does not exist.

If resource information is available, it was gathered on a single disciplinary basis and the study and measurement of natural change phenomena was not included. An indication of the lack of adequate 'historical' data is shown by the airphoto coverage of Canada. Most of the country was covered once and selected parts of the developed areas were covered more frequently. Except for the ERTS coverage this leaves many areas in the north, where presently large scale developments are contemplated, without data on natural environmental change.

To predict impact it is necessary to study the effect of similar activities in the past on similar ecosystems in similar ecoregions. The amount of historic data, as discussed earlier, is quite limited and in many situations we may not be able to learn from the past. However, natural models may exist which may be indicative of the situation after planned actions have taken place. These models should be selected on the basis of ecological similarity between the model and the expected future situation in the areas where the change will occur. For example, South Indian Lake in Northern Manitoba is a part of a large hydroelectric development. Fig. 4 C shows the present situation as indicated by an ERTS band 5 image. The Lake will be flooded; based on a detailed biophysical survey it is predicted that the amount of eroding clay shoreline will increase from about 5% to about 75% and this is similar to the present situation in the highly turbid South Bay area. Based on this similarity one could predict that the turbidity levels in the rest of the Lake may reach the levels of South Bay.

The ERTS satellite is well suited for the purpose of finding such representative natural models especially in water and it can also monitor man-made change in a general way. It may act as a surveillance or warning tool that some impact is occuring, but it will probably not provide adequate detail for impact assessment (Fig. 5 D, F, G). Much of this work will have to be done from aircraft by means of special sensors and supported by ground truthing. However, ERTS can provide the basis for extrapolation of this information over a large area.

Almost any surface change resulting from man's activities can be monitored by using aircraft and satellite remote sensing and ground truthing: land use change, crop response, urban sprawl, new roads, hydrolines, logging areas, forest regeneration, etc. Fig. 3 shows a number of examples of smelter smoke damage, logging areas and new road development. ERTS can demonstrate some of the cause and effect relationships related to land management; Fig. 2 shows the connection between clearing of forest cover, erosion on sloping lands and spring flooding in lowlands in the Whitmud River watershed. Imagery from the ERTS-1 satellite has been used to revise small scale maps in the wilderness areas of Canada. New roads, railroads, hydroelectric transmission lines and reservoirs which are all part of the development of the north can be detected on ERTS imagery and can be plotted with sufficient accuracy for the revision of 1:250,000 topographical maps and 1:500,000 aeronautical charts (Fleming, 1974).

ENVIRONMENTAL PROTECTION SURVEILLANCE

While surveillance in support of resources management activities is conducted to determine the true ecosystem impacts, surveillance is also carried out to determine the effectiveness of measures which are being used to protect the environment.

An essential element of an environmental protection strategy of a particular activity is the systematic verification of the anticipated effectiveness of controls and of predicted ecosystem impacts. In order to make this possible it is necessary to gather, process and coordinate pertinent environmental data and information so as to establish the cause and effect relationships of environmental processes.

For an effective environmental protection program it is necessary to obtain data in order to:

1. Establish environmental baselines, or at least reference levels, against which to judge the extent and severity of impact on the ecosystems.

2. Compare observed impacts with those anticipated in order to improve existing forecasting and impact assessment methods.

3. Ascertain if the controls stipulated in plans, specifications and agreements are in place and if a proponent is carrying out directives.

4. Assess the effectiveness of regulatory measures and of controls to protect the environment and assist in the development of new ones.

While all four elements are required for an effective surveillance program, elements (3) and (4) address primarily the environmental protection function.

Experience has shown that remote sensing has very good capabilities for identifying the broad degradation of the environment which may result from large projects. In such projects the damage may result from a large diversity of causes and may extend over large areas. The environment frequently acts as an integrating mechanism which makes surveillance on a lumped parameter approach necessary. It has been found that by the use of remote sensing it is possible to gather and record the large quantities of diverse environmental information which is involved. Remote sensing has also been used to offer a more rapid, sufficiently accurate and frequently less expensive means of delineating the environmental levels and changes. Furthermore, remotely sensed data are compatible with that obtained by the field methods of observation, immersion sensing and sample analysis. The field methods have been the basic means of carrying out surveillance for environmental protection purposes of biological, chemical, physical and engineering factors. In support of remote sensing these methods provide also ground truth, calibration and quality control.

An operational remote sensing program which is to be used as an aid to environmental protection is being developed and implemented by Environment Canada. Under the terms of their mandate, CCRS is assisting in the developing of the program by providing technical expertise in data gathering procedures, in the analysis and interpretation of the data, and in staff training. Generally, the program is set within the framework of the ecological impact control programs which come under the mandate and responsibility of the Environmental Protection Service. While policy matters and the development of the national program are primarily a headquarters responsibility, the operational aspects depend largely upon the regional and project needs.

