Proceedings
of the Second National Workshop on

ENGINEERING APPLICATIONS OF REMOTE SENSING

February 11 - 12, 1982
Edmonton, Alberta

PROCEEDINGS OF
A WORKSHOP SPONSORED BY
CANADA CENTRE FOR REMOTE SENSING, OTTAWA, ONTARIO

Proceedings of the Second National Workshop
on
ENGINEERING APPLICATIONS OF REMOTE SENSING

FEBRUARY 11–12, 1982

EDMONTON, ALBERTA

Conducted by: THE WORKING GROUP ON ENGINEERING APPLICATIONS OF REMOTE SENSING

Sponsored by: CANADA CENTRE FOR REMOTE SENSING

ONTARIO MINISTRY OF TRANSPORTATION AND COMMUNICATIONS

ALBERTA ENVIRONMENT

Hosted by: ALBERTA REMOTE SENSING CENTER

Prepared by: L. T. Tam

FOREWORD

The main objectives of the Second National Workshop on Engineering Applications of Remote Sensing were to provide an update on engineering applications in general and to develop recommendations pertaining to future high resolution satellite imageries.

These proceedings document the technical papers presented and the recommendations developed as a result of the panel and group discussions.

On behalf of the Working Group, I would like to thank all the participants for their interest and support in making the Workshop a successful occasion. Also, I would like to thank all the authors of presented papers and the following individuals who assisted in the production of those proceedings:

1. Mr. E.A. Godby
2. Mr. P. Hession
3. Mr. L. Tam

B. Sen Mathur
Chairman
Working Group on
Engineering Applications

TABLE OF CONTENTS

PART I INTRODUCTION

Since the First National Workshop on Engineering Applications of Remote Sensing in January - February 1980, announcements were made that high resolution imagery would be available from advanced sensors on board the next generation of satellites - Thematic Mapper (LANDSAT D) and High Resolution Visible and infrared instruments (S P O T). The Canada Centre for Remote Sensing (CCRS) has produced simulated imagery of these two sensors which the Working Group on Engineering Applications evaluated for engineering purposes.

The Second National Workshop on Engineering Applications of Remote Sensing was held to

(a) provide participants with an update on engineering applications in general,

(b) discuss the implication of and to develop recommendations on the use of forthcoming high resolution satellite imagery.

The workshop had 2 themes: Development and Applications of Remote Sensing and High Resolution Satellite Imagery. The program was designed to present the current status of these themes, which were then considered in the panel and group discussions. Technical sessions on the first day and the morning of the second were devoted to formal presentations (Refer Parts 2 and 7). The discussion session on the afternoon of the second day was used to develop and formulate recommendations on high resolution satellite imagery in a workshop setting (Refer Part 3). For the first time, speakers from the U.S. were invited in order to obtain an insight into developments outside Canada.

PART 2 TECHNICAL SESSIONS, FEBRUARY 11-12, 1982

Mr. Mathur announced the beginning of the Workshop and introduced Mr. Bricker, Administrator, Alberta Remote Sensing Center, who welcomed the participants. Mr. Mathur then briefly described the history of this series of workshops and the objective of this particular one.

Dr. Raney, on behalf of the Canada Centre for Remote Sensing, delivered the opening address in which he spoke of the challenges in remote sensing in Canada today, the problems of technical jargon and relating to ultimate users, current and federal-provincial relationships.

The topics presented by the speakers and their contents are reproduced in Part 7.

The session concluded with the screening of "Remote Sensing - A New Angle on the World".

PART 3 DISCUSSIONS: PLENARY SESSION , FEBRUARY 12, 1982

This session, chaired by Dr. MacDonald, consisted of panel discussions, a working session and a group discussion on the feasibility and potential applications of high resolution satellite imageries.

Dr. MacDonald introduced the panel members who then presented their evaluations in the respective areas:

Messrs G. Spafford - Civil Engineering
J.D. Mollard - Civil Engineering
L. Tam - Transportation Engineering
T. Reimchen - Geological and Geotechnical Applications

This was followed by a working session during which Dr. MacDonald directed all the participants to analyze and evaluate the simulated Thematic Mapper and S P O T imageries provided.

The recommendation developed during subsequent discussions were recorded by Mr. Bird and were finalized by the Working Group in an unscheduled session the next day. (Refer Part 4).

The Workshop concluded at 16:00.

PART 4 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Direct Applications

(a) The availability of high resolution Themtatic Mapper and S P O T imagery will increase the general application of satellite imagery by the engineers.

(b) Ground resolution for both types of imagery is still insufficient for detailed terrain analysis. However, it is suitable for general operational planning for large scale engineering projects such as pipeline and hydro-electric developments.

(c) Compared to the Thematic Mapper imagery, S P O T imagery is more useful for visual interpretation since it provides a higher resolution and stereoscopic coverage.

(d) Considering the resolution and scale at which it will be available and its stereoscopic capability, S P O T imagery has the potential to be a substitute for high altitude aerial photography.

(e) Repetitive, up-to-date coverage provided by Thematic Mapper and S P O T imagery is important to engineering studies requiring change detection such as erosion, flooding and instabilities.

(f) The availability and cost of these imageries will be determining factors in the extent of their use.

2. Products

Significant savings in mosaic construction will be realized if high resolution, geometrically - corrected imageries are available.

3. Image Analysis

(a) For the Thematic Mapper imagery, the colour composite which assigns blue, green and red to Bands TM 3, 4, 5 respectively appears to have great potential for engineering applications.

(b) The colour composite (multispectral mode) of the simulated S P O T imagery could approach the small scale colour infrared aerial photography in terms of level of detail and type of information.

4. Education and Training

The full benefits of high resolution satellite imageries can be realized only if sufficient qualified personnel in all related areas of operation is available.

5. Workshop

It is difficult to maintain interest, contact and momentum across the nation when the workshop is held at two-year intervals.

RECOMMENDATIONS

1. Products

(a) Geometrically-corrected imageries, similar to those produced by DICS for the present LANDSAT data, should be available for high resolution satellite imageries from the national facility.

(b) The potential of mapping using S P O T imagery should be investigated.

2. Image Analysis and Pilot Projects

(a) Pilot projects using simulated imageries should be conducted to investigate systematically their application to engineering studies and to demonstrate and document the benefits of digital analysis systems to those who presently rely on airphotos alone.

(b) Pilot projects should be organized by the Working Group, involving personnel having relevant experience, qualification and interest. Projects should be carried out in conjunction with various agencies such as government, industry and educational institutions.

(c) Test areas for such projects should
 (i) be located in different physiographic regions of Canada
 (ii) already have sufficient airphoto coverage and ground truth.

(d) For Thematic Mapper imageries, the rendition which assigns blue, green and red to Bands TM 3, 4 and 5 respectively should be available for all future pilot projects.

(e) The most useful colour composite for analyzing thermal signatures, water quality and rock types from Thematic Mapper imageries should be defined. Special equipment may be required and such needs and corresponding availability should be investigated.

3. Education and Training

The Working Group should investigate, at the earliest possible date, the feasibility of having programs established in colleges and universities to meet the manpower requirements in satisfying future demands in high resolution satellite imagery programs.

4. Workshop

The National Workshop on Engineering Applications should be an annual event, held in rotation across the country to foster national interest and awareness in engineering applications of remote sensing.

PART 5 PROGRAM

SECOND NATIONAL WORKSHOP ON ENGINEERING APPLICATIONS OF REMOTE SENSING

Alberta Remote Sensing Center
9820 - 106 Street, 11th Floor
Edmonton, Alberta

Thursday, February 11, 1982

Theme: *Development and Applications of Remote Sensing*
TECHNICAL SESSION, Chairman: B. Sen Mathur

	Event/Topic	Speaker
Morning	Introduction	B. Sen Mathur
	Welcome	C. Bricker
	Opening Address	R.K. Raney
	From Interpretation to Image Analysis - A Transition	G. Spafford
	Computer-Assisted Photo Interpretation for Terrain Analysis of Landforms	O.W. Mintzer
	Fundamentals of Digital Image Analysis	C. Goodfellow
	Thermal Sensing for Subsurface Soil Moisture	J. Vlcek
Afternoon	Development of Airborne and Satellite Remote Sensing Applications	J.D. Mollard
	Recent Developments in Engineering Applications of Remote Sensing	S.J.G. Bird
	Examples of Remote Sensing Applications to Highway Engineering	H.T. Rib
	An Access Road Project in Arid Environment Using Enhanced LANDSAT Imagery	T.H.F. Reimchen
	Tour of Alberta Remote Sensing Center	C. Bricker

Friday, February 12, 1982

Theme: *High Resolution Satellite Imageries*
TECHNICAL SESSION: B. Sen Mathur

	Event/Topic	Speaker
Morning	High Resolution Visible and Infrared Observations from Space	R. Baker
	RADARSAT - Canada's National Radar Satellite Program	R.K. Raney
	Radiometric and Geometric Correction of High Resolution Data from Space	W.D. Haymond
	Topographic Map Revision Using Satellite Imagery	E.A. Fleming
Afternoon	Movie: "Remote Sensing - A New Angle on the World"	

DISCUSSIONS:

Chairman: J.S. MacDonald

Feasibility and Potential Application of High Resolution Satellite Imageries:	J.S. MacDonald
Panel Discussion	
Group Evaluation	
Group Discussion	
Summary and Conclusions	B. Sen Mathur
Departing Address	R.K. Raney C. Bricker

PART 6 PARTICIPANTS

NAME	AFFILIATION	CITY	PROVINCE/STATE
ANDERSEN, Harry T.	Canadian Western Natural Gas Company Limited	Calgary	Alberta
APEDAILE, Leonard P.	University of Alberta	Edmonton	Alberta
BAKER, Ralph	Canada Centre for Remote Sensing	Ottawa	Ontario
BARACOS, Andrew	University of Manitoba	Winnipeg	Manitoba
BIRD, S.J. Glenn	Bird and Hale Ltd.	Toronto	Ontario
BLACKEY, John H.	Ministry of Transportation & Highways	Victoria	British Columbia
BRICKER, Cal D.	Alberta Remote Sensing Center	Edmonton	Alberta
CAMPBELL, Kenneth M.	Alberta Remote Sensing Center	Edmonton	Alberta
CHOY, Anthony K.Y.	McElhanney Surveying and Engineering Ltd.	Edmonton	Alberta
FLEMING, Elizabeth A.	Energy, Mines and Resources Canada	Ottawa	Ontario
GERLACH, Carol	Alberta Transportation	Edmonton	Alberta
GOODFELLOW, Carolyn	Canada Centre for Remote Sensing	Ottawa	Ontario

NAME	AFFILIATION	CITY	PROVINCE/STATE
HAGMAN, Vic	Public Works Canada	Edmonton	Alberta
HALE, Ian M.	Bird and Hale Ltd.	Toronto	Ontario
HAMMOND, Edward G.	Alberta Transportation	Edmonton	Alberta
HAYMOND, Bill D.	MacDonald, Dettwiler and Associates Limited	Richmond	British Columbia
HODGE, Edwin J.	McElhanney Surveying and Engineering Limited	Edmonton	Alberta
JOHNSON, Coril E.	MacDonald, Dettwiler and Associates Limited	Richmond	British Columbia
KIRBY, Charles L.	Canadian Forestry Service Northern Research Centre	Edmonton	Alberta
KIRK, Edward E.	Department of Indian and Northern Affairs	Ottawa	Ontario
LITTLE, G. Harry	Public Works Canada	Edmonton	Alberta
LODWICK, Graham D.	University of Calgary	Calgary	Alberta
MACDONALD, John S.	MacDonald, Dettwiler and Associates Limited	Richmond	British Columbia
MACLEOD, Donaldson R.	Carleton University	Ottawa	Ontario
MACUAIG, Rob. E.D.	W.D. Usher & Associates Ltd.	Edmonton	Alberta

NAME	AFFILIATION	CITY	PROVINCE/STATE
MATHUR, B. Sen	Ontario Ministry of Transportation and Communications	Toronto	Ontario
MCKINNA, Bernie	McElhanney Surveying and Engineering Limited	Edmonton	Alberta
MINTZER, Olin W.	Ohio State University	Columbus	Ohio
MOLLARD, J.D.	J.D. Mollard and Associates	Regina	Saskatchewan
PARENT, Robert	Royal Military College of Canada	Kingston	Ontario
PATTERSON, D. Bruce	Alberta Environment	Edmonton	Alberta
PROKOPCHUK, Jary R.	Alberta Energy and Natural Resources	Edmonton	Alberta
RANEY, R. Keith	Canada Centre for Remote Sensing	Ottawa	Ontario
RAPP, Egon	University of Alberta	Edmonton	Alberta
REIMCHEN, Ted H.F.	Pegasus Earth Sensing Corp.	North Vancouver	British Columbia
RIB, Harold T.	Federal Highway Administration	Washington	D.C.
SCULLION, Ernest D.	Northway-Gestalt Corp.	Toronto	Ontario
SIBBALD, Cam	Deloitte, Haskings and Sells Associates	Calgary	Alberta

NAME	AFFILIATION	CITY	PROVINCE/STATE
SMITH, David A.	Environment Canada	Dartmouth	Nova Scotia
SPAFFORD, Gordon	UNIES Limited	Winnipeg	Manitoba
STUART, Nicholas G.	McElhanney Surveying and Engineering Limited	Edmonton	Alberta
SUTHERLAND, Ian R.	Alberta Remote Sensing Center	Edmonton	Alberta
TAM, Lawton T.	Ontario Ministry of Transportation and Communications	Toronto	Ontario
TOMLINS, Geoff F.	B.C. Research	Vancouver	British Columbia
VIJ, Kewal K.	Fenco, Lavalin Company	Calgary	Alberta
VLCEK, Jaroslav	University of Toronto	Toronto	Ontario
WINTON, Bruce E.	McElhanney Surveying and Engineering Limited	Edmonton	Alberta

PART 7 PRESENTED PAPERS

From Interpretation to Image Analysis - A Transition	G. Spafford, W.A. Miller
Computer - Assisted Photo Interpretation for Terrain Analysis of Landforms	O.W. Mintzer
* Fundamentals of Digital Image Analysis	C. Goodfellow
Thermal Sensing for Subsurface Soil Moisture	J. Vlcek
Development of Airborne and Satellite Remote Sensing Applications	J.D. Mollard
Recent Developments in Engineering Applications of Remote Sensing *(title revised, see text)*	S.J.G. Bird
Examples of Remote Sensing Applications to Highway Engineering	H.T. Rib
* An Access Road Project in Arid Environment Using Enhanced LANDSAT Imagery	T.H.F. Reimchen
High Resolution Visible and Infrared Observations from Space	W.M. Strome, R.C. Baker, J.P. Hession
RADARSAT - Canada's National Radar Satellite Program	R.K. Raney
Radiometric and Geometric Correction of High Resolution Data from Space	W.D. Haymond
Topographic Map Revision using Satellite Imagery	E.A. Fleming

36786

* Manuscript not received in time for publication.

NOTE

Papers contained in these proceedings are included in order of presentation at the Workshop. All manuscripts received in time for publication have been reproduced exactly as provided by the authors. Where required, the text was retyped only to standardize the format and typeface. Otherwise, no change has been made to the manuscript and all illustrations are reproduced in black-and-white as received. Readers should contact specific authors if illustrations of original quality are desired.

FROM INTERPRETATION TO IMAGE ANALYSIS - A TRANSITION

G. Spafford[1], W.A. Miller[1]

ABSTRACT

Air photo interpretation has been a valuable tool to the civil engineer for many decades. The introduction of satellite imagery has enhanced the ability of the interpreter to define the pattern and composition of the earth's surface. The paper briefly presents several examples in some of which the satellite imagery was used in conjunction with aerial photographs and others in which the satellite imagery alone was used. A variety of devices are used for image analysis, not all of which are of general use to the intepreter. Some of these devices are available through remote sensing centres established by the provincial governments. The quality of service provided at these centres varies and in most cases, the intepretive and analytic devices are limited. Methods of obtaining satellite imagery are summarized and problems in delivery discussed. The authors express the opinion that improvement of remote sensing centre facilities and services is justified.

---

1 UNIES Limited,
1666 Dublin Avenue
Winnipeg, Manitoba R3H OH1

1. INTRODUCTION

The engineer's role in society has, in large part, been that of adapting, adjusting and modifying our world to society's perceived requirements. The civil engineer in particular deals with adaptations, adjustments and modifications which have a direct impact on the visible surface of the earth. He is asked to modify shore lines to form a harbour, to move and re-organize the earth's crust to form a road, railway or airport, to re-route drainage, modify a river's response to precipitation, to form the products of the earth's minerals and biomass into structures. The ability to accomplish these changes infers an understanding of the materials and processes that form the earth's surface. Such understanding involves a wide range of knowledge of biological and physical processes.

For many tasks, the earth's surface and the processes that formed and continue to control it need to be understood over an extended area, much greater than can be discerned from an elevation of 1.7 meters. We can surmise that, before the advent of aircraft, civil engineers and the geological and biological scientists who helped them, spent a lot of time climbing trees and hills. We know they spent a lot of time travelling over the earth's surface to assemble an impression of its pattern and composition.

Aircraft and aerial photography represent a major change in the process by which we develop our understanding of the earth's surface. Still other types of airborne sensing provide perception of what lies beneath the earth's surface. These revolutionary tools have come into use in a single lifetime during which the ability to obtain images from space has added yet another dimension.

The practitioners who apply these rapidly developing tools to their particular field of interest are chronically out of date. Those engaged in civil engineering applications and the definition of the physical and biological processes of the earth's surface find that, for each new task, a new source of imagery or a new image analysis device may have been developed. Whether it is available or useful for his particular problem is another matter.

The purpose of this paper is to define the transition faced by engineers, accustomed to applying air photo interpretation to a variety of civil engineering problems, in making use of satellite imagery and available image analysis techniques. Some review of this transition seems particularly appropriate at a time when stereoscopic viewing, that optical illusion so valuable in air photo interpretation, is soon to be available for satellite imagery.

2. TRADITIONAL AIR PHOTO INTERPRETATION

Engineering applications of air photo interpretation developed during World War II as systematic, high quality aerial photography of the earth's surface became available. Prints from the optically exact overlapping photography usually obtained for topographic mapping enable the interpreter, using a simple stereoscope, to estimate the composition of the land surface and its vegetation over an extended area. To do this, the interpreter requires knowledge of geomorphology and land forms and the geological history of the area being examined. A first hand acquaintance with the area's terrain and vegetation will improve the quality of the interpretation. The interpreter examining the aerial photos sees only:

Variations in tone
Variations in texture
Relief
* Colour

The interpreter interrelates these qualities in a complex manner to convert them to a pattern of vegetation cover, terrain type and surface materials.

---

* Only if colour photography or false colour is used. In many applications colour obscures the more subtle differences in tone and texture used by the interpreter, thus making the interpretation more difficult.

The patterns that may be identified on large scale photography are different from those apparent at a smaller scale. Therefore the interpreter may utilize several scales of photo, if available, to complete his interpretation. Similarly he may gain improved perception by viewing photos taken at different times, particularly if he is attempting to identify active physical processes. In terms of both scale and time frame, the advent of satellite imagery has greatly extended the interpreter's basic data base. The remainder of this paper addresses the application, use and the value of this expansion and the problems faced by the engineering interpreter in making use of this additional data.

3. APPLICATIONS AND LIMITATIONS OF SATELLITE IMAGERY

LANDSAT imagery of the earth's surface began in 1972 with the launching of the ERTS (Earth Resources Technology Satellite). The images are produced in 4 frequency bands and prints or transparencies may be obtained for individual or a combination of frequencies. These images may be used by the interpreter in much the same manner as aerial photographs except that stereoscopic viewing is not possible. (Currently a stereo image system, SPOT, has been developed by the French capable of providing stereo coverage). The LANDSAT images for all of Canada are available through the Canadian Remote Sensing Centre. The actual image transmissions from the satellite are received by a station established for the purpose at Prince Albert, Saskatchewan. Coverage outside Canada can be obtained through the EROS Data Centre in Sioux Falls, South Dakota, U.S.A. operated by the U.S. Geological Survey.

LANDSAT imagery can provide the interpreter with the following capabilities not normally obtainable with aerial photographs:

A larger area covered by a single frame.
Regularly repeated coverage of a given area.
All season coverage.
Frequency separation into 4 bands.

Compared to aerial photography, it has the following shortcomings:

Poorer resolution

An image transmitted in lines which form a pattern that may obscure surface features. (The authors have also observed that light intensity appears to vary from line to line adding a further pattern unrelated to the surface observed).

No stereoscopic image therefore poor potential for relating interpretation to relief.

As an adjunct to aerial photography, the satellite imagery is useful to the interpreter, but, occasions when it alone can satisfy an engineering interpretation requirement are rare. Rather than attempt to present a complete catalogue of potential applications of satellite imagery, some examples within the authors' experience are briefly described as follows:

In route location work, preliminary corridors may be selected using satellite images in conjunction with high level aerial photography. This has become more or less standard procedure for route lengths in excess of 50 km.

Coarse identification of major physiographic units and control for air photo interpretation in the design of an exploration program in support of a regional ground water study.

Observation of the distribution of dredging spoil deposited from a major channel dredging program. In this instance, the observations were independent of air photo interpretation because the observations were made while the work was in progress and current photo was not available.

Identification of ice characteristics on a part of the MacKenzie River. Again no comparable air photography was available and it could have been obtained only at great expense. The interpretation provided an appreciation of channel flow characteristics and identified locations where hanging ice dams are formed. This knowledge was applied in the selection of a pipeline crossing location.

Identification of emergent vegetation on a major lake and river system. This application was attempted as a means of reducing the air photo interpretation effort but was unsuccessful although other researches have met with some success using more sophisticated image analysis techniques.* It did provide some appreciation of relative water depths. This information at a larger scale could have been useful to the project but its application to the smaller irregular areas to be identified was limited by inadequate resolution.

Assessment of hydrological characteristics of glacially fed rivers. The application was used to estimate basin response characteristics of two glacial rivers in the Yukon where flood frequency was to be determined for design of a pipeline crossing. Images showing both minimum and maximum snow accumulation were used. At that time, it was difficult to obtain images not obscured by cloud. However, as LANDSAT imagery accumulates, they will likely include some clear day images.

---

* Reference - Investigation of Remote Sensing Techniques for Wild Rice Inventory - Ontario Ministry of Natural Resources - April 1981.

Estimation of water depths in lakes where bathymetric data are scarce. Satellite imagery has been used on several occasions where precise information was not necessary. In certain frequency bands (LANDSAT 4 or 5) tone of the water surface image varies with water depth. Using a density slicer an image indicating relative water depths can be produced. These have been used in selecting tracks for clear channel soundings and as supplementary data for estimating wind set up. More experience is needed to determine how nearly these images represent bathymetry. Considerable judgement and trial and error is required in selecting the most suitable channels on the density slicer. Near shore interpretation is further complicated by density differences caused by shore line aspect relative to the sun angle and in some cases, by sediment. This method of estimating bathymetry is not so successful with air photos because the tone of the water surface image changes appreciably with reflection angle as well as depth.

4. <u>IMAGE ANALYSIS</u>

There are a variety of devices on the market, including the density slicer referred to above, used for a variety of types of image analysis. Most are expensive and not readily available to the engineer using air photo interpretation and satellite imagery on a casual basis. The provincial governments have established remote sensing centres across the country. These are equipped with devices available in most cases to commercial or institutional users. The quality of the indexing, retrieval and analysis facilities in these centres varies from province to province and, with the exception of the Ontario Remote Sensing Centre, do not provide extensive analytic facilities. The authors are familiar with only the Manitoba Remote Sensing Centre which has the following devices available:

Special Data Density Slicer - Model 703-32 Datacolour
Zeizz/Jena Interpretoscope
K & E Reflector - Projector
Numonics Calculator (Planimeter) Model 277-137
Bausch and Lomb Zoom Transfer Scope
Various stereoscopes, light tables and incidental equipment

Several private companies specializing in interpretation and image analysis have sophisticated devices of their own for the purpose. These are used principally for inventory and classification projects covering relatively large areas.