Cooperation with Environment Canada services and with other federal and provincial departments and agencies are also important elements.

It is anticipated that reliance will continue to be placed on aerial photography, using colour and black/white film both in the visible and infrared light ranges; the remote platforms will be provided by aircraft and the ERTS system. Additional information will be obtained by airborne infrared sensors, SLAR and by other means as and when needed. It is expected that most of the data gathering will be done by industrial firms which are under contract. In order to provide maximum mobility at lowest cost a system is being developed which uses 70 mm and 35 mm motor driven cameras mounted in arrays of 2 or 4. This will make it possible to use small aircraft as remote sensing vehicles. Effectiveness of such systems has been demonstrated by Zsilinszky (1972) and by Meyer (1974).

In some instances reliance will be placed primarily on sensor combinations which have an all-weather and day/night capability. Such operational systems may be needed, for example, to provide real time surveillance in support to containment and clean-up operations of a marine oil spill (Thomson et al, 1974). Suitable sensor combinations may include radar, low light level television, microwave scanners to determine oil thickness, a laser fluorosensor for identification of oil type and a multi-spectral scanner or camera system with sensitivity in the ultra violet range. Support to locate and monitor larger oil spills may further be provided by ERTS (Strumpf et al, 1974).

OPERATIONAL USE OF PRESENT SATELLITE SYSTEMS

Systematic surveillance of a country the size of Canada is made economically feasible only with the aid of satellite remote sensing systems. Two satellites, NOAA -2 and ERTS -1, are presently in use. NOAA covers Canada twice every day. Since it has relatively low ground resolution, about 900 m, it is used primarily for monitoring weather and relatively high contrast phenomena, such as sea ice movements. ERTS, which has been in operation for about 2 years, traverses Canada on an 18-day cycle. The frequency of coverage of images with less than 25% cloud cover is given in Fig. 6. As most areas in Canada are covered by two consecutive passes in the south and more with increasing latitude, the effective coverage may be double or triple these amounts. Many parts of Canada will have one coverage per climatic season and this appears to be the minimum that is required for environmental monitoring. More frequent coverage is desirable and in fact available for many areas.

In order to be most effective as an operational system it is necessary that the data gathered by satellite reach the user as quickly as possible. To that end quick-look hard copy imagery and quick-look microfiche is produced in Canada at the Prince Albert Receiving Station and usually reaches a user by mail within 3 to 5 days after overpass.

In order to facilitate visual data interpretation by users CCRS produces two colour composites. The first (colour 1) is the normal approximation of false colour infra red which is most suitable for the interpretation of land vegetation. The second (colour 2), shown in Fig. 4 C, D, E, F, is a combination of bands 5, 6, and 7 to which red, green and blue have been assigned respectively. ERTS computer compatible tapes can be produced in about two to three weeks after overpass. In addition, CCRS can provide users with space and automated interpretation facilities;

equipment for digital interpretation includes a GE image 100 and a Bendix multispectral analyzer display (MAD).

LONG-TERM ENVIRONMENTAL MONITORING

Some of the large scale developments in northern Canada, including the Lake Winnipeg, Churchill-Nelson Rivers Diversion, James Bay hydroelectric development and proposed highway and pipeline construction, will require long-term monitoring programs. The programs may have to be conducted over 5 to 20 years or even longer in order to better assess and quantify any environmental changes which may result from the projects and to obtain data for control measures and for improved environmental design on similar projects in the future. The size of the areas involved poses problems of program feasibility. A special task force was formed in Manitoba in 1972 to develop a monitoring program for the Churchill-Nelson Rivers Diversion and because of the size of the project, about 100,000 km^2 are involved, and budgetary restrictions, a program was proposed based on full use of satellite and airborne remote sensing. The following summary of the proposal identifies the method and costs (Thie et al, 1973).

<u>Objective</u>: To assess and monitor long-term environmental changes which can be attributed to artificial manipulation of water levels and flows.

<u>Method</u>: A multidisciplinary or multi-agency study team will evaluate the changes occurring in the vegetation, wildlife, soils and water elements of representative ecosystems in the impact areas. By use of airborne and satellite remote sensing, in addition to conventional ground sampling, repetitive surveys can easily be accomplished, while findings in selected ecosystems can be extrapolated over the total impact area at an unusually low cost.

<u>Survey before flooding</u>:

Phase I - selection of representative ecosystems and sample areas by the bio-physical group during 1972-73, based on results of studies in progress directed by the study office;

Phase II - analysis and detailed description of selected ecosystems during the summer of 1973, winter 1973-74.

<u>Monitoring after flooding</u>:

Phase III - repetitive surveys of selected ecosystems;

Phase IV - data interpretation and assessment of change; recommendations.

Monitoring will continue for a period of five years after flooding; some parameters will have to be monitored for periods of up to 30 years.

<u>Cost</u>: Per year for the first 5 to 8 years about $110,000.00

Some aspects of these projects are shown in Fig. 4 and 5. The low cost figures and methods are dependent upon the availability of ERTS imagery. The fact that ERTS-1 produced about 18 cloud-free images in a period of about 2 years for the area in Fig. 5, demonstrated that this dependence is not unwarranted.

CONCLUSION

Environmental monitoring is important for proper management of natural resources. Environmental impact assessment and prediction forms an essential component of the evaluation process of resource alternatives. In Canada, the ERTS-1 satellite has provided repetitive coverage for most parts of the country varying from about 4 to 10 times a year. Such coverage gives a good opportunity to obtain baseline and reference data and to determine and evaluate many environmental changes for purposes of impact assessment. ERTS can also provide some assistance in environmental protection programs; however, airborne remote sensing systems are needed in combination with field observation in order to provide information with great detail. Remote sensing is considered to be particularly advantageous for the surveillance of large scale developments in northern Canada.

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FIGURE CAPTIONS

Fig. 1 A, B: Land regions and snowmelt, Berens River Area, Manitoba. Image A shows ERTS-1 band 7, B shows band 5. Note the climatic transition shown by snowcover and totally frozen lakes in the north, completely melted snowcover in the midzone (meltwater is stored in wetlands, dark on A) and ice covered lakes which show signs of meltwater. In the southern portion ice and snow have disappeared.

Fig. 2 A, B, C, D: Cause and effect relationship, clearing-erosion-flooding, Whitemud River Watershed, Manitoba; winter C (date: 5-1-74), spring melt A (23-4-74) and summer B (16-6-74) can be compared with fall 73 D (18-9-73). Note the snowcovered high plateau (A: 1) and the inundated farmlands (A: 2). B shows erosion (B: 1) on steep slopes cleared of tree cover. Cleared slopes cause rapid run-off in spring and contribute to flooding.

Fig. 2, E, F: Springmelt inundation of sedge wetlands, Interlake, Manitoba. E, band 5, shows fall (15-8-73) conditions; light tones in between darker drumlines are wetlands. F, band 7, shows the inundation areas during snowmelt (23-4-74).

Fig. 3: Man caused impact. A shows the smoke plume of smelters near Sudbury (10-9-72), smelter smoke damage is illustrated by winter image B (14-2-74). A similar situation exists near Wawa C (3-8-73), D (12-1-74). The disturbance area near Flin Flon E (11-10-73), an old mining town, is less extensive. F shows a new mine near Leaf Rapids, Manitoba (25-4-74). G shows recent (1) and older (2) cutover areas in winter. H a new road with borrowpits (3) and clearing (4) for a new channel development along the Rat River, Manitob