Availability and access to imagery is a major concern to the interpreter with respect to both aerial photographs and satellite imagery. The micro fiche indexing systems available in some of the remote sensing centres across Canada are convenient for quick selection of satellite images throughout Canada. World wide, the EROS data centre provides hard copy image indices on request indicating image quality, cloud cover, dates and centre point. As the library of images grows, the variety and quality of imagery will improve but the effort involved in selecting the most suitable imagery will increase.

The time lapse between ordering imagery and receiving it can be a problem for the engineering interpreter just as it has been with aerial photographs. For air photographs most provincial government air photo libraries permit viewing of the library set and photo copies of the prints may be purchased on short notice. High quality prints required for most interpretation must be ordered from the National Airphoto Library and, depending on the demand at the time, can require 2 to 6 weeks for delivery. Delivery of LANDSAT images from the Canada Centre for Remote Sensing Prince Albert Satellite Station has been consistently less than 2 weeks but, currently, changes in the processing system may cause delays up to 6 weeks. The authors' experience with images of non Canadian terrain ordered from EROS data centre is limited but delivery time seems to be highly variable and we are still waiting for part of an order placed 10 weeks ago.

5. CONCLUSION AND OBSERVATION

The authors believe that the addition of satellite imagery and availability of some image analysis devices, particularly the density slicer, enhances the capabilities of the engineering interpreter. They also believe that, in their own case due to inexperience, the potential of these additional tools has not been fully realized. It is also their opinion that, just as the ability to relate relief to other image qualities through stereoscopic viewing greatly extends the usefulness of aerial photography, stereoscopic satellite imagery will represent a major improvement in interpreting ability.

While the number of regular users of the provincial remote sensing centres may be small, the value of these facilities in terms of improved basic information for engineering undertakings and saving in engineering cost, is probably very large. This accounts for only one of many user categories. Some review of the value and definition of the flow of benefits is probably justified to determine the level of service justified and the sources of financial support. The authors are of the opinion that improved service country wide is justified.

COMPUTER-ASSISTED PHOTO INTERPRETATION FOR TERRAIN ANALYSIS OF LANDFORMS

OLIN W. MINTZER[1]

ABSTRACT

A new program has been initiated at USAETL to pursue computer-assisted photo interpretation research (CAPIR). In the CAPIR laboratory, terrain anslysts view high resolution stereo photography that is interfaced directly to a minicomputer-based geographic information system (GIS). The development of new or improved techniques for terrain analysis represent a major goal of the CAPIR program. This paper will describe an application of CAPIR techniques to landform and drainage mapping.

The CAPIR laboratory employs the Analytical Photogrammetric Processing System (APPS-IV) as a computer-interfaced stereoscope. CAPIR software is based on the AMS/MOSS geographic information system developed for the U.S. Fish and Wildlife Service. The terrain analyst uses the APPS-IV as a stereo work station with this software support for real-time encoding of point, linear, and areal features as labelled ground coordinates in digital GIS.

The APPS-IV is a medium-accuracy (RMS errors of less than 10 micrometers) analytical plotter produced by Autometric, Inc. The stereoscopic viewing is with customized high resolution optics over a magnification range of 3X to 18X. Graphic superposition provides a real-time electronic "grease-

---

1 Department of Civil Engineering,
Ohio State University,
470 Hitchcock Hall,
2070 Neil Avenue,
Columbus, Ohio
U.S.A. 43210

pencil" display of spatial data for direct viewing by the terrain analyst in the stereomodel.

The immediate benefits of the CAPIR are the improved point positioning and mensuration, direct capture and maintenance of digital cartographic data files, improved access to data base materials, and on-line graphic displays resulting in a more efficient data extraction process.

This paper documents the computer-assisted photo interpretation process for terrain analysts to apply to landform and drainage mapping.

1. INTRODUCTION

A new program at the U.S. Army Engineer Topographic Laboratories has initiated computer-assisted photo interpretation research for use by the terrain analyst in producing landform and drainage maps, as well as a host of other data with a geographic information system base. This paper documents a recent achievement using a stereoscopic work station (the APPS-IV analytical plotter), a minicomputer system (the guts of which is a Data General Eclipse S/250), and the Analytical Mapping System for aerotraingulation and data base management. Although the production of many other terrain factors is possible using these systems, this paper is limited to outlining landform and drainage mapping to illustrate the systems' capabilities.

The Stereoscopic Workstation

The man/machine interface between the photo interpreter and the digital computer is the stereoscopic workstation. This subsystem consists of an APPS-IV analytical plotter (see Figure 1) with graphics superimposed in the stereomodel (See Figure 2), a conventional graphics display, and a CRT terminal. The APPS-IV is a medium-accuracy (RMS errors of less than 10 micrometers) analytical plotter produced by Autometric, Inc. The stereoscopic viewing is with Bausch and Lomb Stereo Zoom Transfer Scope optics having a magnification range of 3X to 18X. Graphic superposition provides a real-time electronic "grease pencil" display of the results of stereodigitization for operator viewing in the stereomodel. A commercial graphics terminal provides for real-time display of data being digitized as well as supporting display and editing of data base information.
A standard CRT terminal supports conventional interactive communications between the workstation and the host computer.

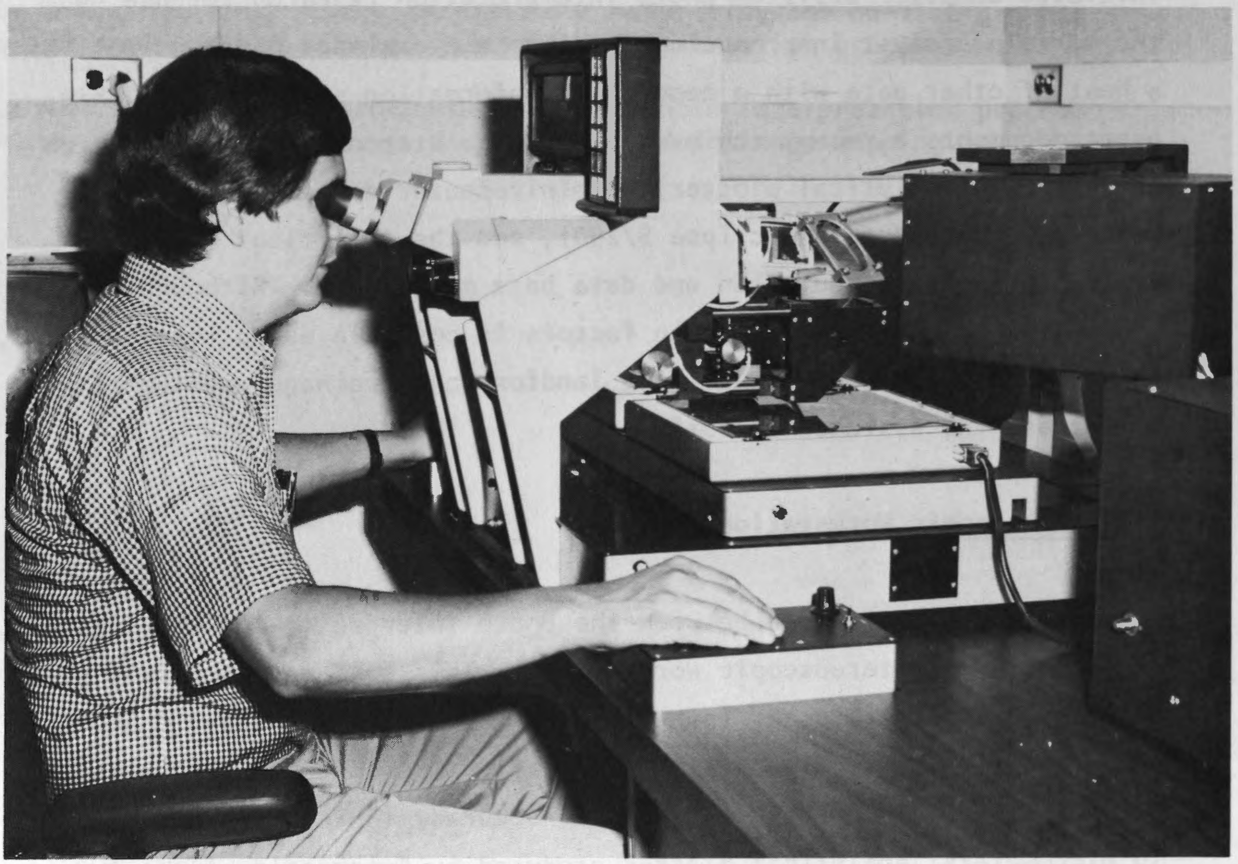


Figure 1 The APPS-IV Stereoscopic Workstation

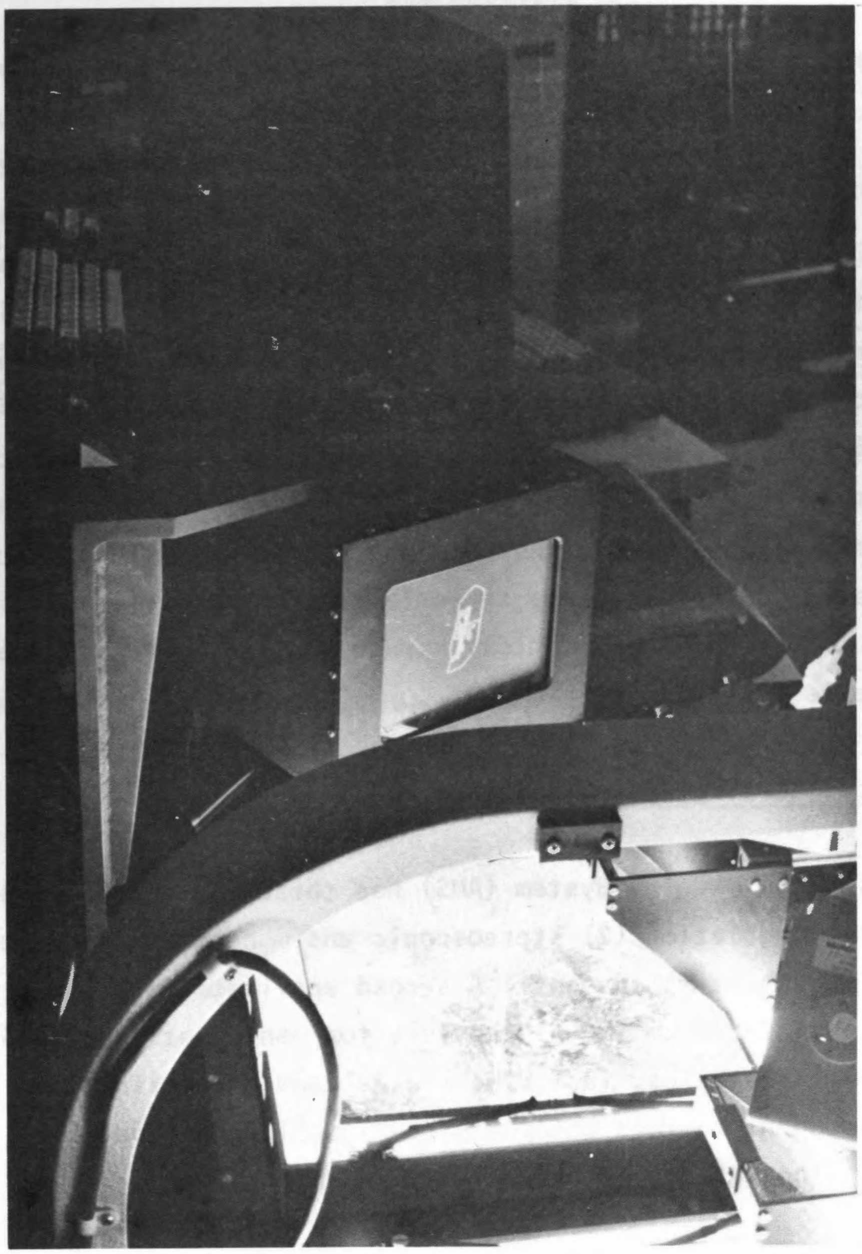


Figure 2 APPS-IV Stereoscopic Workstation, shown with Superposition Graphics on Screen in Center

System Minicomputer and Peripherals

A system minicomputer and associated peripheral devices are required to support the workstation. The digital system components include (1) a central processing unit (CPU), (2) disc drive, (3) magnetic tape drive, and (4) printer. The CPU, a Data General Eclipse S/250, takes full advantage of existing specialized software to exploit the computational power of the processor (see Figure 3). Options selected include 128K semi-conductor memory, floating point hardware and integral array processor. A disc drive supports the operating system and for storage of programs and large data files. The disc provides an on-line storage capacity of 190 Mbytes. A magnetic tape drive is necessary to back up the system, store data files and to transport data to and from other systems. A nine-track, 800 bpi drive is compatible with the system. A 180-character printer is used as an economical hardcopy output device. The computer language is FORTRAN.

Analytical Mapping System Software

The Analytical Mapping System (AMS) has these basic capabilities: (1) aerotriangulation (2) stereoscopic and monoscopic digitization and (3) data base management. A second applications program, Map Overlay and Statistics System (MOSS) provides for manipulation of AMS-created geographic data bases, including spatial and statistical analysis of multi-component terrain data with both tabular and spatially encoded output. (The latter is not included in this paper).

The AMS was developed by Autometric, Inc. for the National Wetlands Inventory Project, U.S. Fish and Wildlife Service, to provide a computer based system to delineate, classify and inventory the wetlands of the United States. It provides on-line stereo digitization from source photography to create a digital geographic data base utilizing the stereo digitizer, x-y digitizing table, and graphics display. With the software in its present format a multiprocessor such as the Hewlett Packard HP21MXE minicomputer system or the Data General Eclipse minicomputer may be used.

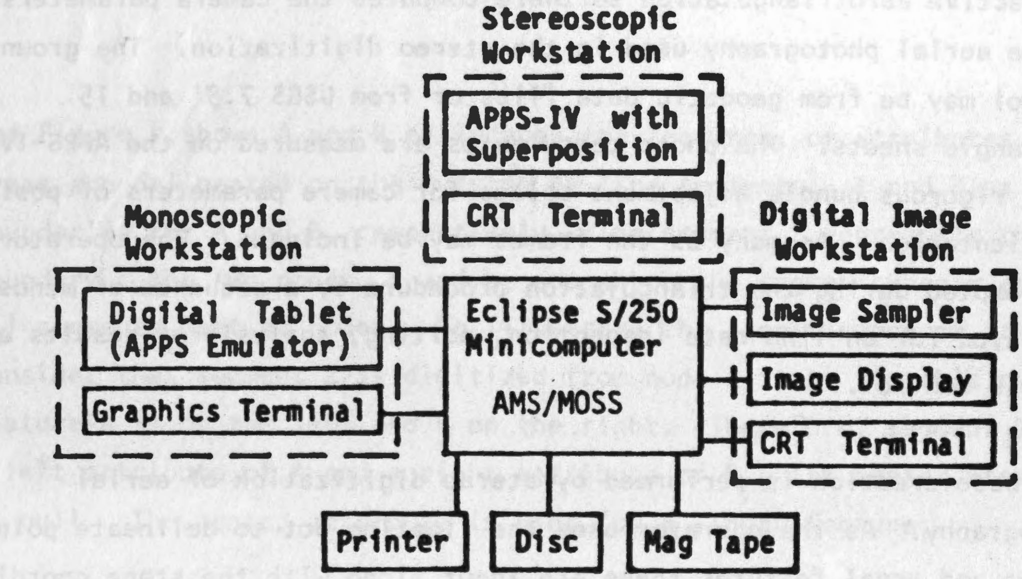


Figure 3 System Minicomputer and Peripheral Support Flow Pattern

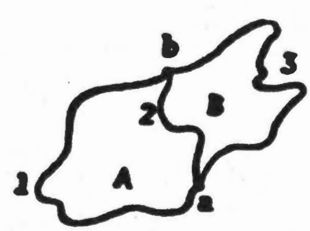


Figure 4 The Analytical Mapping System Line Segments, Node and Attributes

Interactive aerotriangulation software computes the camera parameters of the aerial photography used in the stereo digitization. The ground control may be from geodetic data files or from USGS 7.5' and 15 quadrangle sheets. The photo coordinates are measured on the APPS-IV, and a rigorous bundle adjustment solves for camera parameters of position or orientation. As many as ten frames may be included. The operator is prompted during the triangulation procedure by a sequence of menus displayed for on-line data inspection, editing, analysis of results and process control.

Data base creation is performed by stereo digitization of aerial photography. As the operator uses the floating dot to delineate point, linear and areal features these are input along with the stage coordinates being converted to X-, Y-, Z- ground coordinates for direct data base entry. Previously created data entries are recalled, displayed and edited when needed. Verification of all data base entries is performed on-line under control of the operator to insure the creation of a topologically valid data base.

The data base management system stores all camera data, triangulation results and the encoded terrain data. Simple on-line queries of the data base, as well as generation of hardcopy plots from the digital data base are registered to USGS quadrangle or other user-specified maps.

2. THE DIGITIZING PROCESS

The Analytical Mapping System (AMS) produces three basic elements of information during the digitizing process, namely: (1) line segments, (2) nodes and (3) attributes. Figure 4 illustrates these elements respectively: 1, 2, 3; a,b; A, B.

The Figure 4 shows A and B as independent features, or attributes. The areas are delineated on the outside by line segments: 1 and 3 as boundaries for A and B, respectively, line segment 2 represents the common boundary. The two nodes, a and b, are where the segments begin or end. All segments meet at nodes. To illustrate the significance of attributes, consider that segment 2 is digitized from node a to b. In this case, Feature A is on the left and B on the right. Therefore, segment 2 has a left attribute of A and a right attribute of B. Its center attribute is null. The center attribute is used for a linear feature.

There are three node types: normal, temporary and edge. The node a or b, depicted in Figure 4, is called a normal node. A temporary node is one depicting a tie feature where a new line segment may begin or a connecting one is to be digitized. The edge node is formed at the edge of the model or map as a tie point. An edge node is like the temporary node, only it is formed along the boundary between the "rectangular" geographic areas which serve as the logical unit of division in the data base, referred to as geounit. The edge node is formed automatically as one digitizes over a geounit boundary. The corresponding edge nodes between two adjacent geounits have identical coordinates.

There are three different modes of digitizing: (1) point, (2) curve and (3) stream. In the point mode, the discrete points which delineate straight features are selected by the operator. The curve mode is like the point mode in the manner which points are selected; however, cubic curves are fitted between points. This mode is useful when the feature being digitized can be represented by a gentle breaking curve. The stream mode is used for intricate features selected automatically at specific intervals as the feature is delineated.

The editing of the input can occur at two different times during the digitizing process. If a mistake is made while a segment is being digitized, the operator has two options. The entire segment can be deleted from the data set and the segment started over again, or the end portion of the segment can be "clipped off" and redigitized. If the segment has already been completed and must be redone, the operator identifies it and it is then automatically deleted from the data set. It is best if the operator keeps a numerical tally of segment positions in order to make the necessary segment corrections; this is facilitated by making hardcopy as areas are completed. The segment positions are then marked on the copy for review while proceeding with the rest of the mapping.

When the digitizing for a geounit is completed, a data verification process is performed, during which the attributes, nodes and line segments are checked automatically for topological validity; given these results, segments are tied together to form polygons and the respective areas are computed. This procedure occurs relatively quickly with the operator assisting with the corrections to the data set when necessary. In this case, the exact cause and location of the error is reported by the system. When the verification process is completed, the results are stored in the data base.

3. LANDFORM BOUNDARY DELINEATION

The delineation of landforms was executed for two stereo models, one each in a given flight line, covering portions of Fort Belvoir, Virginia-Maryland and Annadale, Virginia.

The source data input was U-2 photography, colour infrared film, at 1/133,000 scale. Viewing the scene stereoscopically the terrain analyst visualizes the terrain at 1/41,500 scale. The analyst observes and marks the slope breaks that represent landform boundaries. The delineation of the slope/landform breaks was accomplished by placing the floating dot on the ground at the points which successively define the landform boundaries. As the operator moves the APPS-IV floating dot to follow these slope breaks representing the landform boundaries, the computer receives a signal that establishes the line boundary. On both the IMLAC and Superposition displays the delineated line appears. The terrain analyst observes the placement of the landform boundary in its appropriate position; this is similar to the drawing of the landform boundaries on the plastic overlays to aerial photomosaics. As the operator of the APPS-IV reviews the boundaries displayed and discovers an error in position he executes an EDIT MODE and deletes the incorrect line. A new line position is "drawn" and the analyst proceeds to complete the landform map. In the present process, boundary identity in the display is not possible. This will be useful, if and when it becomes available in the software.

Four landform boundaries were executed for the Ft. Belvoir study area; i.e., landforms: Tidal Flat (TF), Low Terrace (TE), Mid Terrace (TI) and High Terrace (TH). See Figure 5. A comparable landform map prepared by conventional photointerpretation is shown in Figure 6. It displays one additional landform: Alluvial Plain (AP). This boundary will be added later to the computer drawn map.