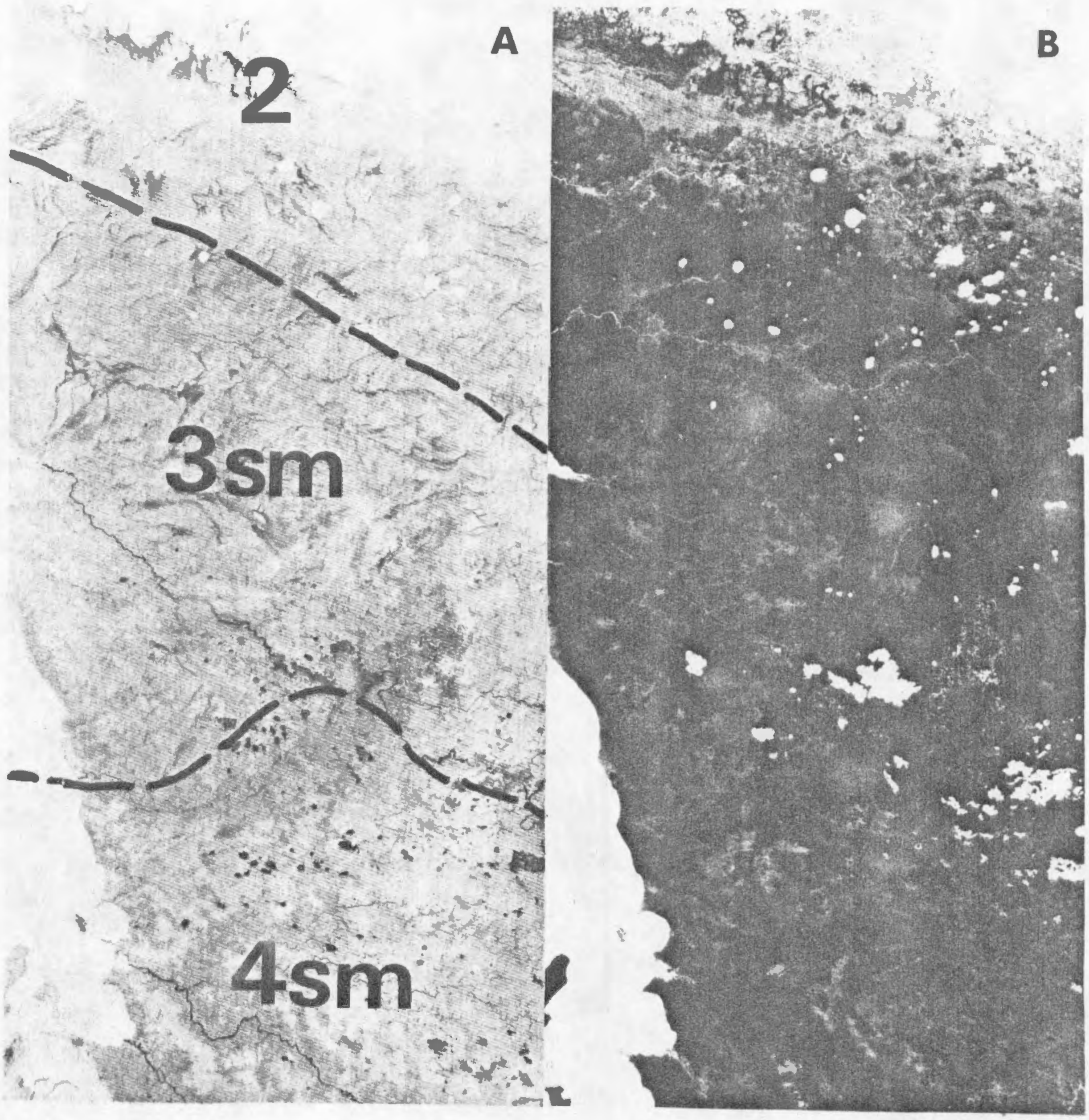
Fig. 4 A, B, C: South Indian Lake (Manitoba) during ice break-up. In late April A (25-4-74) water current patterns become apparent by colour of ice; 18 days later these areas have opened up B (13-5-74). C (17-6-74) shows a colour composite (#2); note the high turbidity in the South Bay area (arrow).

Fig. 4 D: Example of the colour 2 composite showing turbidity in water.

Fig. 4 E, F: Aufeis (icing) development and melt. E shows aufeis in spring (15-5-74); F in later summer (29-7-73).

Fig. 5: Monitoring of progress and impact of channel dredging, Playgreen Lake area, Manitoba. A selection of 5 taken from a total of 18 relatively cloud free passes of ERTS is made displaying bands 7 (B, C, D, E), and 5 (A, E, G, H). Image B (16-5-73) shows the advance of the dredge to that date; progress can be followed on C (20-9-73) and D (14-7-74). The increase in impact of dredge spoil is shown on F, G, H (dates respectively the same as B, C, D). E shows the area in spring (23-4-74), note small amount of inundation. Note the change in turbidity patterns (light tones) between G and H.

Fig. 6: Frequency count of ERTS-1 imagery in Canada with 25% cloud cover 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.