4. DRAINAGE DELINEATION

The recording of the lines representing drainageways (streams, gully threads and the like) was executed using the same imagery/map sources as in the landform delineation. The terrain analyst visualizes the overland flow network, line segment by line segment, by placing the floating dot on the ground to successively define the change in elevation

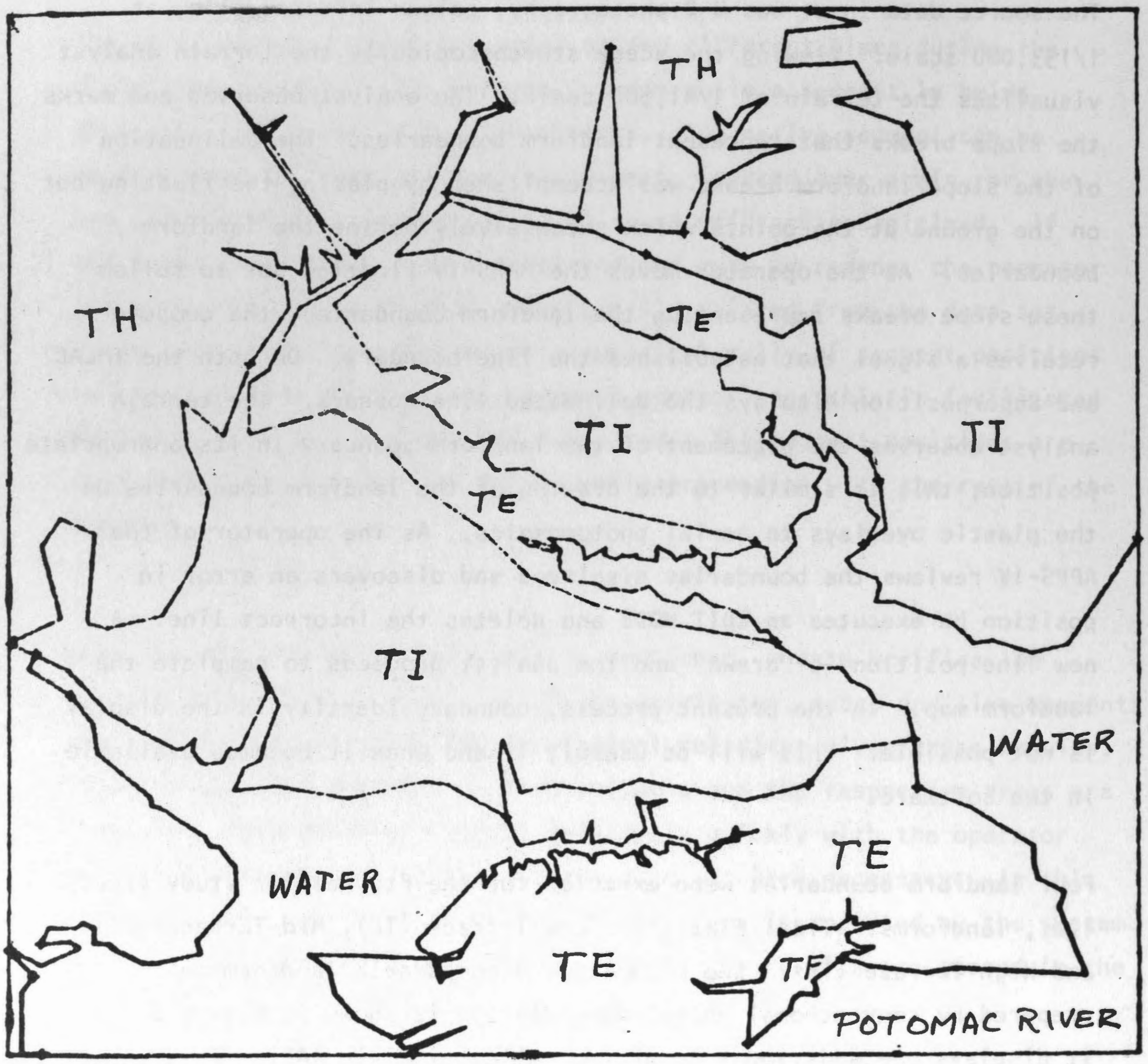


Figure 5 Landforms Prepared by Capir System Jan. 1981
Fort Belvoir, VA. 38° 41'N, 77° 11'W

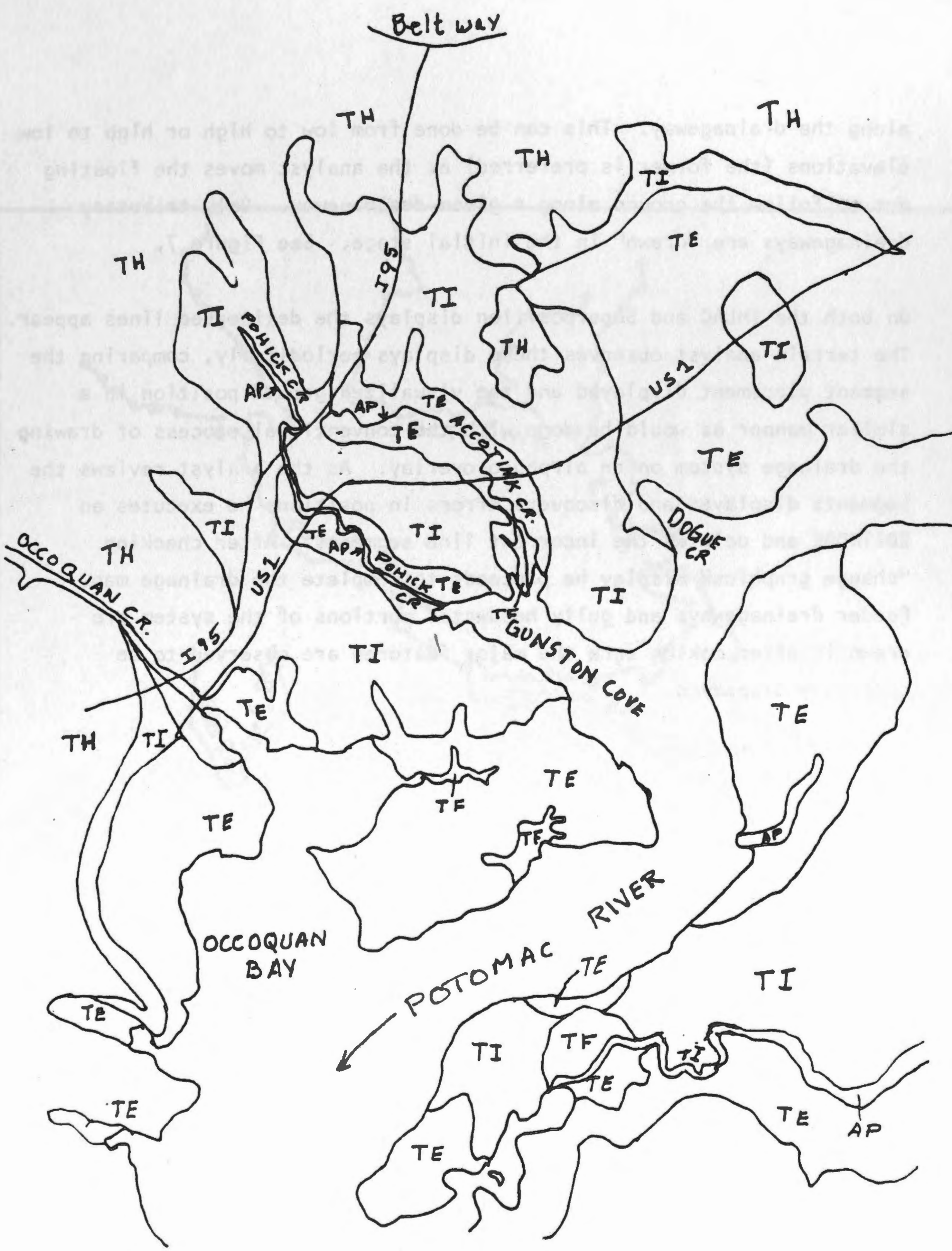


Figure 6 Landform Map of Ft. Belvoir Area Prepared from Airphotos

along the drainageway. This can be done from low to high or high to low elevations (the former is preferred) as the analyst moves the floating dot to follow the ground along a given drainageway. Only tributary drainageways are "drawn" in the initial stage. See Figure 7.

On both the IMLAC and Superposition displays the delineated lines appear. The terrain analyst observes these displays periodically, comparing the segment placement displayed and the visualized ground position in a similar manner as would be done with the conventional process of drawing the drainage system on an airphoto overlay. As the analyst reviews the segments displayed and discovers errors in positions he executes an EDITMODE and deletes the incorrect line segments. After checking "change graphics" display he proceeds to complete the drainage map. Feeder drainageways and gully headwater portions of the system are drawn in after making sure the major features are observed to be correctly displayed.

5. REVIEW AND COORDINATION

Once the landform and drainage features have been established as described above, hard copies of the displayed maps are prepared on the Tektronix graphics. A clear plastic overlay copy of the drainage map is superimposed on the landform map to compare the fit of these landform and drainage maps to each other. Corrections are in order if there are discrepancies. Once there is satisfactory correspondence of the two maps the analyst uses the Verification Mode of AMS and checks to see if all attributes and segments of the maps are correct. After the verification process is completed the results are stored in the data base.

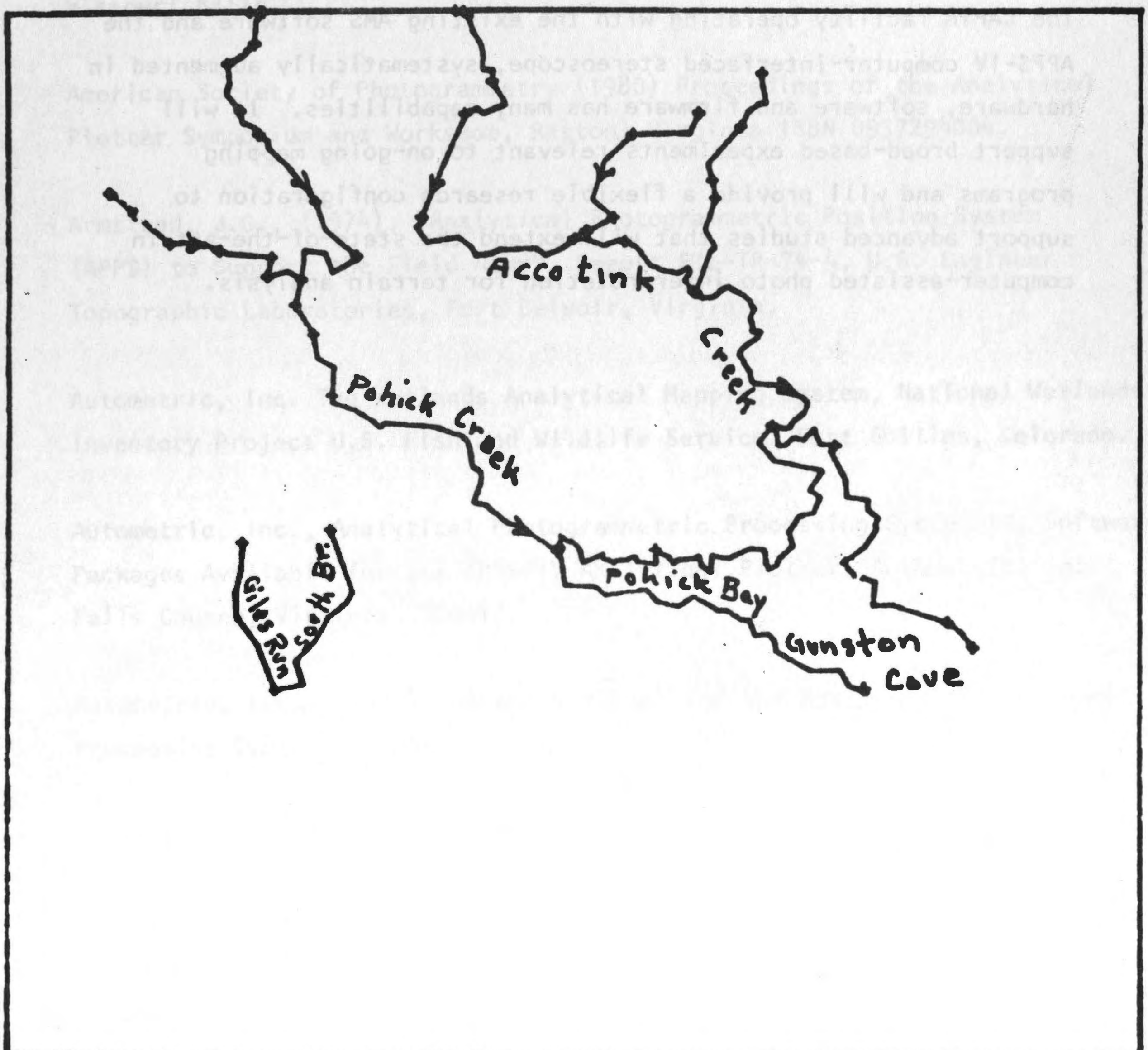


Figure 7 Drainage Map of Study Area, Ft. Belvoir, VA

6. SUMMARY

The CAPIR facility operating with the existing AMS software and the APPS-IV computer-interfaced stereoscope, systematically augmented in hardware, software and firmware has many capabilities. It will support broad-based experiments relevant to on-going mapping programs and will provide a flexible research configuration to support advanced studies that will extend the state-of-the-art in computer-assisted photo interpretation for terrain analysis.

REFERENCES

Alspaugh, D.H., Analytical Photogrammetric Equipment in the Defense Mapping Agency, Defense Mapping Agency Aerospace Center, St. Louis AFS, Missouri 63118

American Society of Photogrammetry (1980) Proceedings of the Analytical Plotter Symposium and Workshop, Reston, Virginia ISBN 0937294004.

Armstead, J.G., (1974), "Analytical Photogrammetric Position System (APPS) to Support the Field Army", Report ETL-TR-74-4, U.S. Engineer Topographic Laboratories, Fort Belvoir, Virginia.

Autometric, Inc. The Wetlands Analytical Mapping System, National Wetlands Inventory Project U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Autometric, Inc., Analytical Photogrammetric Processing System IV, Software Packages Available for the APPS-IV Analytical Plotter, Autometric, Inc. Falls Church, Virginia 22041.

Autometric, Inc., (1980) Operators Manual for the Analytical Photogrammetric Processing System, (APPS-IV).

Autometric, Inc., Autogis, Autometric, Inc., Ft. Collins, Colorado 80526.

Bright, C.R. and H.R. Pywell, (1978) "Data Base Development for the National Wetlands Inventory", Proc. Amer. Soc. of Photogrammetry, 44th Annual Meeting, pp. 328-333.

Gregory, H.E., (1978), Steps of Progress in the Interpretation of Landforms, American Journal of Science, V. 46, p. 104-117; 127-131.

Greve, C.W., R.F. Bunn and H.A. Niedzwiadek, (1979), "Current and Potential Applications of the APPS-IV Analytical Plotter", Proc. Amer. Society of Photogrammetry, 45th Annual Meeting, pp. 80-91.

Greve, C.W., The Analytical Photogrammetric Processing System-IV, Autometric, Inc., Falls Church, Virginia 22041.

Greve, C.W., Niedzwiadek, H.A., Lukes, G., The Implementation of Graphics Superposition on the APPS-IV Analytical Plotter, Engineer Topographic Laboratories (USAETL), Fort Belvoir, Virginia 22060.

The Field Exploitation of Elevation Data (FEED), Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060.

Leighty, R.D., (1977) "Concepts for Automated Pattern Recognition Research with Hybrid Optical/Digital Systems," Proc. SPIE, Data Extraction from Film, Vol. 117, 132.

Leighty, R.D. and Lukes, G.E., (1978), New Approach to Automated Optical/ Digital Pattern Recognition, Proceedings of the Society of Photo-Optical Instrumentation Engineers.

Leighty, R.D., (1967), Boundary Delineation in Photo Interpretation for Engineering Analysis. U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia 22060.

Leighty, R.D., (1967), Remote Sensing for Engineering Investigation of Terrain, Proceedings of Fifth Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Michigan.

Leighty, R.D., (1965), Terrain Factor Mapping from Aerial Photography for Purposes of Vehicle Mobility, International Society of Terrain Vehicle Systems, U.S. Canada Reg. Meeting.

Leighty, R.D., A Research Program for Hybrid Optical/Digital Pattern Recognition, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060.

Lukes, G.E., (1980), Geographic Data Bases Supporting Scene Generation, Society of Photo Optical Instrumentation Engineers, Box 10, Bellingham, Washington 98227, USA.

Lukes, G.E. (1979), Computer-Assisted Photo Interpretation Research (CAPIR): A Prospectus, US Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060.

Lukes, G.E., (1977), "Rapid Screening of Aerial Photography by OPS Analysis," Proc. SPIE, Data Extraction from Film, Vol. 117, 89.

Messmore, J.A., Vogel, T.C., Pearson, A.R., (1979), Terrain Analysis Procedural Guide for Vegetation ETL-0178 (Report No. 1 in the ETL series on guides for Army terrain analysts), U.S. Army Corps of Engineers, Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060.

Mintzer, O.W., (1981), Terrain Analysis Procedural Guide for Surface Configuration, U.S. Army Engineer Topographic Laboratories, Geographic Sciences Laboratory, Fort Belvoir, Virginia 22060.

Mintzer, O.W. and Struble, R.A., (1965), Terrain Investigation Techniques for Highway Engineers, Project 196, Engineering Experiment Station, The Ohio State University, Columbus, Ohio.

Mintzer, O.W. and Mathur, B.S., (1961), The Use of Colour Photography in the Study of Engineering Soils and Landslides, (Unpublished Report) Department of Civil Engineering, The Ohio State University, Columbus, Ohio.

Niedzwiadek, H.A. and Greve, C.W. (1978), "The Wetlands Analytical Mapping System", Proc. Amer. Soc. of Photogrammetry, 44th. Annual Meeting, pp. 320-328.

Pearson, A.R., Wright, J.S. (1980), Synthesis Guide for Cross-country Movement (ETL-0220), U.S. Army Corps of Engineers, Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060.

Reed, C., "Habitat Characterization: A Production Mode Usage of a Geographic Information System, " presented at the Second International User's Conference on Computer Mapping Hardware, Software and Data Bases, Harvard University, Cambridge, Massachusetts, 1979.

Slama, C.C., Special Applications of Analytical Stereoplotters, National Ocean Survey, Rockville, Maryland 20852.

Tazelaar, J. (1979), Terrain Analysis Procedural Guide for Geology, (ETL-0207), U.S. Army Corps of Engineers, Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060.

Worzel, K.J., (1978), "An Interactive Triangulation Station", Proc. Amer. Soc. of Photogrammetry, 44th. Annual Meeting, pp. 334-341.

Wright, J.S., Vogel, T.C., Pearson, A.R., Messmore, J.A., (1981), Terrain Analysis Procedural Guide for Soil (ETL-0254), U.S. Army Corps of Engineers, Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060.

ACKNOWLEDGEMENT

This paper has been written as a result of one year of research effort performed at the U.S. Army Corps of Engineers Topographic Laboratories, Fort Belvoir, VA (USAETL). The effort involved Computer Assisted Photo-Interpretation Research (CAPIR) for the Research Institute under the guidance of Mr. Melvin Crowell and supervised by team leader of the Coherent Optics Center, Dr. Robert Leighty. Much of the earlier work (see references) with CAPIR was accomplished by George Lukes who was directly involved with the research reported herein.

THERMAL SENSING FOR SUBSURFACE SOIL MOISTURE

J. VLCEK[1]

1 Faculty of Forestry,
University of Toronto,
Toronto, Ontario M5S 1A1

1. INTRODUCTION

Soil water content affects physical properties of soil related to engineering applications as well as being a crucial factor in plant life. Survey of soil moisture over large areas by point measurement can be tedious, inaccurate and impractical. It is, therefore, not surprising that attention has been directed toward remote sensing methods as means of obtaining such data. Three remote sensing methods can be used for soil moisture detection: Air photography, thermography and microwave imaging. Each of these methods has certain advantages and limitations. In this paper the application of thermal sensing will be discussed. In the first part basic thermal properties and behaviour of soils will be reviewed to establish a basis for understanding of thermal image patterns. In the second part will be presented experimental results with the emphasis on those obtained at the University of Toronto.

2. THERMAL PROPERTIES AND BEHAVIOUR OF SOILS

Transfer of heat through solid media can be characterized by thermal conductivity (k) and volume heat capacity ($C = c\rho$, c = specific heat capacity and ρ = density) defined as follows:

$$Q = -k\frac{dT}{dZ} \quad \text{and} \quad \frac{dQ}{dZ} = -C\frac{dT}{dt}$$

in which Q = heat flux per unit area
T = temperature
t = time
Z = thickness or depth

Combined effect of these two parameters leads to the definition of thermal diffusivity ($\lambda = kC^{-1}$) and thermal inertia ($P = \{kC\}^{\frac{1}{2}}$). Diffusivity is a measure of temperature change as heat flows through it and thermal inertia is a measure of material's resistance to temperature change.

Soil is a hetergeneous mixture of solids, water and air. These 3 constituents have widely differing thermal properties. Mineral solids have higher conductivities than water but water has higher thermal capacity. On the other hand the values of k and C of air are very much smaller than those of the other two constituents. Thus major changes in thermal properties of soil will accompany the changes in the volume of soil air. The volume of air in the soil can be decreased (1) by compaction and (2) by addition of water. At similar soil densities the thermal properties of soil will depend on water content and total porosity.

Figure 1 shows total porosities (% total volume), available and unavailable water of soils of various textural classes in their natural states (Fraysee 1980). Available water is the amount of water held in the soil between -0.3 and -15 bars pressure which is regarded as a range within which plants can draw sufficient amounts of water from the soil. Thus, at the same volume of water, clay will hold greater volume of air than sand. For this reason plus the fact that clay particles have lower thermal conductivity than sand (quartz) we would expect sand to have better conductivity which is so. However, there is an added reason for sand's higher conductivity which deals with the distribution of water around the particles governed by capillary and adsorption forces. Most of the initial water in sand goes into the formation of capillaries thereby increasing the thermal contact between the sand particles. Thus thermal conductivity of sand increases faster than that of clay even if their porosities are equal. Figure 2 shows thermal conductivity vs. soil water (% vol.) for clay, sand and peat, each at different percent porosity (number by each curve) (deVries 1963).

Volume heat capacity (C) on the other hand is a linear function of porosity, increasing as water fills the available air space or decreasing with increasing porosity as can be seen in Figure 3 (Quiel 1975). From this graph it can also be seen that the same heat capacity can correspond to different combinations of porosity and moisture content. It can also be seen that heat capacity increases about twice as fast as porosity decreases, on percentage basis, in an average soil mixture.

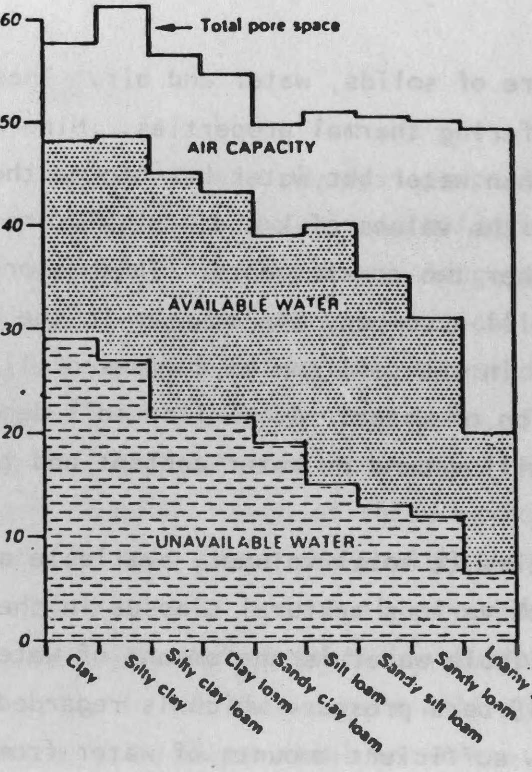


Figure 1

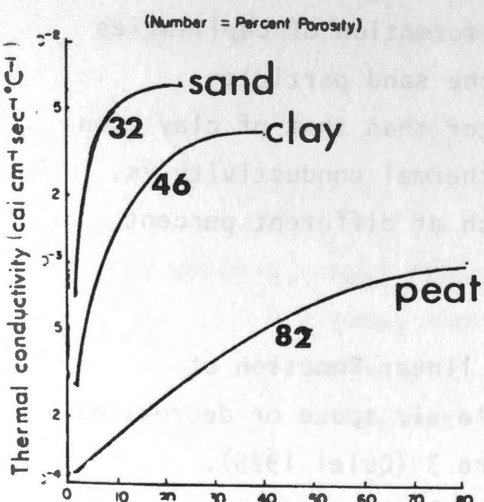


Figure 2

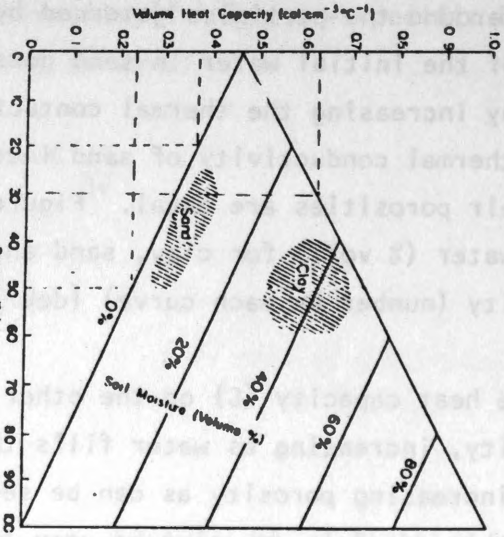


Figure 3

From the above discussion of thermal conductivity and heat capacity their combined effect, defined as thermal inertia, ($P = \{kC\}^{\frac{1}{2}}$) can be inferred. Figure 4 (de Vries 1963) shows an empirical determination of thermal inertia of the soil types shown in Figure 2. It shows that, starting from a dry state the rapid increase of thermal inertia especially in sand, must be caused by rapid increase of its thermal conductivity. Later when the soils reach high water content the inertia is mainly influenced by volume heat capacity.

The important relationship in remote sensing is the relationship between the diurnal surface temperature and thermal inertia illustrated in Figure 5 (Fraysse 1980). It shows that diurnal temperature difference, ΔT (^{o}C) is inversely proportional to inertia. This relationship forms the basis for the thermal sensing method for soil moisture detection.

Based on the above review of thermal properties of soils it is apparent that the relationship between soil moisture and surface temperature is complicated by the variation of thermal properties across textural classes. This has led some investigators to consider other ways to expressing water content with the aim of removing the differences. Quantifying water content by weight ignores differences in density and thus porosity. Water content by volume removes the above difficulty but still does not remove the differences among textural classes due to the variation of water distribution in the soil matrix. One approach toward removing soil type differences is offered by using water pressure potential (tension with which water is held by soil particles). Al-Nakshabandi and Kohnke (1965) showed that different thermal conductivities of soils of different type became almost identical when they were plotted against water potential. Idso et al (1975) applied water potential transformation to their experimental data and were successful in reducing the effect of soil type differences. Expressing water content in terms of pressure potential is of interest in biology because water suction by roots depends on overcoming this potential. Another approach is to express soil water states in terms of percent of field capacity defined as the water the soil can hold against the force of gravity or near that value (e.g. -0.3 bar point) on the potential curve. This is a linear

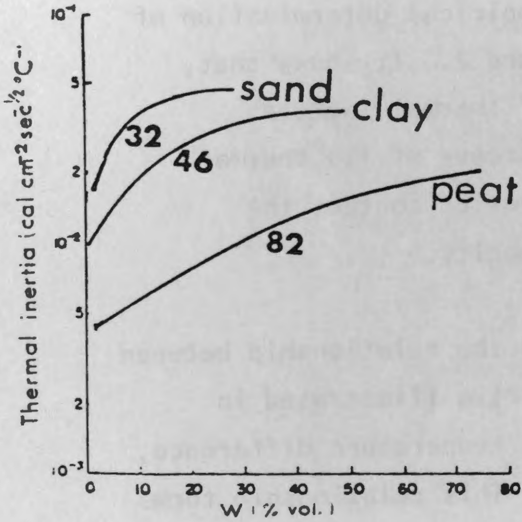


Figure 4

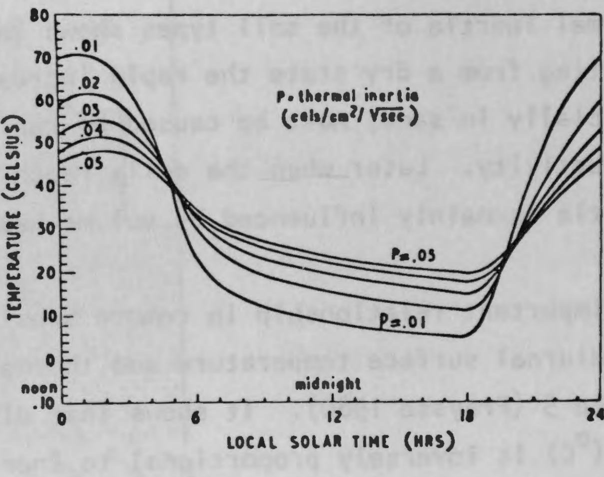


Figure 5

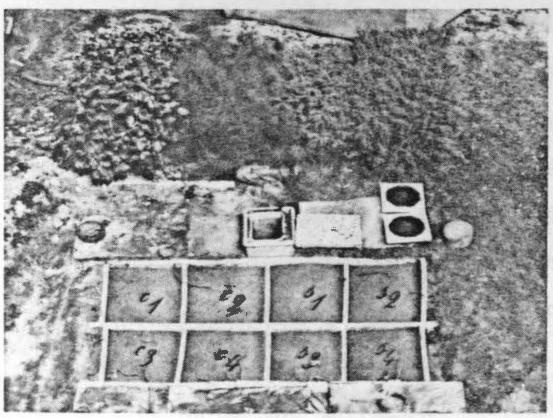


Figure 6

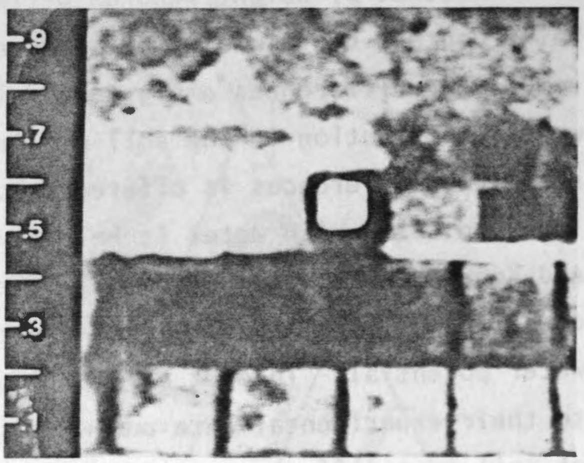


Figure 7

transformation of water content values expressed as percentage of volume and should remove major portion of textural differences. The major practical disadvantages of the attempts to generalize thermal behaviour for all soil types lies in the inaccuracy and uncertainty in determining the relationship such as water potential and field capacity. Even getting undisturbed cores for density and determination under field conditions is not easy.

So far bare soil surface has been assumed. However, experimental evidence is building up to suggest that the soil water content-diurnal temperature difference relationship holds even under considerable ground cover by dry material such as straw (Cihlar 1979) or partial and even full canopy of growing vegetation cover (Heilman and Moore 1980) and Vlcek (in this paper). When soil is covered by dense canopy of crops soil surface temperature can be obtained from a relationship among canopy temperature, minimum air temperature and percent canopy cover.

Another approach to estimation of soil water content, particularly applicable to agriculture and forestry, is offered by measurement of canopy temperature and related meteorological parameters (Jackson et al 1977).

Finally, the development of inertial mapping (Price 1977) is an attempt to determine soil moisture and other properties of surficial geology over large areas using energy balance relationships at the surface. The recent heat capacity mapping mission (HCMM) satellite program was designed to serve this purpose.

3. EXPERIMENTAL RESULTS

A major study of the relationship between soil moisture and soil surface temperature variation was carried out by Idso and his collaborators (Idso et al 1975) using ground based measurements. The study was later augmented to incorporate airborne data which were found to be in good agreement with ground data (Reginato et al 1976, Schmugge et al 1978). The above studies concentrated on the 0-2 cm to 0-4 cm surface soil layer and included a wide variety of textural classes. These authors also used soil water pressure potential to express water content in an effort to remove textural differences and also suggested a method for adjustment of the Δ T values to take into account variation of air temperatures. Their results yielded correlation coefficients between 0.8 - 0.9 for the Δ T vs. water content relationship.

In Canada thermal sensing for soil moisutre was investigated by Cihlar and his coworkers (Cihlar et al 1979). Studies on thermal properties of terrain and more recently work on thermal inertial mapping has been also conducted by Bonn and his group at Université de Sherbrooke (Bernier et al 1981). They expressed water content in percent field capacity and found best correlation for the 0-2 cm layer. However, the overall statistical accuracy of these results is rather low. The results revealed that the Δ T - soil water relationship holds even under considerable ground cover of dry matter such as straw and found improvement of the above relationship by incorporation of soil visible albedo.

At the University of Toronto we have conducted experimental work on thermal properties and behaviour of soil (1) at close range using experimental plots and thermal vision camera (Vlcek 1981) and (2) conducting aerial thermal survey over a forest tree nursery. The main differences between our and other studies was that all our work has been done on the 5-7 cm subsurface soil layer.

Close Range Sensing Results

Soils of different textures and moisture levels were kept in styrofoam insulated compartments in the field and observed at hourly intervals over 24 hour period and with an AGA Thermovision from a 5 m elevated platform. All soil surfaces were covered by thin layers of dry soil so that no albedo differences could be detected among soils of the same type.

Figure 6 is a photo of the experimental plot and Figure 7 a thermogram taken at 22:00 hours local sun time (LST). In this particular arrangement two soil types, S and C, were compared, each at 4 different moisture levels. The subscripts 1.......4 increase with increasing moisture contents. The relationship between Δ T(^{o}C) and percent water volume is shown in Figure 8. Correlation is very good. When the same data were plotted against water pressure potential the correlation became worse, probably a result of a bias in water potential determination.

In later experiments we varied the thickness of the (cover) layers of the soil up to 5 cm depth and still continued to get fairly good correlations. In a seperate experiment we studied the resistivity of the T - soil water relationship to depth of sampling. Correlation fell off with depth and broke down at about the 9 cm depth.

Airborne Thermal Sensing Results

Three aerial thermal sensing missions including black-and-white and colour infrared photography were conducted over a forest tree nursery at Orono, Ontario at a scale 1:5,200 for thermal imagery and 1:7,500 for photography. The tree nursery was chosen for several reasons:

(a) It consisted of flat rectangular compartments, between 1-2 ha in size.

(b) It presented a variety of uniform surface conditions: fallow fields, plowed and freshly tilled fields, fields covered with planted trees ranging from 5 cm height with sparse ground cover to 30-50 cm height with almost a full canopy.

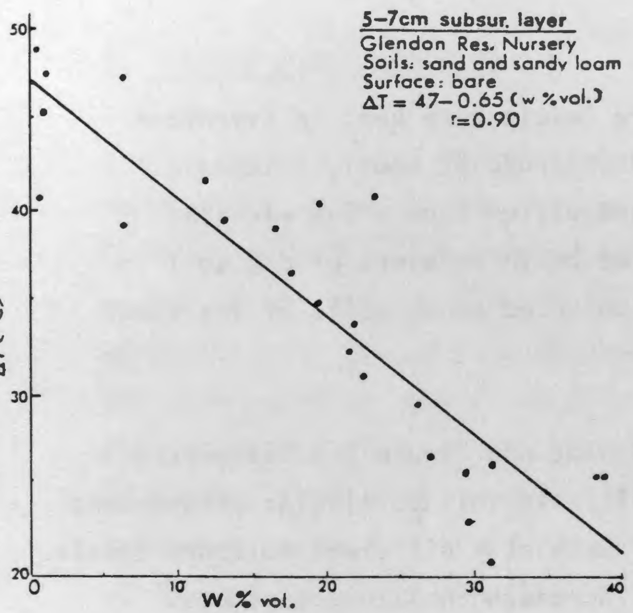


Figure 8

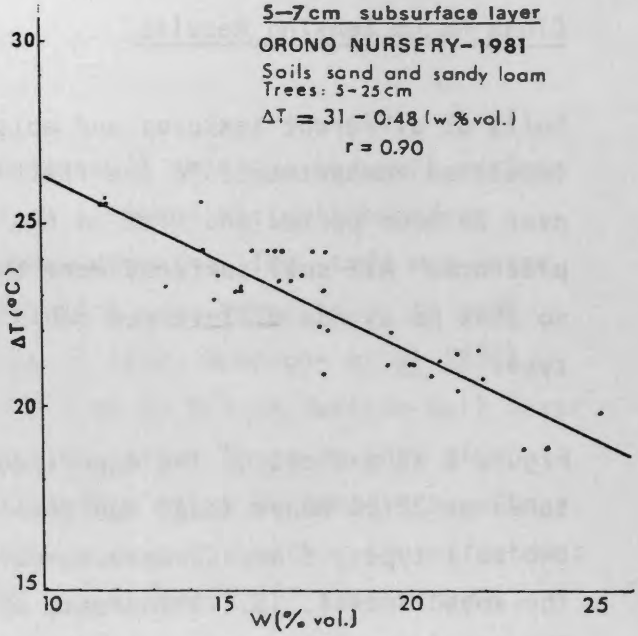


Figure 9

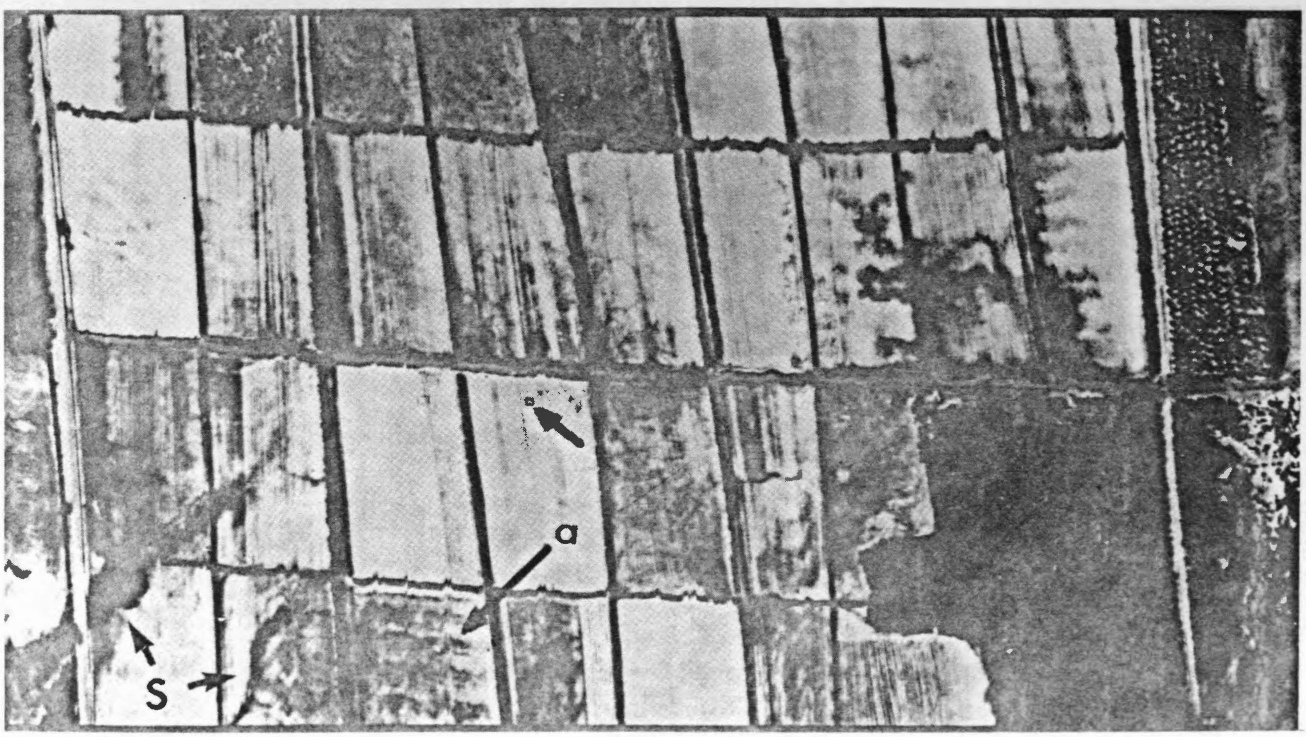


Figure 10

(c) It provided an opportunity to study the effect of irrigation.

A drawback of the site was that it featured very light soils which is the usual case in tree raising operations. The soils ranged from fine sand with some peat admixture to loamy and sandy loam.

The dates of the missions were: (1) early May, (2) middle of July and (3) end of August 1981. Soil samples were collected from the 5-7 cm layer for gravimetric water content determination during and after the day-time overflight. Simultaneously, soil moisture and density readings were collected using a neutron probe by the staff of the nursery. Major soil sampling sites were targeted using crinkled aluminum foil (an arrow in Figure 10 points to one of the targets). Such targets appear very cold on the imagery since they reflect only the sky long-wave radiation which even in the summer will equal a blackbody temperature of only -5^{o} to $-20^{o}C$ in the 8-14um spectral range.

There were some serious problems with the quality of the imagery. In the May mission malfunctioning gyro control on the scanner disrupted contiguity of neighbouring scan lines resulting in along-the-path straight lines to appear wiggly and thus distorting the thermal patterns (see Fig. 10). In the daytime July mission we had some problems with clouds suddenly appearing during the overflight. The most serious problem affecting all the data was the loss of signal from all the high temperature fields due to improperly set upper black-body reference. In spite of these difficulties we were able to demonstrate a strong correlation (r=0.90) between the diurnal soil surface temperature differences and the 5-7 cm subsurface soil water content expressed as percentage of volume as shown in Figure 9. The data in Figure 9 represent almost exclusively the fields covered by rows of tree seedlings ranging in height from a few centimeters to 25 cm. These trees did not form closed canopies and in most cases the rows were aligned with the scan lines. The data are pooled data from the July and August missions. The May mission data were not included since the "night" overflight took place the same day, post-dusk rather than predawn as in the other two missions.

Some other thermally related features that might be of interest in engineering were uncovered in this study. One of them was the effect of an old artificial drainage (tile) system that was installed to facilitate field use of heavy automation equipment in early spring and late fall which is the optimum time for the harvesting and planting operations. As an example, Figure 10 is the May 2 day-time thermogram that shows four rows of fields in one section of the nursery. The lines of drainage tiles run parallel to the service roads (across the page) and their effect can be seen in several fields. A good illustration is in the field pointed to by an arrow marked a. This is a bare field (an old plough) and in this case the stripes are enhanced by a pattern of tilling. Under the conditions of high surface moisture the drainage patterns can also be seen on black-and-white and colour infrared photography. What the photography does not show, however, is the form and extent of the natural sub-surface drainage in the area. At least two different sub-surface drainage basins can be seen in the thermogram: (a) one associated with the two surface channel scars at S that drain toward the left lower corner of the picture. This basin is obscured in places by very warm (light uniform tone) fields that were either freshly tilled or planted near the time of the May 2 mission; (b) another drainage pattern near the upper right corner of the picture. The striped pattern caused by the drainage tile is well illustrated here as well as the fact that the natural drainage is oriented at right angles to the tile lines and down into the forested area (dark tone) below the main service road. The road has no culvert and acts somewhat as a dam in both drainage systems. It is likely that if this information regarding natural drainage had been available at the time the artificial drainage was being considered a more efficient and probably less costly system could have been designed. Unfortunately, the articicial drainage system has also proven to be costly from the silvicultural viewpoint, since the natural soil horizons were dislodged by ditching and could not be reconstituted resulting in unbalanced chemical and physical soil matrix leading to stunted growth of trees along the drainage lines. To illustrate further how competing demands can incluence a situation, all the growing stock in the nursery has to be regularly irrigated because of the very light and draughty soils best suited for fast development of planting stock. Summer missions imagery in this regard shows thermography to be an excellent tool of determining the uniformity of an irrigation system.

4. CONCLUSIONS

- This paper presents further evidence that diurnal thermal sensing provides a means of quantifying moisture levels in a subsurface layer of soil of similar textural properties.

- It further demonstrates that the above relationship holds even when the soil surface is in part covered by a uniform plant growth such as rows of small trees.

- The paper illustrates the value of thermography in studying subsurface water migration.

ACKNOWLEDGEMENT

The experimental work was supported partially by the National Science and Engineering Research Council and Canadian Forest Service. All airborne data were generated at no cost to us by the Ontario Centre for Remote Sensing.

REFERENCES

Al-Nakshabandi, G. and H. Kohnke 1965: "Thermal conductivity and diffusivity of soils as related to moisture tension and other physical properties" Agricultural Meteorology 2:271-79.

Bernier, M., R. Brochu and F. Bonn 1981. "Cartographie de l'inertie thermique de certains secteurs du Quebec a partir de donnes aeriennes et du satellite H.C.M.M. "Proceedings, International Symposium on Remote Sensing of Environment", Ann Arbor, Michigan.

Cihlar, J., T. Sommerfeldt and B. Peterson 1979: "Soil water content estimation in fallow fields from airborne thermal scanning measurements." Canadian Journal of Remote Sensing 5:18-33.

Fraysse, G., Editor 1980 Remote Sensing Application in Agriculture and Hydrology. J.R. Hardy, author "Survey of methods for the determination of soil moisture content by remote sensing". A.A. Balkevia, Rotterdam.

Heilman, J.L. and D.G. Moore 1980: "Thermography for Estimating Near-Surface Soil Moisture under Developing Crop Canopies". Journal of Applied Meteorology 19:324-28.

Idso, S.B., T.J. Schmugge, R.D. Jackson and R.J. Reginato 1975: "The Utility of Surface Temperature Measurements for the Remote Sensing of Surface Soil Water Status "Journal of Geophysical Research " 21:3044-49.

Idso, S.B., R.D. Jackson, R.J. Reginato 1977: "Remote Sensing of Crop Yields" Science 196:19-25.

Jackson, R.D., R.J. Reginato, S.B. Idso 1977: "Wheat Canopy Temperature: Practical Tool for Evaluating Water Requirements". Water Resources Research 13:651-6.

Price, J.C. 1977: "Thermal Inertia Mapping: A New View of the Earth". Journal of Geophysical Research 82:2582-90.

Quiel, F. 1975. "Thermal/IR in Geology" Photogrammetric Engineering and Remote Sensing. 44:341-46.

Reginato, R.S., S.B. Idso, J.F. Vedder, R.D. Jackson, M.B. Blanchard and R. Goettelman 1976. "Soil Water Content and Evaporation Determined by Thermal Parameters from Ground-based and Remote Measurements". Journal Geophysical Research. 81:1617-1620.

Schmugge, T.J. 1978. "Remote Sensing of Surface Soil Moisture". Journal of Applied Meteorology 17:1549.

Vlcek, J. 1981. "Thermal Vision Camera in Forestry Research". Canada Journal of Forestry Research 11:730-35.

Vries, D.A. de 1963. "Thermal Properties of Soil in van Wijk: Physics of Plant Environment". Amsterdam.

DEVELOPMENT OF AIRBORNE AND SATELLITE REMOTE SENSING APPLICATIONS

J.D. Mollard[1]

ABSTRACT

I plan to use about 30 slides to illustrate this talk, which deals with my experiences in developing remote sensing applications. The projects discussed date back to the 1940s. Remote sensing case history examples begin with searches for sand and gravel construction materials, and with the location and mapping of dense concentrations of boulders and frost-shattered rock. Studies involving the selection of different types of engineering sites and routes, and with terrain mapping along them, are discussed next. An example of surficial geology and lineament mapping for oil and gas prospecting is followed by one carried out for base metal exploration. Slides of airphotos interpreted for groundwater location and development, and others illustrating shoreline erosion and bank stability mapping around recreational lakes and man-made reservoirs are then presented. The next slide shows one facet of a study showing historical (50-year) changes in erosion and sedimentation affecting wildlife habitat at a large modern delta in northern Canada. My final series of slides present examples of terrain data base mapping and eight derived land suitability maps for use in guiding regional planning and resource management. Each of the case history examples is illustrated by a slide showing a portion of an interpreted black and white panchromatic airphoto, an airphoto mosaic, or a LANDSAT data product.

---

1 J.D. Mollard and Associates Limited
510 Avord Tower
2002 Victoria Avenue
Regina, Saskatchewan S4P OR7

NOTE:

Dr. Mollard's presentation was originally delivered at the 7th Canadian Symposium on Remote Sensing in Winnipeg, Manotiba in 1981. It was repeated at this workshop by popular demand. Because the complete text will appear in the Proceedings of the 7th Canadian Symposium on Remote Sensing, only the abstract is provided here.

REMOTE SENSING APPLICATIONS FOR THE ONTARIO MINISTRY OF TRANSPORTATION AND COMMUNICATIONS REGARDING BURIED GRAVEL AND WATER RESOURCES

S.J.G. BIRD[1,2] AND L. HELLAS[1,3]

ABSTRACT

In October, 1981 the Remote Sensing Section of the Ontario Ministry of Transportation and Communications contracted with Bird and Hale Limited, Consulting Engineers and Biologists, to prepare two state-of-the-art reports on the following topics:

1. The detection and evaluation of buried sand and gravel deposits.

2. The detection and mapping of water resource parameters.

These state-of-the-art reports have been completed.

During these studies emphasis was placed on identifying and evaluating remote sensing systems/techniques which are presently operational or have the immediate potential to be operational after sufficient field testing.