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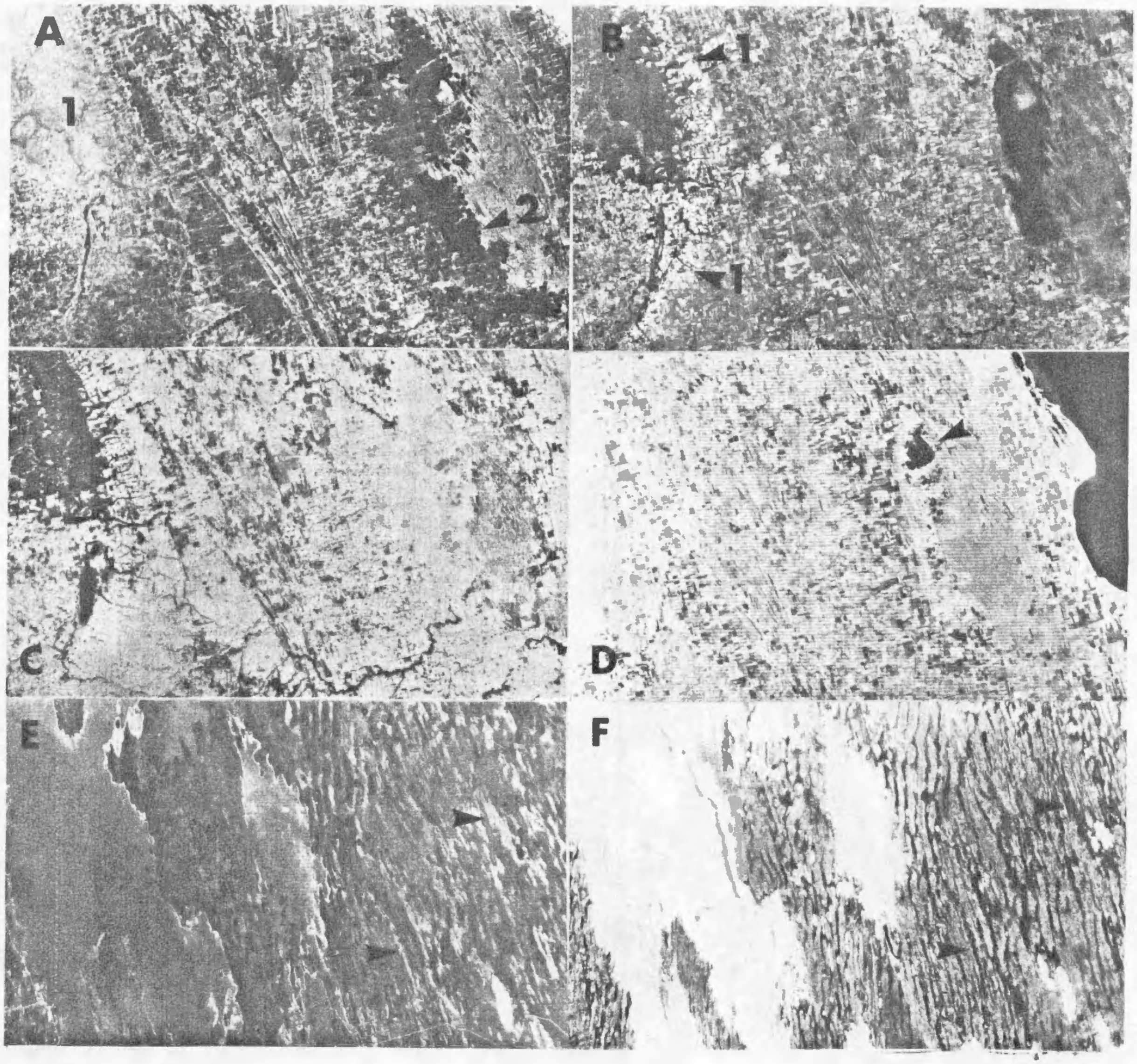