---

1 Bird and Hale Limited
1263 Bay Street
Toronto, Ontario M5R 2C1

2 Author, Part I: Detection and Evaluation of Buried Granular Deposits

3. Principal author, Part II: Detection and Mapping of Water Resource Parameters

PART I - DETECTION AND EVALUATION OF BURIED GRANULAR DEPOSITS

1.1 Background

The demand for granular construction materials continues to be high. As only a finite quantity exists, the known deposits in Ontario are or will be depleted in the foreseeable future. In addition, new highways to mineral and timber resources are planned for construction particularly through areas in Northern Ontario. Surface deposits in these areas are rare, as lacustrine clays and/or glacial tills have frequently buried previsously deposited granular materials.

The techniques for locating surface granular materials using airphoto interpretation are proven and documented. Buried granular deposits have also been located using airphotos providing that a surface pattern expression of the underlying materials such as drainage, vegetation, tone, texture, etc., is visible to the interpreter. If this pattern is not visible on airphotos, then the applications of non-photographic techniques must be investigated.

1.2 Objectives

The main objectives of this study involves the assessment of remote sensing techniques, primarily non-photographic, in locating, delineating, and determining the quality (crushable versus non-crushable) of buried granular deposits.

The final objective relates to setting out the optimum remote sensing systems to be used in test areas within Ontario.

1.3 Scope

This report is limited to the available information and data acquired from previous and ongoing studies related to the objectives, prior to March 31, 1982. While the evaluation of the significance and relevance of the results of previous work are presented as factually as possible, a degree of subjectivity based on the author's experience in locating granular materials using remote sensing is inevitable. Consequently, in the absence of factual investigative evidence regarding a particular remote sensing system, the opinions expressed by the author in this report are set out with regard to providing the Ministry (Ontario Ministry of Transportation and Communications) with the most useful information.

While non-photographic remote sensing systems are the primary focus of this investigation, the use of established photographic systems is incorporated where appropriate. This was considered necessary and practical, as most publications and persons contacted stressed the utility of combining photographic and non-photographic systems for any future investigations.

The geographical boundaries of the study are not limited to Ontario. Investigations have been carried out in areas having similar geologic characteristics, and these are included where applicable.

Detailed evaluation of all applicable remote sensing systems from several standpoints form part of the scope of this study. Equipment availability, capability, reliability, weather dependency, data processing equipment requirements and mode of presentation of results are critical factors. Capital and operating costs of equipment, processing, and analysis are the most significant factors.

The size of buried deposits to be located is of concern only with regard to the associated costs. Beyond this consideration, areal extent, depth of granular material, and volume are not limited for the purposes of this study. However, the removal of non-granular material overlying gravel deposits and associated costs are not within the scope of this investigation. These considerations are solely related to the demand for the product and the economic climate at the time of extraction.

Personnel qualifications and experience for future studies are considered to be within the scope of this study. These form part of the recommended remote sensing systems for future recommended test investigations.

1.4 Study Procedures

To successfully complete this project, it was necessary to meet with Ministry personnel; to undertake an extensive literature search and review; and to correspond with and interview remote sensing practitioners and researchers. Details of each of these study components are presented as follows.

a) A meeting was held with Ministry personnel at the start of the project to clarify and finalize the objectives of the study. An interim meeting was held to discuss the progress of the study. Ministry staff who participated and gave valuable aid and direction included Sen Mathur, Head, Remote Sensing Section; Lawton Tam, Remote Sensing Engineer; J.E. Gruspier, Head, Earth and Environment, Research and Development Branch; and Z.L. Katona, Senior Aggregate Resources Engineer.

b) Reference information was identified by having computer searches undertaken by the Canada Centre for Remote Sensing (CCRS) and Earth Resources Observations Systems (EROS) of the U.S. Geological Survey. As well, university libraries were searched and issues of applicable journals were reviewed. These journals included the Canadian Journal of Remote Sensing, Photogrammetria, Photogrammetric Engineering and Remote Sensing, Proceedings of International Symposia on Remote Sensing of Environment (ERIM), and Remote Sensing of Environment. Pertinent articles and publications were acquired and reviewed.

c) Agencies and researchers active in the discipline were identified through the literature and discussions with people in such agencies as CCRS. These groups were contacted, by letter, telephone and in some cases personally for pertinent information.

d) This report is written with the intent to provide an update to Ministry personnel of the extent to which remote sensing techniques are presently operational related to locating and evaluating buried granular deposits. The emphasis in the discussion of remote sensing systems is on those systems which are presently operational.

2. Overall Evaluation of Remote Sensing Systems for Granular Material Detection

General conclusions are stated first, followed by specific conclusions and recommendations regarding each remote sensing system evaluated.

2.1 General

Three conclusions are particularly significant.

1. A substantial number of investigations have been carried out with the primary intent to evaluate the capabilities of one remote sensing system for locating granular materials. If the specific system selected fails to produce the desired results, the techniques used fall into disrepute in the eyes of certain investigators. The use of remote sensing systems for any investigation requires a combination of systems to reach the most reliable conclusion. Therefore, all applicable, available, and economical systems must be applied to such a complex objective as locating buried gravel deposits.

2. The critical importance of verification of investigative results through extensive, yet selective, test hole drilling has not been recognized by many contractual agencies. Personnal communications with personnel carrying out the investigations have verified that the majority lamented the fact that sufficient funding was not provided for detailed ground truthing. The net results of certain investigations are, therefore, highly inconclusive regarding remote sensing system capabilities. As a result, the accumulated knowledge of the capabilities of combined remote sensing systems has not advanced nearly as rapidly under these circumstances.

3. The technical and professional background of personnel involved with the detection of buried gravels is critical. Airphoto interpretation capabilities and geological background, particularly glacial, are the primary requirements. The investigative team should definitely include personnel with detailed knowledge of and experience with the local geological conditions.

2.2 Specific Remote Sensing System Evaluations

1. Photographic remote sensing techniques are well established for locating and delineating surface or near surface (within 1m or 3 ft.) gravel deposits. Buried granular deposits have been discovered at depths between 1m (3 ft.) and 3m (10 ft.) under geologic conditions where the well-drained buried gravels change traditional surface pattern elements, particularly tone, texture, and vegetative cover type. As these changes are rarely detectable on aerial photographs, particularly at depth in excess of 3m (10 ft.) due to the complexities of glacial geology, other remote sensing techniques must be investigated.

2. Panchromatic photography is the most available and economical photographic sensing system. The interpretive techniques are well established. This photography is therefore very useful for acquiring an understanding of complex glacial depositional processes. As this knowledge is essential for any successful granular materials search, panchromatic photographic interpretation by experienced personnel is an essential first step in any buried granular material investigation.

3. Colour, colour infrared, and black and white infrared photography do not have sufficient available areal coverage throughout Ontario. As these types of photography present no significant benefit over panchromatic and are more costly to acquire and interpret, these photographic systems are not recommended as being any practical aid for the location of granular deposits.

4. LANDSAT imagery is available for the entire province. The detection of granular materials is restricted to surface expressions of pattern elements covering areas greater than one pixel (0.4 ha or 1 acre). This resolution limits its applicability to relatively large granular deposits having direct surface expression. Digital analysis is required to analyse the imagery, thus incurring relatively high costs. Analysis of LANDSAT imagery would be practical for the Ministry, only if the digital analysis equipment was made available at minimal charges. Should this be arranged, the resulting imagery would be useful to indicate directional trents of surface expression of granular materials. Consequently, the lack of continuous surface expression along these trend lines would likely indicate the presence of buried gravel. However, the use of this imagery is recommended only under the arrangements stated above.

5. Multispectral scanning imagery provides higher resolution than LANDSAT, but is very expensive to acquire as it is generally unavailable. The benefits of this imagery for locating buring gravel deposits are very questionable. For the above reasons, its use for the purposes of this study is not recommended.

6. Radar imagery records subtle soil moisture variations, possibly resulting from buried gravel deposits. At this time, its use is not economical for the purposes of this study. However, should Canada be able to obtain RADARSAT imagery through involvement in the satellite program, radar applications for this study should be investigated at that time (mid 1980's) providing that acquisition and analysis costs are acceptable to the Ministry. This sensor system has potential, but has yet to be proven.

7. The principal application of seismic data is differentiation among rock, sand, and gravel. Because of these limited applications, difficulties in interpretation of data, and time consuming data collection procedures, seismic is recommended as a support sensing system, applicable only to the specific situations discussed above.

8. Airborne and ground resistivity techniques have the greatest potential for locating buried granular deposits.

The advantages of these systems are:

(a) Operational throughout all seasons of the year.
(b) Available from companies in Southern Ontario.
(c) Provide readings at depth penetrations up to and beyond 30m (100 ft.) below ground surface.
(d) Do not require expensive analytical equipment, particularly ground systems.
(e) Provide data on deposit thicknesses under certain geological conditions.
(f) Do not require highly qualified personnel except geophysicist for airborne systems.
(g) Flexible regarding selective areal coverage particularly ground surveys.

The disadvantages of these systems are:

(a) Not operational in rain and/or fog.
(b) Not yet proven for reliable detection of buried granular materials under variable terrain conditions as no truly comprehensive studies have been carried out primarily for this purpose.
(c) Subject to interference with readings from cultural sources such as high voltage hydro wires and buried pipelines.
(d) Do not always identify relatively small, localized buried deposits due to spacing between flight lines and resolution of system.

As the advantages outweigh the disadvantages, and meaningful readings at depths below ground surface are required to detect buried granular deposits, resistivity techniques should definitely form an integral part of further investigations.

PART II - DETECTION AND MAPPING OF WATER RESOURCE PARAMETERS

1. Background and Objectives

The type of water-related information required, and the method by which it is acquired, will vary with the specific application for which it is intended. This document reports on the use of remote sensing systems and techniques in water resources management and monitoring, as related to the specific needs of the Ontario Ministry of Transportation and Communications (OMTC). These needs fall into two broad categories: locating highway corridors to avoid environmentally sensitive water-related biological communities; and, detecting and monitoring surface water quality and quantity modifications due to highway constuction, operation and maintenance.

The specific objectives of the study included: the identification of the water resource parameters which would be of interest and value to OMTC in maintaining high environmental quality standards while at the same time fulfilling their mandate to provide transportation networks; and, the identification of remote sensing systems and techniques which are presently operational for the detection and monitoring of these water resource parameters.

The report was written with the intent to provide an update to OMTC personnel of the extent to which remote sensing techniques are presently operational related to their requirements in water resources. In this sense, it is not a comprehensive state-of-the-art report, since only those parameters and features of interest to OMTC are discussed. Moreover, the emphasis in the discussion of remote sensing systems is on those systems which are presently operational.

2. Water Resource Parameters

Table 1 lists the components of the physical, chemical and biological categories which may be of interest to OMTC in their water resources program. Thus, the list can in no way be considered complete. Each component is defined, and its significance is given. This significance relates more to OMTC needs, and not necessarily to the components' absolute limnological significance. The "significance" column also serves to direct all readers to the same frame of reference. It assumes that the reader has some familiarity with limnological/biological terminology; other readers are referred to Hutchinson (1957 and 1967), Wetzel (1975) or any other good reference book on the subject.

The importance of land use and cover type changes within the drainage basin in relation to water quality and runoff quantity cannot be overemphasized. Simply stated, natural processes on watersheds can contribute their share of any pollution load and in many cases this share may be substantial. It is mandatory, therefore, to establish the land cover types and the corresponding water quality in order to assess the effects of increased inputs caused by human activities.

3. Location and Quantity Components

This is the traditional area in water-related studies in which remote sensing techniques have been, and are usually first, applied.

An overview of regional drainage basins and patterns is best obtained using a scale of at least 1:20,000. Coverage at scales larger than that should be supplemented by topographic maps, since clues to landform identification, etc., occur at a regional rather than a local level, (Bird and Hale, 1978). Moveover, in many cases, drainage divides can be drawn on Landsat images more accurately than on 1:250,000 scale topographic maps (Moore, 1977).

TABLE 1 WATER RESOURCES COMPONENTS

Physical Location and Quantity Components

Component	Explanation	Significance
Water Distribution	drainage basin delineation, location of lakes, rivers and drainage channels; drainage density; form (i.e. snow, water) and extent of surface storage.	size of basin upstream from transportation structure or facility gives indication of potential contribution of land to quality of water; density, type and location of waterbodies relates to topography, rock and soil, potential for nutrient and sediment-rich runoff, and flood-crests.
Lake Morphology	structure and form of lake, including bathymetry	reflect modes of origin, regulate and modify water movements within lake (e.g. extent of stratification) and the degree of loading from drainage basin.
Lake Morphometry	most relate to details of bathymetry, including maximum fetch length, maximum and mean depth, shoreline length and configuration (shoreline development), surface area, volume	high productivity is favoured by low ratio of depth to area, and by high ratio of shore length to area (greater development of littoral communities in proportion to volume).
Stream Characteristics	channel width, depth and configuration, long slope, substrate characteristics, bank stability, water velocity and discharge.	indicates potential for permanent change resulting from nutrient enrichment (potential to recover); indication of potential extent of lake currents which may be generated by river influents; extent of natural siltation; potential for flooding.
Drainage Basin Characteristics	land uses, cover types, soil type, and slope.	runoff amount and characteristics (i.e. nutrient, sediment and toxin levels, and temperature).

Physical/Chemical Water Quality Components

Component	Explanation	Significance
Temperature	both horizontal and vertical gradients.	influences oxygen solubility, redox, conductivity, density and stratification, rate of photosynthesis; reflects changes in cover in drainage basin.
Colour	colour (brightness and lightness) of water compared against a "colour scale" or standardized chromaticity coordinates.	can be related to dissolved organic compounds, minerals, and life forms.
Turbidity	a measure of water transparency, affected by suspended particles, both biotic and abiotic, and to some extent, dissolved compounds	in productive water there is often a relationship between a measure of turbidity and algal population densities; highlights increased suspended matter influents to waterbodies
Dissolved Gases	primarily oxygen, but others important under specific conditions, e.g. radon, hydrogen sulfide.	amount and solubility of oxygen present is related to water temperature and clarity, and amount of light, and organic matter present.
Salinity	frequently determined by electrical conductivity (indicates presence of inorganic acids and bases in addition to dissolved salts); specific gravity; and, measurement of specific ion (e.g. chloride).	increase in background levels indicate runoff contaminated with salts from wastewater or road maintenance; measurement of chloride would be most specific for OMTC purposes.
Acidity and Alkalinity	acidity is used infrequently as a parameter - in practice, pH is used; alkalinity reported in terms of $CaCO_3$.	pH influences biota, measurement of conductivity, form of alkalinity, and solubility of many toxins; alkalinity indicates how well buffered the system is.
Other Parameters	specific locations and circumstances may warrant interest in heavy metals (especially lead and cadmium); pesticides; and oils and grease.	may be of interest in relation to vehicle exhaust; right-of-way maintenance; surfacing practices.

Biotic Water Quality Components

Component	Explanation	Significance
Biota	includes macrophytes (large forms of aquatic vegetation), algae, zooplankton, benthos and fish.	types indicative of prevailing conditions; sudden increases/decreases in population of a species and/or changes in community structure and composition (e.g. high number of few species) may indicate change in water quality (nutrient enrichment; high sediment load; toxins)
Pigments	includes chlorophylls, carotenoids and biliproteins; chlorophyll *a* is usually measured since it is present in all algae.	indicator of productivity of waterbody; must be corrected for degradation products and natural, seasonal variations
Nutrients	primarily controlling nutrients, usually phosphorus and, rarely, nitrogen.	increases in phosphorus, especially, are culturally oriented; again, amount of phosphorus especially, is used as an indicator of productivity of waterbody.

At a regional level, satellite imagery (primary Landsat) offers excellent small-scale, systematic coverage of hydrologic geometry (Gregory, 1978). For instance, four methods of measuring basin length (important in determining peak rates of runoff) have been proposed: (1) main channel length, (2) main valley length (ignoring stream meanders), (3) longest basin diameter from mouth to most distant point on the drainage divide, and (4) length from mouth to centroid, the point where main channel crosses an imaginary line dividing the basin into two equal areas (Potter, 1961). Any of these indices could be measured on Landsat images (Moore, 1977).

Landsat images are suitable for studying drainage patterns of all larger streams and rivers. Although many streams are too narrow to be visible or are obscured by vegetation, drainage lines commonly can be detected by shape, shadows (caused by discontinuities in slope at the edges of channels and valleys), and association with related features (zones of high soil moisture, alignments of trees, and discontinuities in land-use patterns). The factors that determine whether or not a channel position is visible on Landsat images are related to the time-of-year that the image was obtained (sun elevation angle, width and stage of stream, and soil moisture and vegetation conditions). A number of Landsat images obtained at various times-of-year generally are available. Two images which represent similar conditions may provide a more hydrologically consistent base for comparison of drainage patterns than two topographic maps, particularly maps at different scales made from aerial photographs obtained at unknown stream stages (Moore, 1977).

Black and white panchromatic imagery remains the standard format for water location and geometry studies (Sabins, 1976; Gregory, 1978).

Numerous techniques have been applied to determine the boundary between land and water. In this regard, the conclusions of Parry and Turner (1971) still remain valid:

- The contrast ratio between water bodies and living vegetation is at a maximum in the infrared wavelengths because of the high absorption by the water and the high reflectance by the foliage, and so infrared air photos offer the best prospects within the photographic spectrum for the detection of drainage channels in forested areas.

- For small drainage basins of headwater type ranging from first to fourth-order, modified infrared air photos, as used in this study, can improve channel detection and identification by approximately 37 percent compared with panchromatic photographs.

- The maximum benefit from infrared photography is experienced for second-and-third-order channels with progressively less advantage for larger channels.

- Infrared air photos are less effective in the detection of first-order channels, particularly if they are turbid or choked with vegetation; however, they are still superior to the panchromatic. With a small sample of first-order channels it was found that 73 percent of the actual channel length was imaged on the infrared photos compared with 30 percent for the panchromatic.

- Infrared air photos have the additional advantage of revealing shallow channels through bar complexes which could be negotiated by small craft, emphasising fording points, and permitting the differentiation of fluvial depositional forms.

- Infrared air photos provide a more precise indication of the extent of shallow water inundations, such as beaver ponds, backswamps, meander cut-offs, point-bar swale swamps, and even saturated ground conditions.

Radar has also been applied to this problem. As Schmugge (1980) states, in the absence of vegetation, the discrimination between water and land surfaces by passive radar sensors is made on the basis of the large difference in emissivity between water and land at all radar frequencies. Longer wavelengths are particularly appealing because of their superior vegetation penetration capabilities and because the difference in emissivity between water and land surfaces increases with wavelength. Active radar can almost always map water bodies; in virtually all cases, water is observed to produce a much lower return (tone) on radar imagery due to the relative smoothness of the water surface.

The ability of radar sensors to map flood inundated areas under cloud cover conditions is the prime advantage radar has over other methods of discerning flood lines. Such a capability could be useful for conducting relief efforts, assessing loss of property or stability in transportation structures, and permitting the issuance of warnings.

Various investigators have found that Landsat Satellite data can be used effectively for delineating flood boundaries (e.g., Hallberg et al., 1973; Deutsch and Ruggles, 1974; Rohde et al., 1976; Sollers et al., 1978). Philipson and Hafker (1981) undertook a study to compare the effectiveness of: digital versus visual Landsat analysis; anslysis of Landsat band 7 versus combinations of spectral bands; and the use of band 7 images versus aerial photographs. They found that: visual analysis of aerial photographs (1:19,000) and a Landsat band 7 image (at 1:84,000) gave similar results; visual and digital analysis of Landsat band 7 data gave similar results; and digital analysis of Landsat band 7 data gave results which were at least as good as digital analysis of combinations of spectral bands.

Philipson and Hafker concluded "that visual analysis of Landsat band 7 images will produce results that are likely to be as accurate as any other approach which relies on Landsat data. If Landsat data are to be used for delineating flood boundaries, there seems little justification for applying more costly digital analysis if visual analysis of images from a single spectral band produces comparable or better results."

At present, the most frequently used method of determining water depths, especially for nautical charts, is through the use of precision three-dimensional photogrammetric techniques. This method is well documented (see, for instance, ASP, 1975, pp. 1574-1580, for a detailed presentation of photogrammetric bathymetry) and thus is not explained in this discussion.

Aerial photography of shallow water areas can provide useful qualitative information on bottom composition and water depth. However, the interpretation of this photography is impeded by the fact that water depth variations are not easily distinguished from bottom colour differences. Surface reflection effects add another element of confusion to the interpretation of the photography, (Lyzenga, 1978). Regardless, photography is still frequently used to gain an understanding of the relative depths in a waterbody. SO397 (Ektachrome EF Aerographic Film on a 4-mil base) with a Wratten 3 filter for atmospheric haze reduction has been found to be the best overall imagery for water depth penetration at all depths (Lockwood et al., 1975).

Satellite imagery has been used on several occasions where precise information was not necessary. Some studies (e.g. Byrne and Honey, 1977); Polcyn, 1976; and Higer et al., 1975) have demonstrated that, under favourable conditions Landsat is able to measure water depths up to approximately 20 metres within 10 percent of the measured value. However, extensive personal knowledge and ground support has usually been necessary.

The use of airborne multispectral scanner measurements for computing water depths has recently received considerable attention. Moniteq Ltd. (Ontario) have developed the software necessary to deduce water depths from the airborne MSS of CCRS so that routine automatic processing is possible. Presently the system has only been tested to 10m, consequently its range is unknown. Moniteq have found the system to have an accuracy of approximately 0.5m.

Other techniques for remotely determining depths are currently under investigation. Prime among them is the use of laser sensors.

CCRS has a lidar bathymeter for measuring water depths from an airborne platform. It is for use over relatively clear and/or shallow bodies of water such as lakes, rivers, and coastal areas. It operates by sending a light pulse to the water's surface. This light pulse is reflected off the air/water interface and scattered from the lake bottom back to the receiver in the aircraft. The depth is obtained by measuring the time interval between the arrival of the light pulses returning from the top and bottom surface of the water. The maximum depth recorded should be six attenuation lengths for wavelength used (530 nm). This corresponds to approximately 10m in relatively turbid waters and greater than 30m in clear ocean water, (CCRS, 1980).

For waterbodies that are too deep to have their bases imaged directly or when the expense of obtaining new imagery is not warranted, substrate characteristics can be quite accurately inferred from an evaluation of the surficial material adjacent to and upstream of the waterbody. This is most readily determined by interpreting panchromatic black and white photography.

Knowledge of bank stability provides information on the potential for natural variability in sediment load, and on safe set-backs. Stephens and Cihlar (1981) established a "base" erosion situation by visually interpreting 1:10,000 colour infrared photographs. The interpretation permitted delineation of erosion mapping units which are homogeneous in terms of soil, slope length, slope angle and soil conservation practice.

Singhroy (1981) used multidate black and white, normal colour and colour infrared aerial photographs at various scales ectensively to identify areas of bank instability and rill and wash erosion within the Annapolis Valley. He also assessed contributions of thermal infrared, X and L band dual polarized ERIM radar and digital Landsat data for bank erosion, flood plain delineation and general land use studies. He found that normal colour and colour infrared air photographs (scales 1:20,000 to 1:50,000) were especially useful in determining areas which potentially would contribute sediment to the stream.