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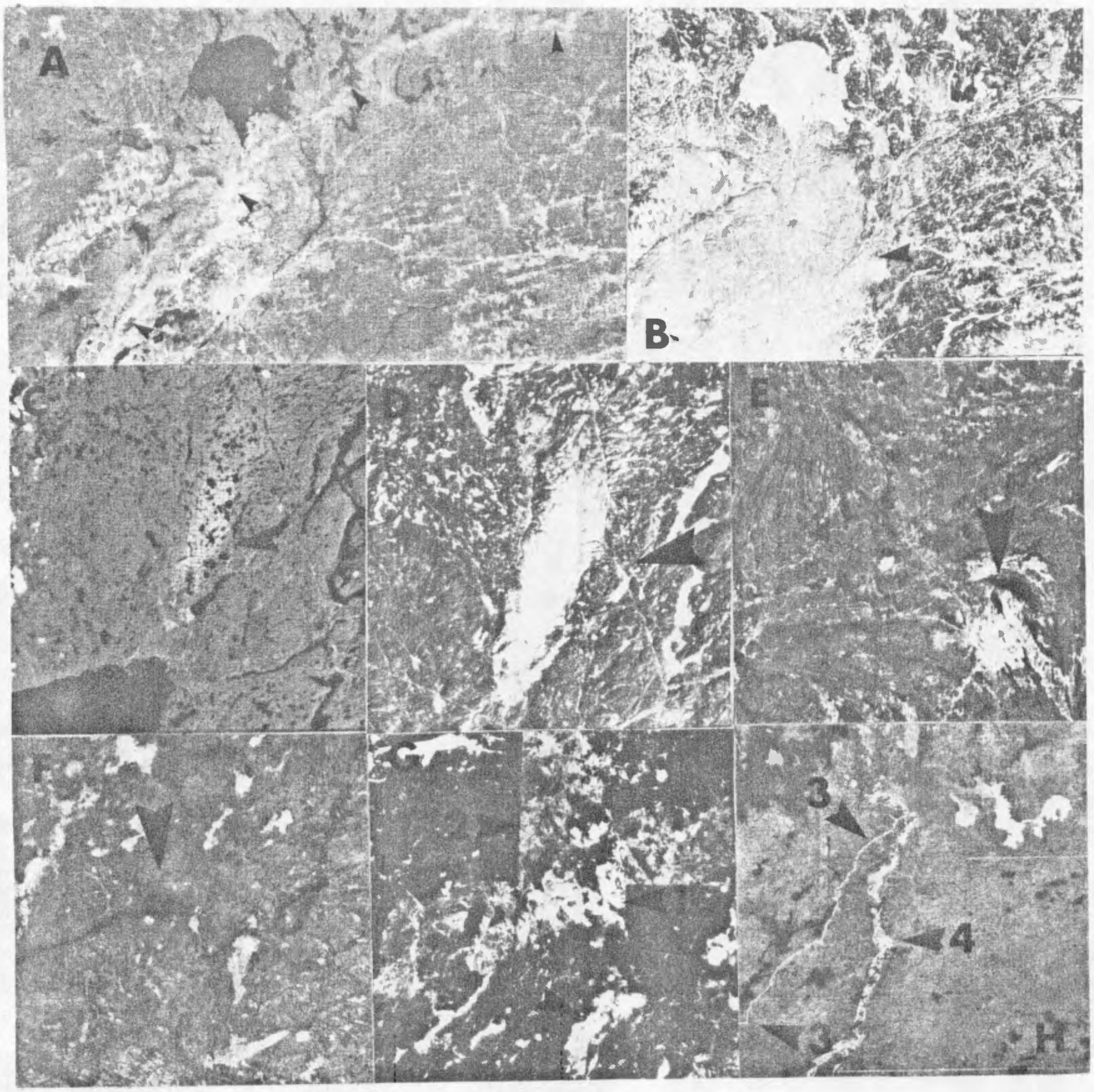

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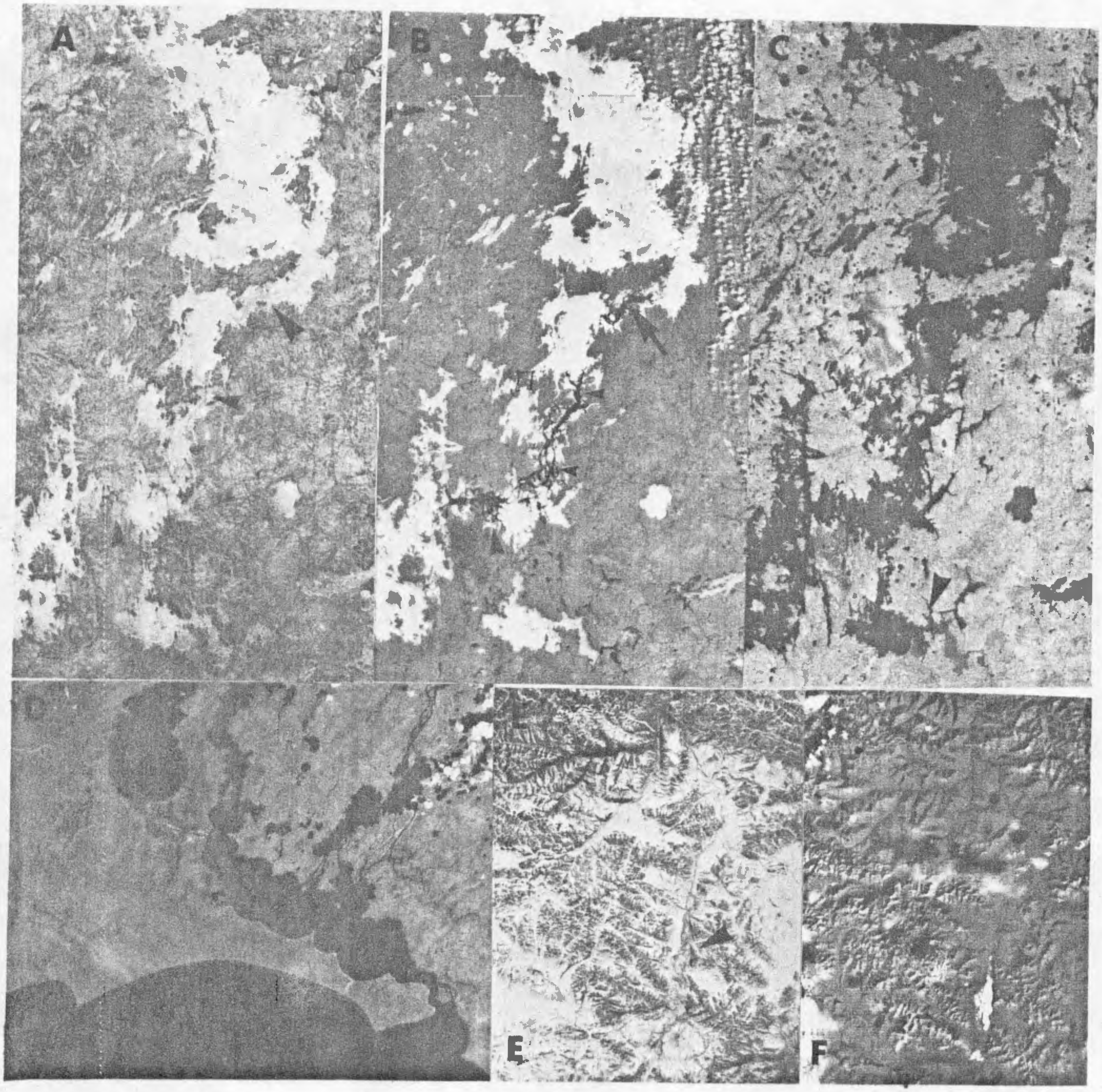
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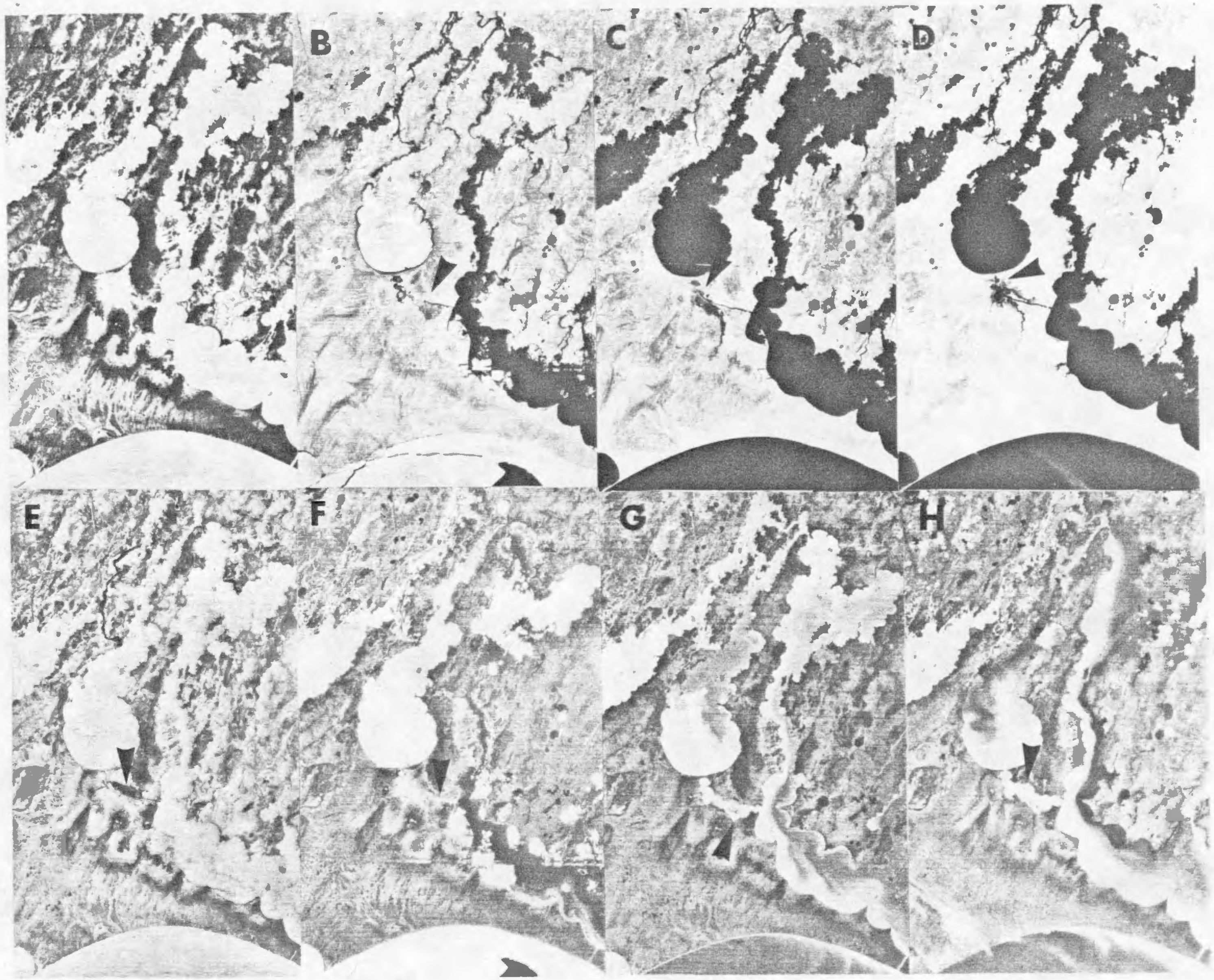