Remote sensing techniques, such as low-angle oblique photography, colour photography, and thermal IR scanning, can provide information on surface-water patterns that are related to major changes in channel topography. Studies have shown that water surface roughness, turbidity contrasts, and turbulent boils can be correlated with channel topography (Coleman and McIntire, 1971). Relatively smooth water normally overlies the shallow bar that exists on the point-bar side of a river. A highly turbulent region that shows up as a patchy pattern on a photograph results from bank-shedding vortices and eddies which normally characterize the deeper parts of the channel. Low-angle oblique photography reveals these patterns as a result of light reflection from various magnitudes of surface roughness. Vertical colour photography (conventional or IR) shows similar patterns, but they result from differences in turbidity imparted by turbulent mixing. In deep scour pools along a river's course, water masses having thermal properties differing from those of the surface flowing water are often trapped. Mixing induced by turbulence between the different water masses can be detected by thermal IR scanners, the patterns marking the location of deeper channel. These techniques, however, are very subjective, require extensive field verification and rely on the interpreter's knowledge of the topography.

Landsat data are more suited to inventorying land uses within a watershed than the determination of internal water parameters, since the sensors are geared to determining land-based rather than water-based data. In terms of water quality determination or monitoring, the land cover categories can be classified in relation to their potential for discharging natural and human sources of nutrients and toxins into surface waters. The loadings can be determined from literature (Rogers et al, 1975; Omernik, 1976), or by establishing water quality sampling stations (Schecter, 1975). As well, changes in land use over time can be measured and related to changes in streamflows.

The use of Landsat data for categorization can be merged with aerial photography, conventional maps and, if required, ground data. The information can also be interfaced with precipitation, surface runoff, or pollution loading models. In addition, if surface waters are seen to change, it may be possible to determine nonpoint (and point) contributing factors by comparing an updated land cover drainage basin map with the previous land cover map. The land cover update could be undertaken utilizing municipal land use maps, current aerial coverage for relatively small areas, or Landsat images for large, regional scale areas.

For OMTC purposes, it appears that, for determining the location and geometry of water resources, the following remote sensing techniques are applicable: at a regional scale, visual interpretation of Landsat images; to determine storage areas related to runoff potential, and specific-spring high water levels at small scales, visual interpretation of Landsat band 7 images; and for information on smaller areas, the traditional use of black and white panchromatic photos remains the most cost-effective, although in cases where very detailed information is required, the acquisition of infrared photography would be justified. In all likelihood however, field methods of depth determination (soundings) will remain the most suitable technique.

In relation to watersheds, after land cover changes have been determined and speculations concerning non-point reasons and sources of water quality changes have been made, examination for new, additional drainage channels entering the waterbody should be undertaken. All potential drainage patterns, detectable either by topography or breaks in vegetation continuity (variations in vegetation vigor are included here), should be traced away from the shoreline to a possible source. Often, a pattern may lead to a building complex, a treatment pond, a feedlot, or some other source of contaminated runoff.

4. Water Quality Components

Included in this section are dissolved gases, salinity, acidity and alkalinity, heavy metals, chlorinated hydrocarbons, oils, nutrients, water clarity and temperature.

Dissolved Gases

As for any parameter to be remotely determined, a dissolved gas must either be directly detected or measurably cause a change in some other parameter which can be directly detected by a sensor. Thus, for instance, if by being dissolved in water a gas is known to change the colour or temperature of the water in direct relation to the quantity of gas, then the concentration or amount of gas can be inferred from remotely sensed data. Oxygen, which is the primary gas of concern in aquatic systems, cannot be remotely detected when it is dissolved in water. Since the absorption spectrum of oxygen dissolved within water is not detectable, and since dissolving oxygen in water does not appreciably change the colour, clarity, temperature or density of water, there is nothing that a remote sensor can detect.

Regression analysis techniques can be applied to digitized photographic imagery and ground data to obtain information on the surface (horizontal) distribution of dissolved oxygen. This technique is of little value since it is both spatially and temporally dependent and requires ground data. Moreover, it is the vertical rather than the surface horizontal distribution of dissolved oxygen that is of interest.

Salinity

Techniques for remote measurement of waterbody salinity are not well developed. There are two main areas of investigation: measurements from emissive microwaves, and from resistivity. The effect of salinity changes on the emissive brightness temperature of water surface has been used to survey salinity. Because of the low sensitivity, the method is not well suited to detecting salinity changes in inland waters.

The electrical resistance of water decreases as the concentration of ionized substances, such as salts, dissolved in water, increases. However, there have been no investigations into the utility of airborne resistivity to determine surface waters salinity.

Acidity and Alkalinity

It is not likely that acidity or alkalinity, or pH, which is the routine measurement taken that reflects changes in acidity and alkalinity, has any spectral properties of its own. Moreover, since it is not one environmental parameter but numerous parameters which contribute to the measured levels of acidity/alkalinity/pH, it is not possible to identify a more readily remotely measured indicator.

Various regression analyses using remotely measured data and pH values determined at sample sites, can be used to generate surface maps of pH. This approach, using linear regressions of blue, green and red chromaticities against pH, has been used by Hardy and Jeffries (1981). Although the approach offers the advantage of a direct relation between remotely measured values and pH, it suffers from the fact that the calibration curves tend to be sensor and, sometimes, location and time specific.

Heavy Metals and Chlorinated Hydrocarbons

Few, if any, of these categories of water pollutants are currently measurable by remote sensing at the low levels typical of chronic water pollution. However, heavy metal and chlorinated hydrocarbon pollutants are highly insoluble in water and are transported in partuculate form (Johnson and Harriss, 1980). For example, recent studies on the chemistry of lead, a high priority potential pollutant, in the coastal waters of Long Island Sound demonstrated that virtually all lead transport and fate is associated with suspended sediment dynamics (Johnson and Harriss, 1980 after Turekian, 1977).

Oil

Oil can be directly detected remotely when it exists on the water surface as films or slicks. However, there is no remote sensing technology available to measure oil dissolved or dispersed in water. Massive amounts of oil on water are detectable by essentially any type of a remote sensing method because of the gross changes in water reflectivity and emissivity caused by such events.

Slicks can be detected using black and white aerial photography, depending upon the spectral band exposed. The best detection occurs in the blue and ultraviolet parts of the spectrum; the poorest occurs in the infrared, red, yellow, and green and in combinations of these spectral regions. Colour photography is not satisfactory for detecting very thin oil slicks except when using the sun glare reflected from the water surface as a means to reveal oil slicks.

Another passive technique, best suited to airborne systems, is microwave radiometry, which senses a surface's brightness temperature. Oil slicks exhibit a higher brightness temperature than the surrounding water; moreover, the increase in brightness temperature from the oil film is quantitatively related to the film's thickness.

There are two active remote sensing techniques for examining oil slicks. The first is an airborne microwave radar system that has been tested by both the U.S. and Swedish coast guards (White, 1981). This system senses the suppression of wind-driven surface capillary waves by oil films. Film thickness cannot be measured, and other ocean processes can cause a similar suppression of capillary waves, creating ambiguities in discriminating oil films from other surface phenomena.

The second active technique is laser fluorosensing (Bristow, 1978; Sato et al, 1978; Visser, 1979; Hoge and Swift, 1980). In this approach, an airborne laser is used to excite the surface water. The signal strength of the water Raman backscatter is depressed when an oil film covers the water surface. The degree of depression, after correction for background and oil fluorescence, together with laboratory measured oil extinction coefficients, is used to calculate the oil film thickness. Very thin films can be detected even when barely visible to the naked eye or airborne cameras.

For the measurement of films the present airborne method appears to give adequate sensitivity for the resolution of oil slick thicknesses between ~0.05 and 5μm using existing nitrogen laser technology, (Hoge and Swift, 1980). Hence, roadway runoff and other processes leading to very thin oil films may lend themselves to monitoring by laser fluorosensing. In addition, some characterization or "fingerprinting" of the oil may be possible, by monitoring a number of fluorescence parameters concurrently. Three properties which are already available from existing technology and which may identify the oils are the fluorescence emission spectrum, fluorescence conversion efficiency, and the fluorescence lifetime.

Nutrients

Nutrients cannot be sensed directly by remote sensors. However, statistically significant correlations may exist between remotely acquired data, and the 'nonsensible' parameters, as a consequence of secondary effects.

Rogers et al (1976) and McKeon et al (1977) developed regression models for prediction of several water quality indicators in Saginaw Bay (Michigan) from Landsat MSS data. Their models included significatn regression correlation coefficients for total phosphorus and total Kjeldahl nitrogen. Scarpace et al (1979) found similar results when evaluating the applicability of Landsat MSS imagery for assessing the trophic status of waterbodies in the Tennessee Valley.

Boland and Blackwell (1977) conclude, after comparing Landsat MSS, airborne scanner data, and surface information related to five Colorado Lakes, that regression models can be developed from both satellite and airborne data; however, the model estimates do not have the precision and accuracy of those measurements acquired through contact sensing methods. Further, airborne-related models gave better estimates than the Landsat MSS-related models.

Although these procedures are scene and surface truth dependent, they provide both a basis for extrapolating water quality parameters from point samples to unsampled areas and synoptic view of water mass boundaries. Nevertheless, from OMTC's perspective, since the primary parameters (i.e., turbidity) can be more directly remotely determined, and also provide information on water quality (and water quality changes from multidate coverage), there is little value in attempting to remotely measure nutrients.

Water Clarity

Water clarity has components of colour and turbidity. Strictly speaking, colour is imparted to water by dissolved compounds, and is measured on filtered samples of water. However, the colour we perceive is often the result of light scattered by matter suspended in the water - that is, turbidity. Thus, it makes sense to talk about colour and turbidity together. Moreover, turbidity includes both organic and inorganic particulates.

Remote detection of dissolved constituents is possible in very narrow wavelength bands by reflection, absorption, or laser Raman spectroscopy (Moore, 1979) but such techniques are not truly operational. In addition, dissolved luminescent materials such as organic wastes can be detected by the Fraunhofer Line Discriminator (FLD). The FLD has the capability of measuring luminescence as small as 0.25 part per billion Rhodamine WT dye in 0.5m of water at 20^{o}C. A helicoper-mounted FLD has been used successfully for detection of oil slicks, sewage effluent, lignin sulfonate, and phosphate mining wastes (Watson, et al, 1975).

Suspended particles increase total scatter, increase backscatter, change the spectral distribution of light, and reduce average path length. The most important results of these effects are: (1) a turbid water is more reflective than clear water at all visible and near infrared wavelengths (a lighter tone on aerial photographs and satellite images) but (2) the remote signal from a turbid water represents only near-surface conditions; and (3) the measured signal at any wavelength interval is dependent on particle size and may be dependent on the absorption (reflection) and refraction characteristics of the suspended material (Moore, 1980).

Remote sensing can be used to obtain either qualitative or quantitative estimates of water trubidity. In some cases, it is adequate to simply detect and delineate the area of turbidity. These changes can be detected using conventional black and white and/or colour photography. In addition, tonal gradients on the photography may be significant indicators of concentration differences.

Quantitative remote sensing of water turbidity is possible under some conditions, but a thorough understanding of the effects of all variables is necessary to interpret the remote signal. It is important to understand that remote sensing results in an optical measure of water turbidity (and colour). Although some studies have shown a correlation of remotely measured fluxes with concentrations of suspended sediment or chlorophyll and carotin pigments, such relationships are secondary; suspended sediment and pigment concentrations may or may not correlate with water turbidities.

Johnson (1975), Polcyn and Sattinger (1979), and others have applied classification or regression techniques to calibrate Landsat (and other satellites) multispectral scanner data to map distributions of water quality parameters in inland systems. Using Landsat data, suspended inorganic sediment has been most frequently mapped for single dates using MSS band 5 regression analysis (see references in Mundy and Alfoldi, 1979). However, all bands have been used visually.

Multidate analysis has been successful, using more sophisticated techniques such as the chromaticity technique, which involves total radiance normalization and subsequent atmospheric adjustment. In chromaticity analysis, instead of "removing" atmospheric effects, the technique permits an "adjustment" of the satellite data so that relative atmospheric differences among scenes are removed. Alfoldi and Jaques (1980) state that a) a scene with no calibration data can be made to correspond atmospherically to another scene with calibration, thus permitting the temporal extrapolation of calibration; and b) several scenes with calibration data can be combined into a composite calibration group, which removes reliance on calibration data acquisition during the very narrow time window of a single satellite overpass. The most extensive application of the technique is for the Bay of Fundy. There, successful results have led to the use of Landsat data by the Department of Energy, Mines and Resources of Canada for engineering evaluations related to the Bay of Fundy Tidal Power Project. However, as stated by Middleton and Munday (1980), "Although operational in the Bay of Fundy, more chromatic testing is desirable in other water-bodies where chlorophyll levels are higher and different sediment types and particle sizes are present."

Hardy and Jeffries (1981) have applied a form of chromaticity analysis to photographs. Using densitometer measurements of the spectral transmission properties of direct diapositives, they calculated a series of trichromatic coefficients which, when they represent the blue, green and red wavebands, are analogous to CIE (Commission Internationale de l''Eclairage - see ASP, 1975 for a complete explanation) chromaticities and therefore may be interpreted in a similar manner. The authors feel that the method can detect very subtle changes in the spectral properties of lakes, and that the technique represents an improvement in remote detection of water quality, using aerial photographs. However, because of the limited number of lakes on which the method was tested, further investigation is warranted before the merits of the method can be truly ascertained.

In 1979 and 1980, multi-stage (CZCS, airborne MSS, shipboard scanners, and a ground radiometer) data collection projects were organized by CCRS to develop and verify remote sensing water quality algorithms. CCRS, CCIW and Moniteq Limited were involved (Zwick et al, 1981). Moniteq (1981) stated that quantitative mapping of total suspended mineral concentration and chlorophyll a in the Great Lakes can be done on a regular operational basis using airborne MSS. They have validated capabilities of mapping total suspended solids, in the range of 0.1 mg/L to 15 mg/L, and chlorophyll concentration, in the range of 0.2 mg/m^3 to 25 mg/m^3, with approximately 50% accuracy.

Another technique for distinguishing the organic component of turbidity, and which is currently receiving considerable attention, is measurement of fluorescence.

Chlorophyll fluorescence is best excited by light of wavelength 400-500 nm (Rayner and O'Neil, 1979). Current prototype laser fluorosensors for monitoring chlorophyll are based on flashlamp-pumped dye lasers operated in this range. Emission is monitored at 680 nm. The low repetition rate of these lasers means that they must be operated from a helicopter. A sensor has been built using a laser that sequentially scans four excitation wavelengths to give added discrimination of the chlorophyll fluorescense through its excitation spectrum. A problem in these measurements is variability in penetration depth that is due to variations in the water turbidity. Proposals to correct this problem include measurement of the strength of the water Raman scatter and the degree of polarization of the backscattered excitation light, both of which can be related to the water turbidity.

The laser fluorosensor has been used to produce flightline profiles of relative surface water chlorophyll a concentrations that vary over a range from 3 µg/L to 20 µg/L at operating elevations from 200 m to 400 m (Bristow et al, 1979). In its original form the laser fluorosensor is estimated to be capable of monitoring chlorophyll a concentrations down to 0.4 µg/L with a minimum signal-to-background noise ratio of 3. With the implementation of measures to increase the laser power and reduce the background noise, it will be possible to monitor chlorophyll a concentrations down to 0.1 µg/L with a minimum signal-to-background noise ratio of 20.

From the preceding discussion, it is evident that the analysis of turbidity by remote sensing is still very inexact. Inasmuch as OMTC's operational concern related to water quality is to monitor against detrimental changes, the need to remotely ascertain chlorophyll <u>a</u> levels will probably not be required. Visual analysis of turbidity on airphotos remains an economically viable technique to monitor qualitative changes. In an operational plan, the appearance of rivers and lakes could be compared on sequential images; if changes in relative appearance occur, water samples could be collected to determine the nature of the change. If data are required over large areas, a few field samples could be collected to confirm the nature of the turbidity changes and to correlate these measurements with digital values of water radiance, perhaps obtained by airborne MSS. The absolute values of the concentration at all points can frequently be determined if the absolute concentration is known at a single point (or few points).

Temperature

Both thermal infrared scanners and infrared radiometers are currently utilized to obtain information on the surface distribution of temperature in waterbodies. The measurements from these sensors relate to the temperature on the extreme surface of the water and provide no information concerning vertical temperature gradients within the waterbody. Unfortunately, these latter data are often the ones of prime interest in aquatic ecosystems.

An infrared radiometer compares the intensity of the infrared radiation from an object's surface to the intensity of a known temperature source, usually within the meter inself. The radiation is then assigned an equivalent radiation temperature. The accuracy of temperature determinations is a function of altitude of the observing instrumentation; the effects of viewing angle; the non-blackness of water; and, atomospheric effects (atmospheric attenuation and spectral radiance emitted by the atmosphere). Uncorrected radiometric measurements from low-flying airplanes can be expected to have an uncertainty of at least 1°C (Polcyn and Sattinger, 1979). The primary limitations of radiometric data relate to the narrow field of view (usually ~2°). In plume contouring, contours between temperature points must be interpolated; thus, several flight lines are required to provide the temperature points and an instantaneous record is not obtained.

Thermal line scanners can provide a complete temperature picture of a plume in one pass. Because the temperatures are recorded on magnetic tape, electronic data processing can be applied to provide temperature contours at any selected interval. Using this technique, the Ontario Centre for Remote Sensing (OCRS) are currently able to map surface water temperatures to a thermal resolution of 0.2°C and a spatial resolution of 1 m (OCRS, pers. comm., 1982). Although the technique is operational in the sense that it has proven capabilities, the mission costs and the software necessary to acquire the information limit its application.

Although sensors on Landsat do not measure temperature, linear regression analyses on radiance measurements and surface data have been used to produce maps of surface temperature. However, the equations developed to relate surface water temperatures with the Landsat data are scene and surface truth dependent. Thus, this technique would have to be repeated from processing Landsat data of a different date, and is of very limited use.

Leonard et al, (1979) report on experimental remote sensing of subsurface water temperature using the Raman technique. The physical basis of the measurement is explained as follows: (a) liquid water exists in at least two forms, monomer and polymer; (b) the two forms are in chemical equilibrium as a function of temperature; (c) the O-H Raman stretching frequency is significantly different for the monomer and polymer forms; (d) the relative concentration of monomer versus polymer can be determined from the Raman spectrum, and thus the temperature can be inferred. They estimated that the expected performance of an airborne system would be a temperature determination accuracy of 0.5^{o}C at a depth of four diffuse attenuation lengths per joule of laser energy transmitted. This system offers real potential for the future but since it is a lidar system, its cost effectiveness will have to be carefully considered.

5. Trophic Classification

Boland and Blackwell (1977), Scherz (1977), Rogers et al (1978) and Scarpace et al (1979) among others, have investigated the use of multistage data acquisition (Landsat, airborne MSS, surface data) for the trophic classification of lakes. The trophic indicators used typically include: a measure of water clarity (Secchi disk transparency, turbidity reflectance); nutrients (phosphorus and/or nitrogen); and chlorophyll a. The basic characteristics of the method are supervised multispectral classification, and regression analysis correlating the remotely acquired data and the individual indicators of the trophic condition.

An example of a lake classification program is the one undertaken by Rogers et al (1978) on Wisconsin, Michigan and Minnesota Lakes. The procedure established and monitored the trophic status of inland lakes with the use of Landsat data, aerial observations and surface sampling. Landsat and surface data were applied to computer processing to generate colour maps showing lake weeds and six to ten concentrations of algal biomass. The biomass is related to chlorophyll a concentrations, water clarity and trophic state. The authors concluded that the procedure provided a 90% or better correct classification for lakes of about 20 ha or larger and is cost-effective when the scene contained 200 or more lakes. Moreover, it provides a consistent method of comparing a lake's water quality from one time to another.

This procedure may be useful to OMTC at the small scale level of corridor location for the avoidance of sensitive groupings of lakes (i.e., oligotrophic).

6. Summary

The aim of remote sensing, from an operational perspective, is to learn more, or to learn more efficiently, in relation to a specfically defined problem. OMTC's two broad problem areas with regard to water resources are: locating new transportation corridors to avoid, as much as is practicable, environmentally sensitive water-related areas; and, detecting and causally defining water resource changes. In the first area, well established operational remote sensing procedures are of use. Most of the techniques will not be new to OMTC interpreters. The prime addition to existing procedures will be in perspective and not in technique: What is mainly required is an awareness of the sensitivity, functioning, and importance of a water resource. In the second area, much of the remote sensing technology is not truly operational in the sense that it can be applied cost effectively to the problem, and eliminate traditional methods of acquiring data for specific parameters. Furthermore, many of the systems and techniques which have proven capabilities in this area provide information beyond that which would be required by OMTC.

REFERENCES

*Part I - Detection and Evaluation of Buried Granular Deposits

Culley, R.W., 1974. Evaluation of an airborne resistivity measurement system (E-PHASE) for gravel location. Saskatchewan Department of Highways, Regina, Saskatchewan, 54p.

Hanson, D.S., and D.R. Morganstein, 1970. Analysis of multispectral scanner data for location of sand and gravel. Aerospace Systems Division, Bendix Corp., Ann Arbor, Michigan.

McFee, John E. and Y. Das, 1980. The detection of buried explosive materials in Canadian Journal of Remote Sensing, Vol. 6, No. 2, pp. 104-121.

McNeill, J.D., 1980a. Electrical conductivity of soils and rocks. Geonics Ltd., Mississauga, Ontario.

McNeil, J.D., 1980b. Electromagnetic terrain conductivity measurement at low induction numbers. Geonics Limited, Mississauga, Ontario.

Middleton, R.S., 1977. Ground and airborne geophysical studies of sand and gravel in the Toronto region. Ministry of Natural Resources, Ontario, 37 p.

Russell, O.R., et al., 1978. Airborne resistivity techniques for locating constuction materials; Geneseo, New York, test site. Earth Satellite Corporation, Washington, D.C., 77 p.

Russell, O.R., et al., 1978. Airborne resistivity techniques for locating construction materials; Springfield, Ohio, test site. Earth Satellite Corporation, Washington, D.C., 77 p.

Russell, O.R., et al, 1978. Airborne resistivity techniques for locating construction materials. Department of Transportation, Office of Research and Development, Federal Highway Administration, Washington, D.C., Report No. FHWA-RD-78-106.

Russell, O.R., et al., 1978. Airborne resistivity techniques for locating construction materials, Granite Falls and Big Falls, Minnesota, test sites. Earth Satellite Corporation, Washington, D.C., 104 p.

Singhroy, Vernon, 1980. Operational remote sensing for aggregate exploration and inventory. Technical Report for Nova Scotia Land Survey Institute, Lawrencetown, Annapolis County, Nova Scotia.

Singhroy, Vernon and Richard Werstler, 1980. Quaternary geology and gravel resources of the Pas region. Geological Report for the Province of Manitoba, Department of Energy and Mines, Mineral Resources Division.

Sugiura, R. and F. Sabins, 1979. The evaluation of 3-cm-wavelength radar for mapping surface deposits in the Bristol Lake/Granite Mountain area, Mojave, Desert, California. JPL Publication 80-61/Report of Radar Geology Workshop, Snowmass, Co, July 16-20, 1979.

West, T.R., S.A. Mundy, and M.C. Moore, 1979. Evaluation of gravel deposits using remote sensing data, Wabash River Valley, north of Terre Haute, Indiana. The Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana, 23 p.

*Part II - Detection and Mapping of Water Resource Parameters

Alfoldi, T.T., D. Jaques, 1980. Landsat chromaticity techniques applied to water quality monitoring - and speculations on their application in agriculture III Symposium on Remote Sensing, Warsaw, Poland, April 19 and 20, 1979, 13 p.

ASP, 1975. Manual of Remote Sensing. Volumes I and II. R.G. Reeves, (ed) The American Society of Photogrammetry, Falls Church, Va.

Bird and Hale Limited, 1978. Handbook on remote sensing for national parks. (Unpublished).

Boland, D.H.P., R.J. Blackwell, 1977. Trophic Classification of Colorado Lakes utilizing contact data, landsat and aircraft-acquired multispectral scanner data. The Joint Conference on Sensing of Environmental Pollutants, November 6-11, 1977, pp. 888-894.

Bristow, M.P.F., 1978. Airborne monitoring of surface water pollutants by fluorescence spectroscopy in Remote Sensing of Environment 7, pp. 105-127.

Bristow, M., D. Nielsen, and R. Furtek., 1979. A laser-fluorosensor technique for water quality assessment. Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Las Vegas, Nevada, pp. 397-417.

Byrne, P.M., and F.R. Honey, 1977. Air survey and satellite imagery tools for shallow water bathymetry, presented at the 20th Australian Survey Conference, Darwin, May 1977, pp. 103-119.

Canada Centre for Remote Sensing, 1980. Canadian industry involvement in the airborne program of the Canada Centre for Remote Sensing. Request for Proposal, Supply and Services, Canada. File No. 19SQ-23413-0-1147.

Deutsch, M. and F. Ruggles, 1974. Optical data processing and projected applications of the ERTS-1 imagery covering the 1973 Mississippi River Valley floods in Water Resources Bulletin 10(5), pp. 1023-1039.

Gregory, A.F., 1978. Geological applications of remote sensing with emphasis on Landsat data, prepared for 6th Alberta Remote Sensing Course, Edmonton, Alberta, February 27-March 3, 1978.

Hallberg, G.R., B.E. Hoyer, and A. Rango, 1973. Application of ERTS-1 imagery to flood inundation mapping in Proc. Symp. Signigicant Results Obtained from the Earth Resources Technology Satellite-1, pp. 745-753.

Hardy, N.E., W.C. Jefferies, 1981. Chromaticity analysis of color aerial photography and its application to detection of water quality changes in acid-stressed lakes in Canadian Journal of Remote Sensing, Vol. 7, No. 1, pp. 4-23.

Higer, A.L., A.E. Coker, E.H. Cordes, R.H. Rogers, 1975. Water-management models in Florida from ERTS-1 data. U.S. Geological Survey, Water Resources Division, Miami, Florida, 42 p.

Hoge, F.E., R.N. Swift, 1980. Oil film thickness measurement using airborne laser-induced water Raman backscatter in Applied Optics, Vol. 19, No. 19, pp. 3269-3281.

Hutchinson, G.E., 1967. A treatise on limnology. II. Introduction to lake biology and the limnoplankton. John Wiley & Sons, Inc., New York, 1115 p.

Hutchinson, G.E., 1957. A treatise on limnology. I. Geography, Physics, and Chemistry. John Wiley & Sons, Inc., New York, 1015 p.

Johnson, R.W., R.C. Harriss, 1980. Remote sensing for water quality and biological measurements in coastal waters in Photogrammetric Engineering and Remote Sensing, January 1980, pp. 77-85.

Johnson, R.W., 1975. Quantitative suspended sediment mapping using aircraft remotely sensed multispectral data. Bendix Aerospace Systems Division Ann Arbor, Michigan, 12 p.

Leonard, D.A., B. Caputo, F.E. Hoge, 1979. Remote Sensing of subsurface water temperature by Raman scattering in Applied Optics, Vol. 18, No. 11, pp. 1732-1745.

Lyzenga, D.R., 1978. Passive remote sensing techniques for mapping water depth and bottom features in Applied Optics, Vol. 17, No. 3, pp. 379-383.

Mckeon, J.B., R.H. Rogers, V.E. Smith, 1977. Production of a water quality map of Saginaw Bay by computer processing of Landsat-2 data. Bendix Aerospace Systems Division, Ann Arbor, Michigan, 10 p.

Middleton, Elizabeth M., and John C. Munday, 1980. Landsat--what is operational in water resources? in Proceedings of the Sixth Canadian Symposium on Remote Sensing, Halifax, Nova Scotia, May 1980.

Moniteq, 1981. Shallow water bathymetry. Moniteq Limited, Condord, Ontario, May 1981, 5 p.

Moniteq, 1981. Quantitative mapping of chlorophyll and total suspended materials. Moniteq Limited, Concord, Ontario, 9 p.

Moore, G.K., 1980. Satellite remote sensing of water turbidity in Hydrological Sciences 25, pp. 407-421.

Moore, G.K., 1979. Satellite surveillance of physical water-quality characteristics. U.S. Geological Survey, Sioux Falls, South Dakota, pp. 445-462.

Moore, G.K., 1977. Possible uses of Landsat data for studies of drainage characteristics. U.S. Geological Survey, 23 p.

Munday, J.C., Jr., T.T. Alfoldi, 1979. Landsat test of diffuse reflectance models for aquatic suspended solids measurement in Remote Sensing of Environment 8, pp. 169-183.

Omernik, J.M., 1976. The influence of land use on stream nutrient levels. EPA-600/3-76-014, January 1976.

Ontario Centre for Remote Sensing, 1982. Personal Communication

Parry, J.T., and H. Turner, n.d. Infrared photos for drainage analysis, in Photogrammetric Engineering, 1971, pp. 1031-1038, from a study at McGill University, Canada.

Philipson, W.R., W.R. Hafker, 1981. Manual versus digital landsat analysis for delineating river flooding in Photogrammetric Engineering and Remote Sensing, Vol. 47, No. 9, pp. 1351-1356.

Polcyn, F.C., I.J. Sattinger, 1979. Marine ecosystems analysis program: a summary of remote sensing investigations in the New York bight. Environmental Research Institute of Michigan, Ann Arbor, Michigan, 165 p.

Polcyn, F.C., 1976. Bathymetry experiment: remote bathymetry using high gain landsat data. NASA Publication: CR-ERIM-118500-1-F, July 1976.

Potter, W.D., 1961. Peak rates of runoff from small watersheds. U.S. Bureau of Public Roads, Hydraulic Design Ser. 2, 35 p.

Rayner, D.M., and R. O'Neil, 1979. Laser fluorosensors for remote environmental monitoring in Optical Society of America.

Rogers, R.H., L.E. Reed, N.F. Schmidt, T.G. Mara, 1975. Landsat-1: automated land-use mapping in lake and river watersheds. Bendix Aerospace Systems Division, Ann Arbor, Michigan, 13 p.

Rogers, R.H., J.B. McKeon, V.E. Smith, J.P. Scherz, 1978. Summary: application of landsat to the surveillance of lake eutrophication of the Great Lakes basin. Environmental Research Institute of Michigan, Ann Arbor, Michigan, 12 p.

Rohde, W.G., J.V. Taranik, and C.A. Nelson, 1976. Inventory and mapping of flood innundation using interactive digital image analysis techniques in Proc. 2nd Ann. Wm. T. Pecora Memorial Symp., pp. 131-143.

Sabins, F.F., 1976. Geologic applications of remote sensing in Remote Sensing of Environment, J. Lintz and D.S. Simonett (eds.), pp. 508-571.

Sato, T., J. Suzuki, H. Kashiwagi, M. Nanjo, Y. Kakui, 1978. Laser radar for remote detection of oil spills in Applied Optics, Vol. 17, No. 23, pp. 3798-3803.

Scarpace, F.L., D. Malone, D. Meinert, A. Voss, 1979. Trophic classification of Tennessee Valley area reservoirs. American Society of Photogrammetry, Vol. 1, pp. 40-55.

Schecter, 1975. Resource inventory using landsat data for areawide water quality planning. ERIM for Triangle J. Council of Governments, Research Triangle Park, North Carolina, 10 p.

Scherz, J.P., 1977. Lake water quality mapping from landsat. University of Wisconsin, Madison, Wisconsin, 9 p.

Schmugge, T.J., 1980. Microwave approaches in hydrology in Photogrammetric Engineering and Remote Sensing, Vol. 46, No. 4, pp. 495-507.

Singhroy, V., 1981. Bank erosion and flood plain studies on the Annapolis River, Nova Scotia, from Integrated Remote Sensing Data, N.S.L.S.I. Technical Report 1981. 25 p.

Sollers, S.C., A. Rango, and D.C. Henninger, 1978. Selecting reconnaissance strategies for floodplain surveys in Water Resources Bulletin 14 (2), pp. 359-373.

Stephens, P.R. and Cihlar, J. 1981. Remote sensing-based methodology to map and monitor soil erosion. in Proceedings of the 7th Canadian Symposium on Remote Sensing, Winnipeg, Manitoba, Sept. 8-11, 1981.

Visser, H., 1979. Teledetection of the thickness of oil films on polluted water based on the oil fluorescence properties in Applied Optics, Vol. 18, No. 11, pp. 1746-1749.

Watson, R.D., W.R. Hemphill and R.C. Bigelow, 1975. Remote sensing of luminescing environmental pollutants using a Fraunhofer Line Discriminator (FLD) in Proceedings of 10th International Symposium on Remote Sensing of Environment, Michigan. ERIM, Vol. 1, pp. 203-222.

Wetzel, R.G., 1975. Limnology. W.B. Saunders Company, Philadelphia, Pa. 743 p.

White, Dr. H.H., 1981. The potential role of remote sensing in marine pollution monitoring in Sea Technology, October 1981, pp. 15-19.

Zwick, H.H., S.C. Jain, 1981. Recent CCRS work in passive optical imaging of water from Proceeding of an EARSEL-ESA Symposium, Voss, Norway, pp. 189-194.

EXAMPLES OF REMOTE SENSING APPLICATIONS TO HIGHWAY ENGINEERING

H.T. Rib[1]

1 Environmental Design and Surveys Branch,
Federal Highway Administration,
Department of Transportation,
Washington, D.C.
U.S.A. 20590

The application of remote sensing techniques to highway engineering is not a recent development. In 1928, A.N. Johnson reported using aerial photography for a traffic survey of the Baltimore Washington Parkway in Maryland. Since then its use has grown to where many highway organizations throughout the world use remote sensing techniques for a variety of highway applications. In my presentation I would like to illustrate some of the major areas of applications, and some special applications of remote sensing as applied to highway engineering. I will also highlight those areas of application where some of the newer sensor systems and analysis techniques have been utilized.

Before progressing with the application, I would like to make a few observations on the overall use of remote sensing in the highway field as I have noted during my 25 years of association with this field.

1. Although most of the major applications of remote sensing have been demonstrated over 30 years ago, it is not universally applied by all highway organizations or for all possible uses. In a 1974 survey of 53 highway organizations in the United States, all indicated they were using remote sensing in some phase of their work, but only 23 were using it extensively. A positive response was noted if they used aerial photography just for illustrations in their reports to indicate existing conditions or as a base for indicating proposed changes.

2. Some of the applications involved direct identification of features recognizable on the remote sensing data, but many applications are based on inferring or deducing information not directly observable on the remote sensing data. The later case requires more highly trained and experienced personnel. There is a direct relationship between organizations using remote sensing techniques extensively and the presence of experienced remote sensing interpreters on the staff. Most of these organizations also have special remote sensing sections that assist various departments in accomplishing their projects.

3. Remote sensing techniques can be applied in every aspect of highway engineering as listed below. The limit is in the experience and imagination of the interpreters and their availability, not in the application of the technique.

4. Very few interpreters trained in highway or even engineering applications of remote sensing are graduated from engineering universities. Many of the interpreters presently in the highway field are from other degree programs such as geology or geography and/or obtain their experience on the job and from special training courses.

5. A major factor in the extent of use of remote sensing techniques by a highway organization is the degree of acceptance of this technique by middle and upper management. Even with trained interpreters on the staff, this technique will not be extensively applied if the management does not accept and actively promote the technique.

The practice of highway engineering can be divided into seven major stages. Table 1 lists these major stages and the types of studies for which remote sensing techniques have been applied. The remainder of the presentation will illustrate examples of some of these applications. Cases where the newer sensor systems and computer technology have been applied will be emphasized.

Table 1: Application of Remote Sensing Techniques in Various Stages of Highway Engineering

STAGE

Areas of application

Data Interpreted

1. PLANNING: Needs are determined; termini, standards and priorities are established.

A. Condition and Inventory Surveys

1. Regional Surveys

- Land use/natural resources
- Geology/engineering-soils
- Materials
- Drainage networks/watershed areas

2. Traffic Surveys

- Regional surveys
- Origin and destination surveys
- Traffic flow patterns
- Parking surveys

II RECONNAISSANCE SURVEY OF AREA: Determine all feasible route alternatives between termini.

A. Terrain Analysis (see Item IA1)

B. Environmental Analysis

- Economic factors
- Social factors
- Aesthetic/biologic

III RECONNAISSANCE SURVEY OF ROUTE ALTERNATIVES: Evaluation of feasible route alternatives.

A. Comparison of Route Alternatives

- Visual interpretative analysis
- Computer-aided analysis

IV PRELIMINARY SURVEY: Development of plans, specifications, and engineering design for chosen route.

A. Engineering - soils strip survey

B. Slope Stability/Foundations

C. Construction Materials

D. Drainage

V LOCATION SURVEY: Delineation of designed route on ground.

VI CONSTRUCTION SURVEY: Construction of facility.

A. Analysis of Special Construction Problems

1. Landslides
2. Pollution
3. Damage

B Evaluation of Construction Conditions

1. Construction progress
2. Traffic flow

VII MAINTENANCE: Determine condition of highway facility and requirements to return facility to acceptable level.

A. Condition and Inventory Surveys (see item 1A2)

B. Damage Assessment

HIGH RESOLUTION VISIBLE AND INFRARED OBSERVATIONS FROM SPACE

W.M. Strome[1], R.C. Baker[2] and J.P. Hession[1]

ABSTRACT

The National Aeronautics and Space Administration series of Earth Observation satellites, LANDSAT's -1, -2 and -3, have provided frequent, reliable high quality global observations using a high quality Multispectral Scanner (MSS) operating in the visible and near infrared region of the spectrum. The use of these data to provide information to improve the effectiveness of resource management is increasing. For some applications, the resolution of the data provided by the current LANDSAT series, 80 metres, is a limiting factor. In 1982, LANDSAT-D will be launched by the United States. In addition to the familiar MSS, this satellite will carry a new sensor, the Thematic Mapper (TM) which will have 30 metre spatial resolution and several new spectral bands. The data from this instrument will not be widely available until 1983 or later. In 1984, France is planning to launch the first SPOT satellite, which will contain two scanners which have 20 metre resolution in the multispectral (three channel) mode and 10 metre resolution in a panchromatic mode. Canada is developing plans to read out and process data from both of these satellites, as well as those from several other remote sensing satellites whose launches are being planned by the European Space Agency and Japan later this decade.

---

1 Canada Centre for Remote Sensing,
717 Belfast Road,
Ottawa, Ontario K1A 0Y7

2 Canada Centre for Remote Sensing,
2464 Sheffield Road,
Ottawa, K1A 0Y7

1. INTRODUCTION

For several years prior to the launch of LANDSAT-1, experiments were conducted using airborne multispectral scanners. These experiments served to demonstrate the type of information which could be derived from remote sensing. However, the limited availability of these data and the difficulty in their processing coupled with the high cost of operating aircraft blocked the effective use of this technology for operational resource management, except in a very limited number of situations.

In the summer of 1972, the United States launched the first of its Earth Resources Technology Satellites, ERTS-1, later renamed LANDSAT-1. It carried a Multispectral Scanner System (MSS) which provided large-coverage, high quality multispectral data. The data were free from many of the artifacts commonly present in similar airborne data up to that time. The result was that relatively little effort had to be expended in developing and applying corrections, so that maximum effort could be applied to developing analysis techniques. The wide availability of the data encouraged a large community of scientists to investigate analysis techniques and their application to resource management problems. After a decade of widespread availability of LANDSAT MSS data, resource management agencies are using the data in their information systems to an increasing extent, despite the limited spatial resolution, 80 metres.

A new generation of earth observation satellite sensors is being developed which will provide finer spatial resolution data in the visible and near infrared range. The first of these to be launched is the Thematic Mapper (TM) to be carried aboard the United States' LANDSAT-D. This satellite will also carry the familiar MSS. Although the satellite will be launched in the summer of 1982, TM data will not be widely available until 1983 at the earliest, as the first year of operation will be used to evaluate the performance of the sensor and to develop ground processing systems to perform the more complicated corrections required for this instrument.

In 1984, France plans to launch the first of its SPOT series of satellites. A unique feature of SPOT will be the ability to point its scanners off nadir to provide more frequent coverage of selected sites than would be possible otherwise. Because of this pointing capability, the planning for data acquisition from SPOT will be much like that for airborne remote sensing missions.

Canada is developing plans to readout and process the data from both LANDSAT-D and SPOT. Other satellites will be developed in the future, and the readout of these will be carefully considered.

2. LANDSAT-D

In addition to the MSS, LANDSAT-D will carry a high resolution scanner, the Thematic Mapper. The important characteristics of this instrument, compared to the MSS are summarized in Table 1. Notice that the TM will provide seven narrow spectral bands covering four major regions of the spectrum: visible (bands 1, 2 and 3); near infrared (band 4); middle infrared (band 5 and 6); and thermal infrared (band 7). The resolution field of view (RFOV) (called Instantaneous Field of View or IFOV in the past) will be 30 metres on bands 1-6 and 120m for band 7. The spectral bands are all narrower than those of the MSS and the radiometric sensitivity is generally slightly improved. The quantization will be to eight bits or 256 levels as compared to six bits or 64 levels for the MSS. The finer resolution, increased number of spectral bands and greater quantization level results in an order of magnitude increase of data volume for approximately 190 megabits per scene to more than 2,000 megabits.

LANDSAT-D will be in a circular, sun-synchronous orbit at a 705 km altitude. The TM will scan a swath on the earth 185 km in width. The orbital repeat cycle will be 16 days and will follow the pattern depicted in Figure 1.

	Thematic Mapper (TM)		Multispectral Scanner Subsystem (MSS)	
	Micrometers	Radiometric Sensitivity (NEΔP)	Micrometers	Radiometric Sensitivity (NEΔP)
Spectral band 1	0.45 - 0.52	0.8%	0.5 - 0.6	0.57%
Spectral band 2	0.52 - 0.60	0.5%	0.6 - 0.7	0.57%
Spectral band 3	0.63 - 0.69	0.5%	0.7 - 0.8	0.65%
Spectral band 4	0.76 - 0.90	0.5%	0.8 - 1.1	0.70%
Spectral band 5	1.55 - 1.75	1.0%		
Spectral band 6	2.08 - 2.35	2.4%		
Spectral band 7	10.40 - 12.50	0.5K (NEΔT)		
RFOV		30M (bands 1-6) 120M (band 7)	82M (bands 1-4)	
Data rate		85 MB/S	15 MB/S	
Quantization levels		256	64	

Table 1 COMPARISON OF LANDSAT-D TM AND MSS SENSOR CHARACTERISTICS

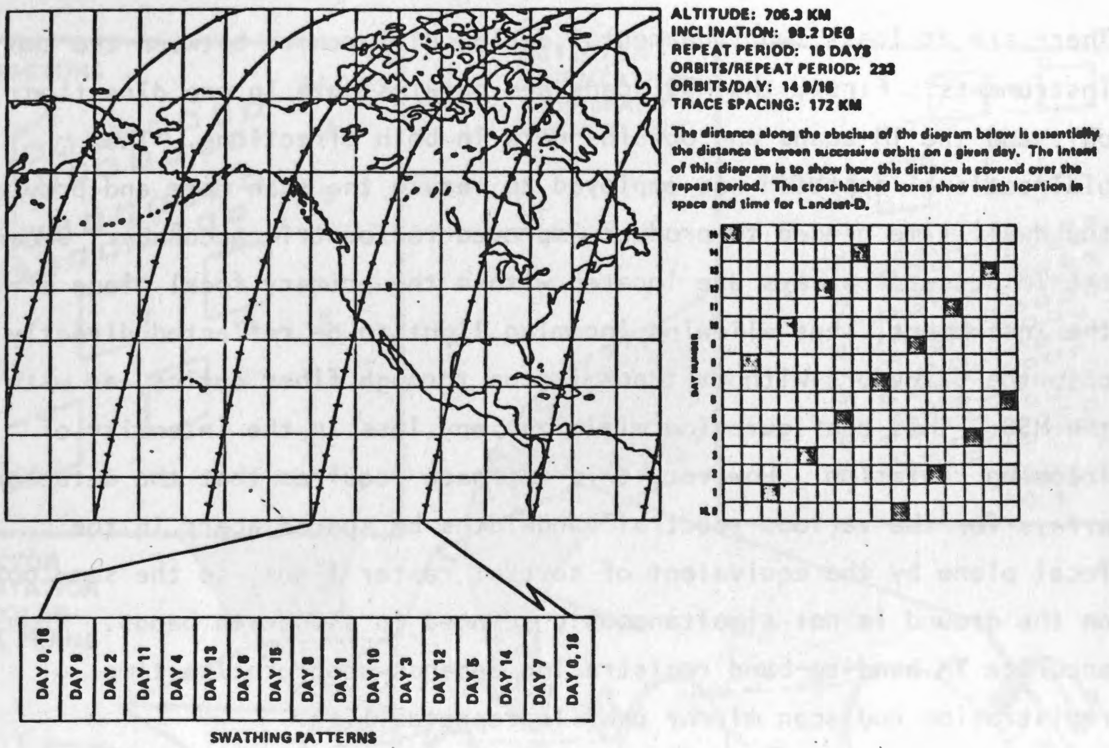


Figure 1 LANDSAT-D Orbit Characteristics

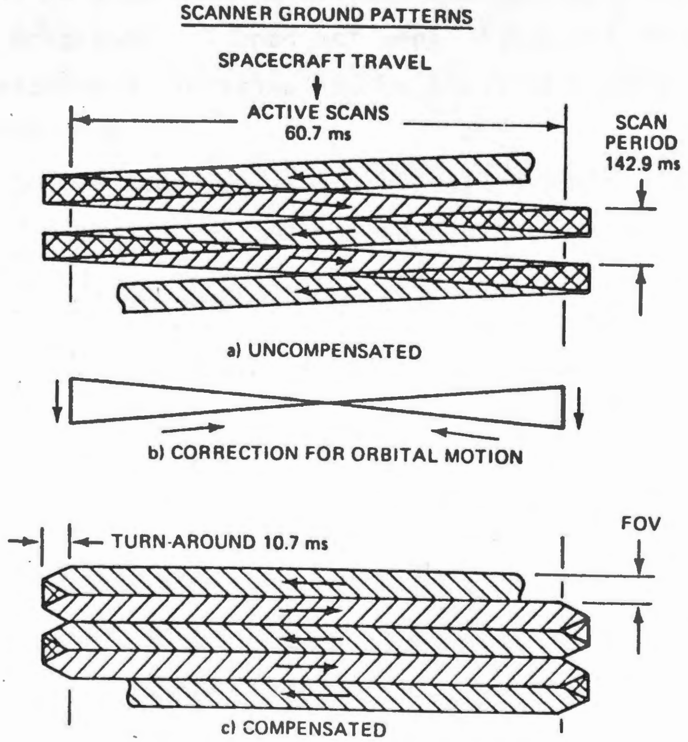


Figure 3 Scan Line Corrector Function

There are at least two fundamental design differences between the two instruments. First, the MSS scans and obtains data in one direction only and the TM scans and obtains data in both directions. The bidirectional approach was employed to reduce the scan rate and provide the dwell time needed to produce improved radiometric accuracy. Second, the TM detector arrays are located within the primary focal plane of the instrument, thus allowing incoming light to be reflected directly onto the detectors without transmission through fiber optics, as with the MSS. This configuration minimizes any loss in the intensity of incoming radiation. However, this approach requires that the detector arrays for the various spectral bandwidths be spaced apart in the focal plane by the equivalent of several raster lines, so the same point on the ground is not simultaneously scanned in all seven bands. Thus, accurate TM band-to-band registration depends upon precise time registration and scan mirror profile repeatability.

Figure 2 illustrates the construction of the TM, the layout of the detectors at the primary focal plane and the ground projection of the scan pattern. Each sweep of the mirror results in a scan of 16 raster lines for each of bands 1-6 and 4 lines for band 7. Each band is defined by an optical filter placed in front of its array of 16 detectors.