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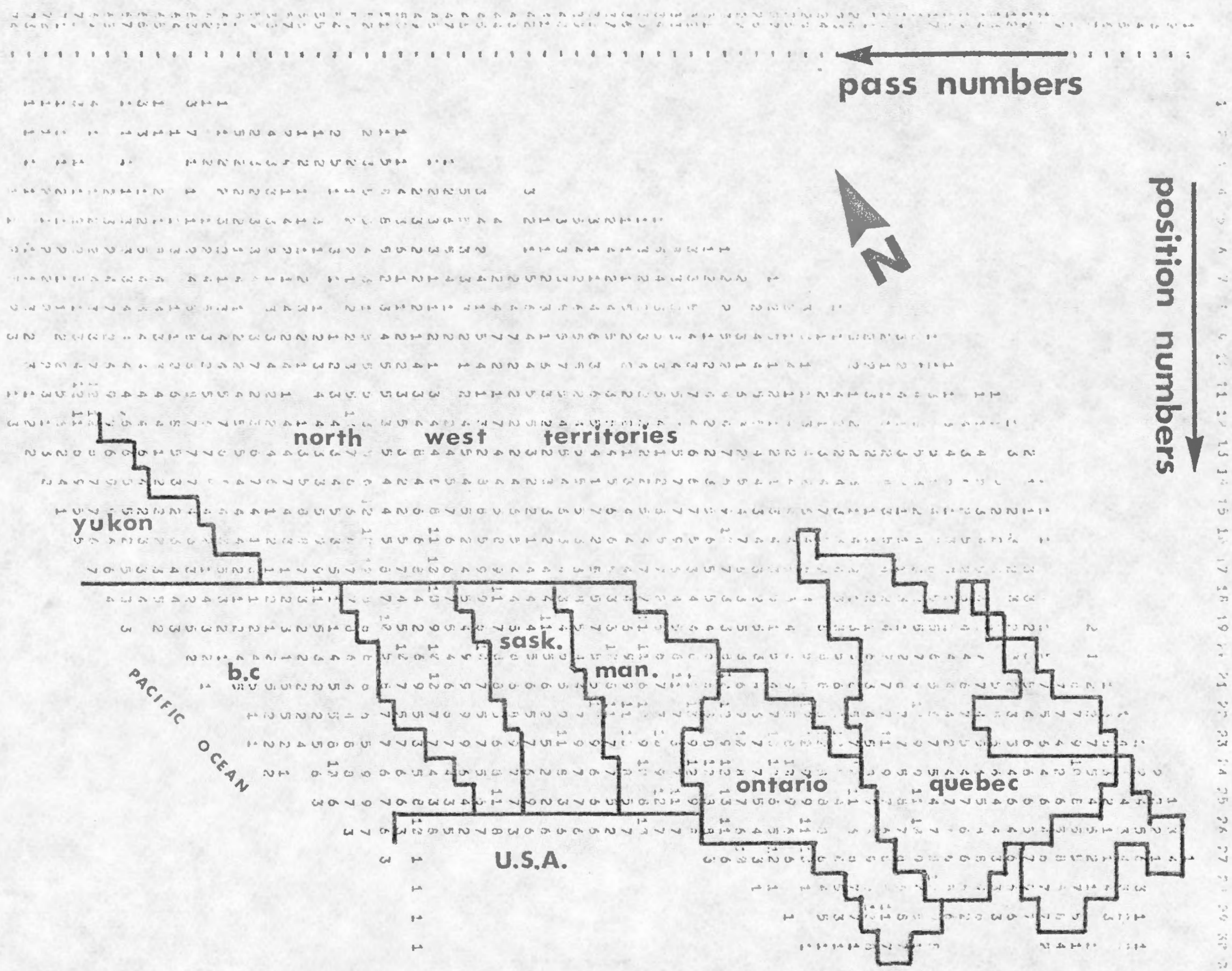
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