A scan line corrector preceeding the detectors compensates for the southerly drift of the array's swath due to the spacecraft orbital motion, so the scan lines will be straight and perpendicular to the ground track as illustrated in Figure 3 so that both directions of scan mirror motion can be used to obtain high scan efficiency. In MSS, only one direction is used. The seven sets detectors representing the seven different times, making time registration extremely important. In MSS, all detection for a given band image the same point at the same time. The result of this difference in design philosophy of the TM is that there will be systematic geometric erros which are more objectionable and more difficult to correct than has been the case with MSS. Thus, the first year of operation of the TM will be devoted to experiments to evaluate its data and to develop the algorithms and system to make these corrections.

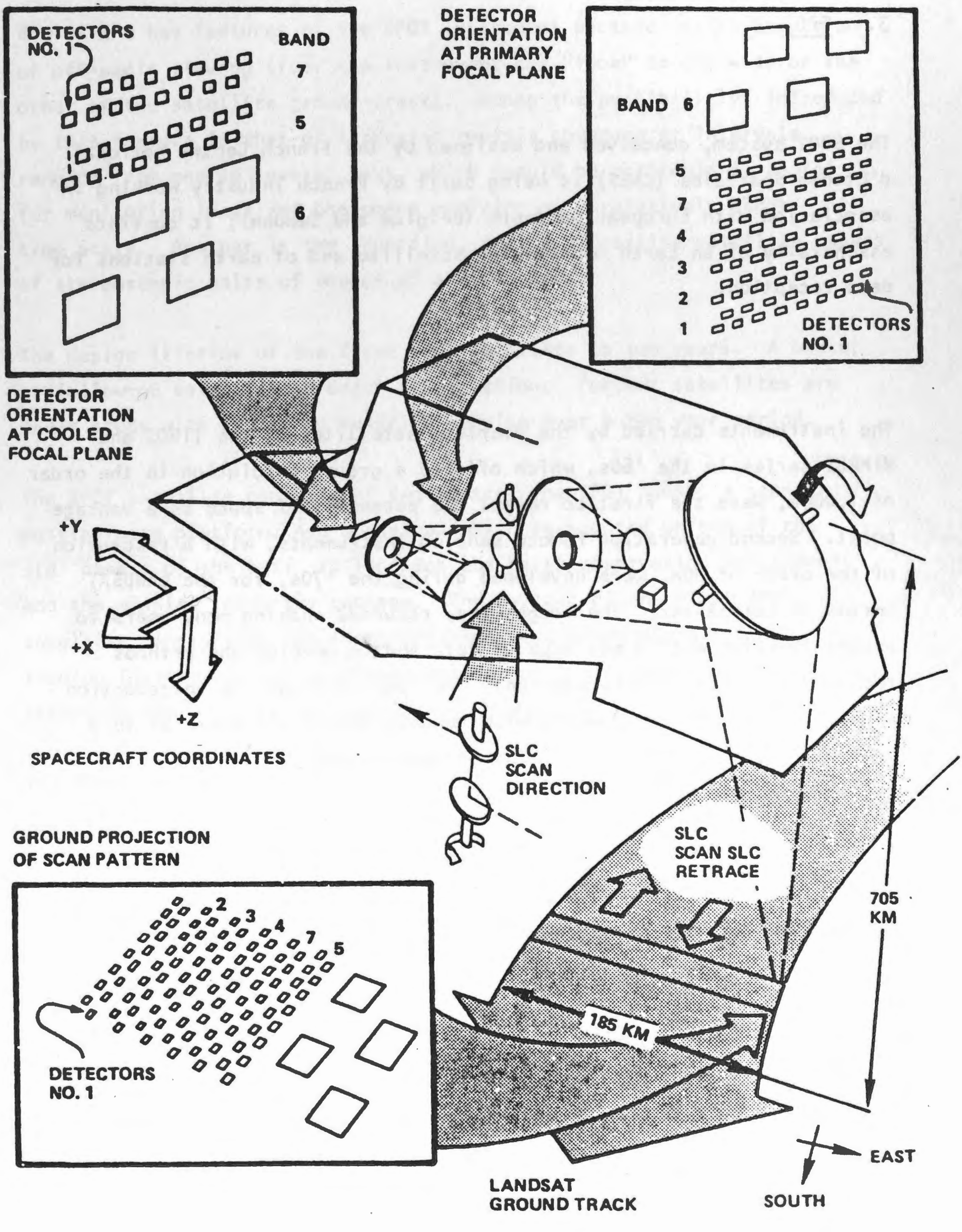


Figure 2 Detector Array Projects on Ground Track

3. SPOT

The SPOT system, conceived and designed by the French Centre National d'Etudes Spatiales (CNES) is being built by French industry working in association with European partners (Belgium and Sweden); it consists essentially of an Earth observation satellite and of earth stations for data reception.

The instruments carried by the American satellites of the TIROS and NIMBUS series in the '60s, which offered a ground resolution in the order of 1,000m, were the first to reveal the potential of space as a vantage point. Second generation remote sensing instruments, with a resolution of the order of 80m, were developed during the '70s, for the LANDSAT series of satellites. The images they returned enabled many users to become familiar with a new type of data and to develop the methods required for their interpretation. The '80s will see the introduction of satellite-borne instruments with resolutions of the order of 10 m which will open up many new fields of application.

The benefits of Earth observation data obtained from space are such that France decided in 1977 to go ahead with the SPOT programme and to plan for a 1984 launch date.

The first SPOT satellite will observe in three spectral bands (in the visible and near infrared portions of the spectrum) with a ground resolution of the order of 20 meters, and in a broader spectral band (panchromatic black-and-white) with a ground resolution of the order of 10 meters.

One of the key features of the SPOT instrument package is the provision of off-nadir viewing (i.e. the instrument can "look" to one side or the other of the satellite ground track). Among the possibilities introduced by this feature is that of increased revisit coverage at intervals ranging from one to several days, which should be particularly useful for monitoring localized phenomena evolving on a relatively short time scale. Another is the recording, during successive satellite passes, of stereoscopic pairs of images of a given area.

The design lifetime of the first SPOT satellite is two years. A backup or follow-on satellite is under construction. Further satellites are under study with a view to ensuring service over a ten year period.

The SPOT satellite consists of two parts: The SPOT "bus", a standard multipurpose platform, and a payload which is mounted on one of the side panels of the bus: it includes the Earth observation instruments and the mission telemetry package. The payload of the first SPOT satellite consists of two identical high resolution visible (HRV) imaging instruments and a package comprising two magnetic-tape data recorders and a telemetry transmitter (Figure 4).

The HRV instrument is designed to operate in either of two modes, in the visible and infrared portions of the spectrum:

- o a panchromatic (black-and-white) mode corresponding to observation over a broad spectral band, and;

- o a multispectral (color) mode corresponding to observation in three narrower spectral bands.

The instrument's sampling mesh corresponds to a ground element (pixel) that is 10 m X 10 m in the first case and 20 m X 20 m in the second,. for nadir viewing. This basic design decision was dictated by the small-scale subdivision of much of the agricultural land in many parts of the world and was also required for cartographic applications.

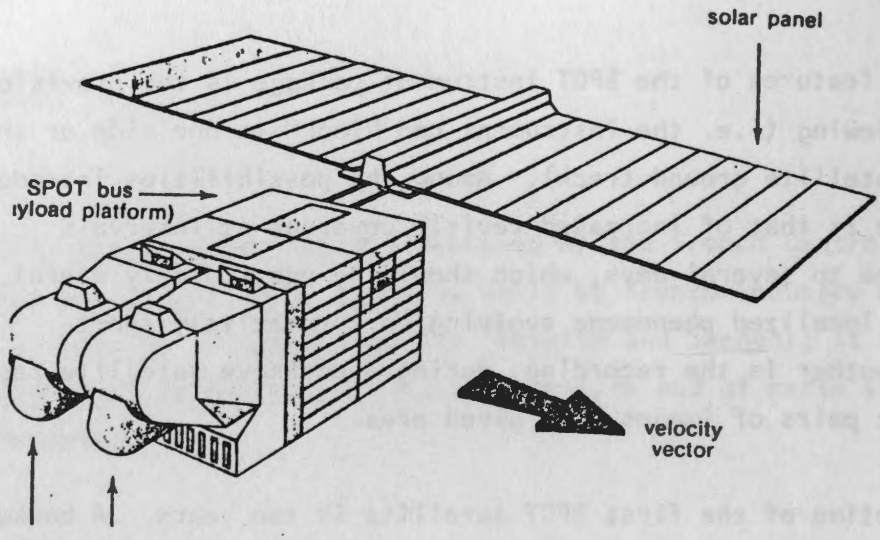


Figure 4

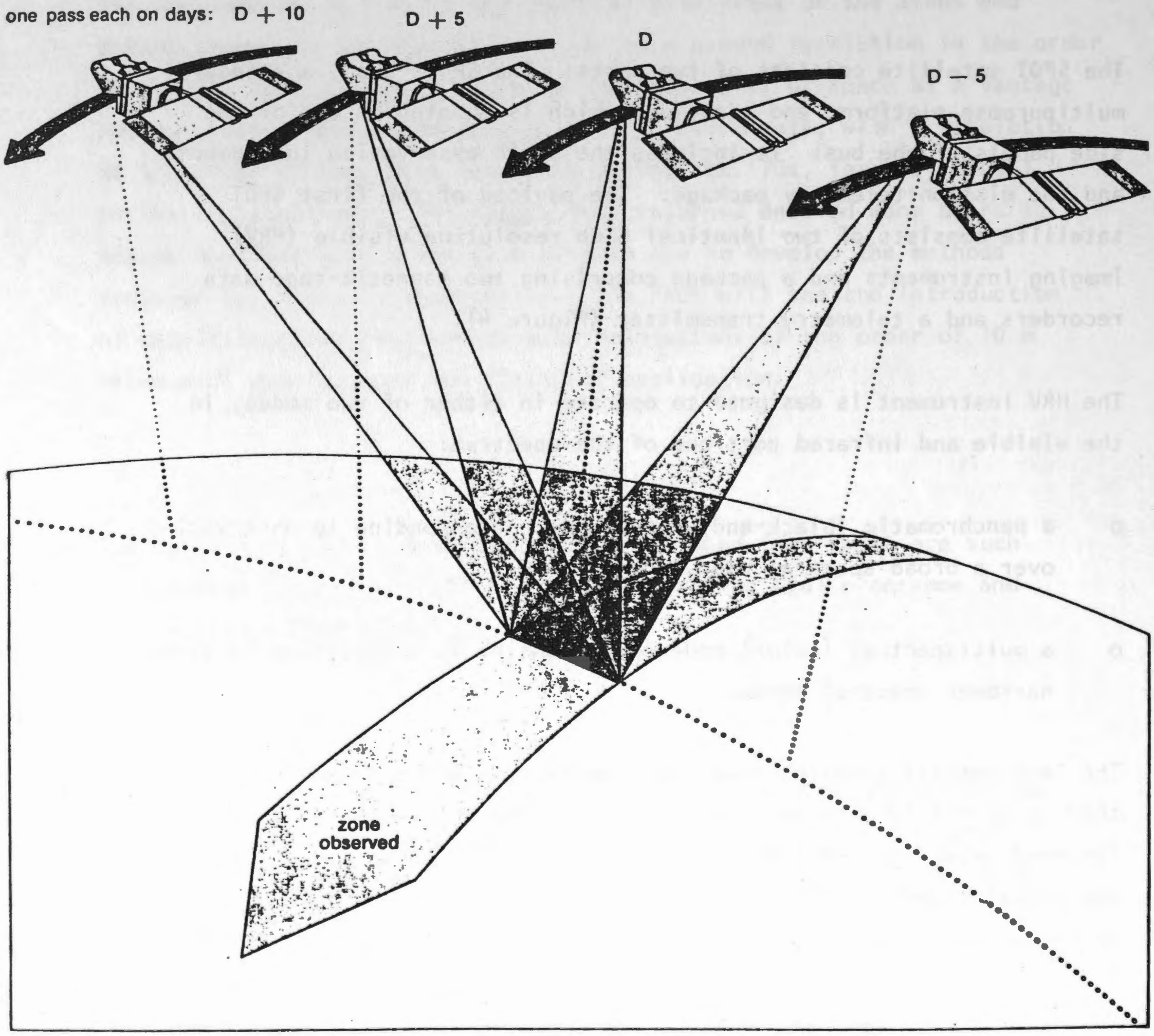


Figure 5

Light from the scene being viewed entered the HRV instrument via a plane mirror that is steerable by ground control. The viewing axis can thus be oriented as required in the plane perpendicular to the orbit. This off-nadir viewing capability covers a range of $\pm$ 27o relative to the vertical (in 45 steps of 0.6o each). This allows the instrument to image any point within a strip extending 475 km to either side of the satellite ground track. Because of the earth's curvature, the maximum viewing angle at the ground is 33^{o} from the vertical.

This off-nadir viewing capability, along with the high resolution, are two of the most innovative features of the satellite. Characteristics of the HRV are shown in Table 2.

The orbital altitude and the inclination of the orbital plane have been chosen so as to provide a sun-synchronous orbit. The orbital plane rotates about the Earth's axis, completing one revolution per year. The angle between the orbital plane and the sun direction is thus constant throughout the year. An important consequence is that for any given region of the Earth, the satellite always passes overhead at the same (solar) time, the actual time being determined solely by the latitude.

In its nominal orbit, the SPOT satellite will cross the descending node (or point of intersection of its South-going ground track with the equator) at about 10:30 a.m., and at 10:30 a.m. precisely on June 15 of each year. The local solar time of satellite passes over the day side of the Earth is represented in the graph below as a function of the latitude of the point concerned.

The satellite's motion is also synchronized with the daily rotation of the Earth in such a way that the pattern of successive ground tracks is repeated exactly at 26 day intervals. It is thus possible to observe a given region of the Earth at regular intervals under the same viewing angles.

Characteristics of the HRV instrument	Multispectral mode	Panchromatic mode
Spectral bands	0.50-0.59 μm	0.51-0.73 μm
	0.61-0.68 μm	
	0.79-0.89 μm	
Instrument field of view	4.13°	4.13°
Ground sampling interval (nadir viewing)	20 m × 20 m	10 m × 10 m
Number of pixels per line	3 000	6 000
Ground swath width (nadir viewing)	60 km	60 km
Pixel coding format	3 × 8 bits	6 bits DPCM (1)
Image data bit rate	25 M bits/s	25 M bits/s

Table 2

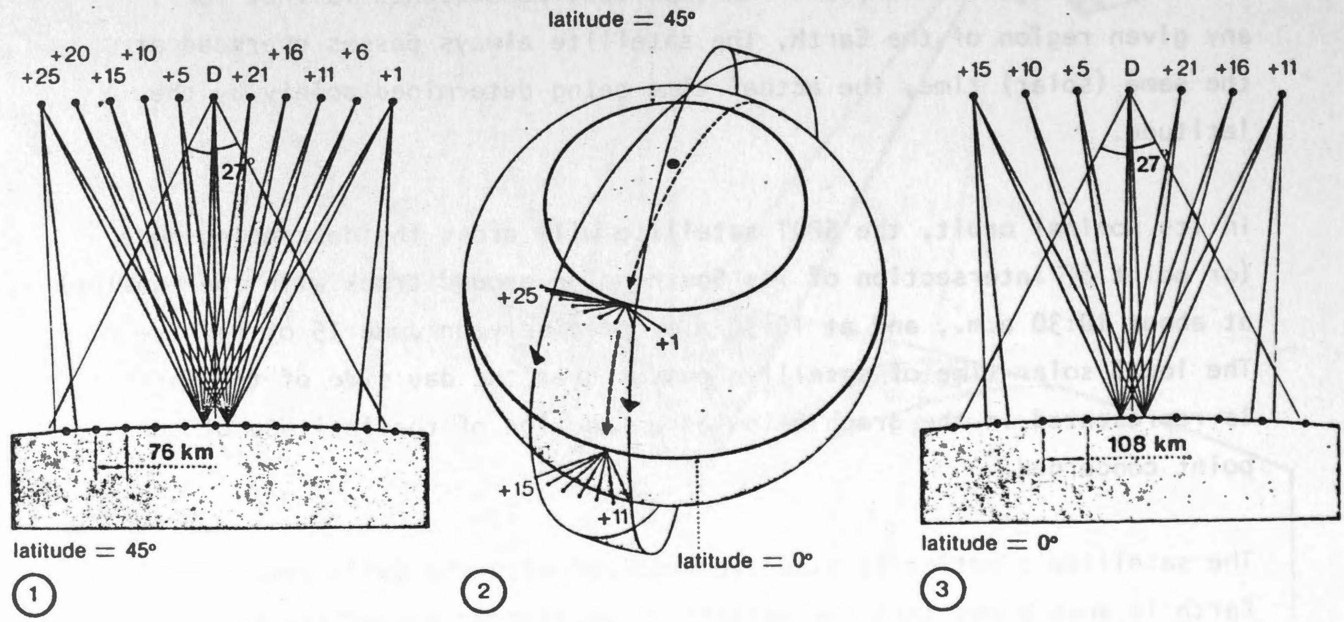


Figure 6

The two HRV instruments can be pointed so as to cover adjacent fields. In this configuration the total swath width in 117 km (nadir) and the two fields overlap by 3 km. Since the distance between adjacent ground tracks at the equator is approximately 108 km, complete Earth coverage can be obtained with this fixed setting of instrument fields.

By appropriately selecting the orientation of the pointing mirror, which is controlled from the ground it is possible to observe any region of interest within a 950 km wide strip centered on the satellite ground track, i.e., the observed region needs not necessarily be centered on the ground track.

The width of the swath actually observed varies between 60 km for nadir viewing and 80 km for extreme off-nadir viewing.

The program of observations to be made is controlled by the satellite's onboard computer. A sequence of recorded images may include both modes of instrument operation (multispectral or panchromatic mode) and changes in each instrument's viewing directions.

Were the satellite instruments only capable of nadir viewing, the revisit frequency for any given region would be 26 days.

This interval is unacceptable for the observation of phenomena evolving on time scales ranging from several days to a few weeks, especially where the cloud cover hinders the acquisition of useable data.

However, with SPOT, the capability for off-nadir viewing during satellite passes in the vicinity of a region of interest considerably increases the revisit possibilities, as shown in Figure 5.

What, precisely, are the revisit frequencies that can be achieved?

During the 26-day period separating two successive satellite passes over a given point on the Earth's surface, and taking into account the steering capability of the instruments, the point in question could be observed on 7 different passes if it were on the equator and on 11 if at a latitute of 45^{o}. More specifically, if the day on which the satellite first passes vertically over the point of interest is represented by D, then the same days on which this same point can be observed are as shown in Figure 6.

Another important possibility offered by the HRV instruments' off-nadir viewing capability is that of recording stereoscopic pairs of images of a given scene (i.e. images recorded at different viewing angles during successive satellite passes in the vicinity of the scene concerned).

Figure 6 shows that two observations can be made on successive days such that the two images correspond to pointing angles on either side of the vertical. In such cases, the ratio between the observation base (or distance between the two satellite positions) and the height (or satellite altitude) is approximately 0.75 at the equator and 0.50 at a latitude of 45^{o}. (See Figure 7).

The observation sequence is loaded every day into the onboard computer by the Toulouse ground control station while the satellite is within its range.

The viewing angles of the two instruments, the modes of operation (multispectral or panchromatic), the instants at which images are to be recorded, the mode of operation of the image data telemetry subsystem (direct data transmission or/and on-board recording) are controlled by the sequence. The operation sequences for the two HRV instruments are entirely independent.

An image receiving station can receive satellite telemetry when the satellite is within a "range of visibility" approximately 2600 km in radius. This corresponds to a satellite elevation of about 3^{o} above the horizon.

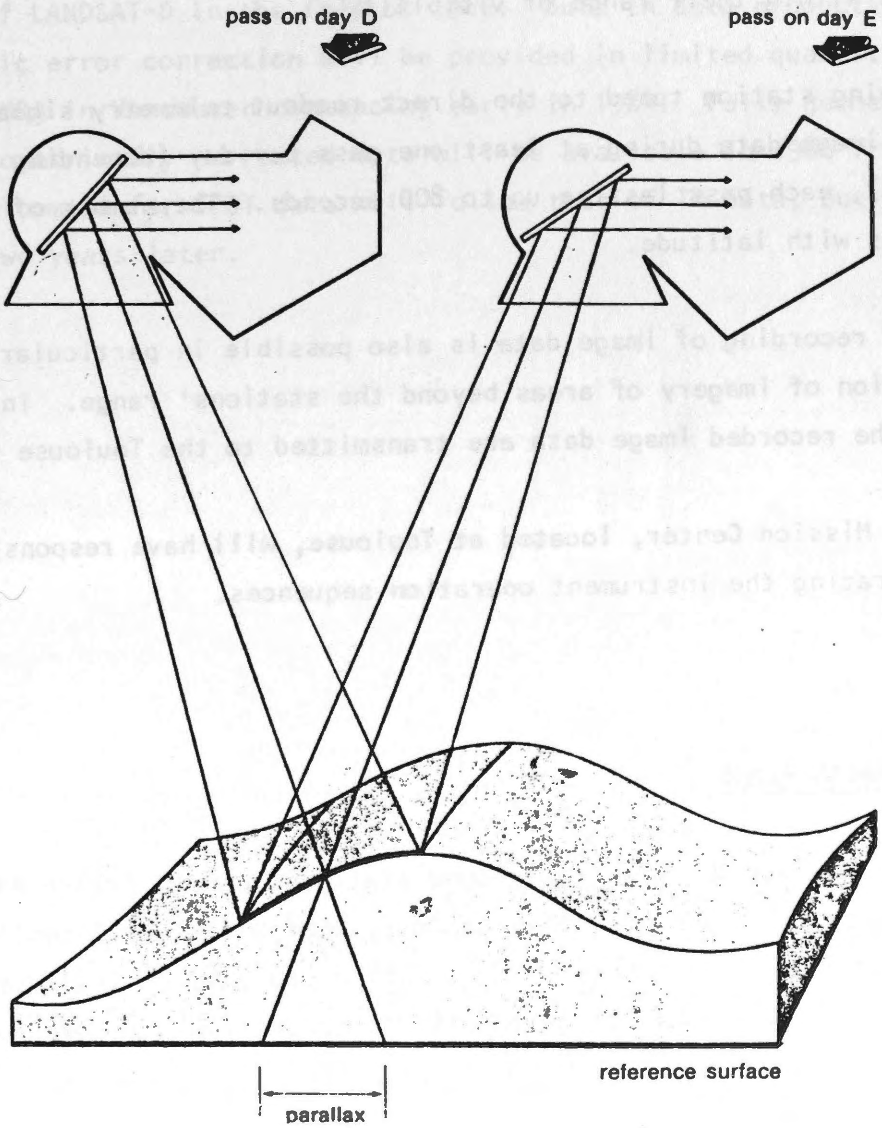


Figure 7

When activated, the satellite's "direct readout" telemetry transmitter transmits image data as it is gathered by the onboard instruments. This mode of operation permits receiving stations to acquire image data of areas within their range of visibility.

A receiving station tuned to the direct readout telemetry signal can receive image data during at least one pass per day (depending on its latitude), each pass lasting up to 800 seconds. The number of passes increases with latitude.

On board recording of image data is also possible in particular for the acquisition of imagery of areas beyond the stations' range. In such cases, the recorded image data are transmitted to the Toulouse station.

The SPOT Mission Center, located at Toulouse, will have responsibility for generating the instrument operation sequences.

4. CANADIAN PLANS

Currently, Canada operates two ground stations, one in Prince Albert, Saskatchewan and the second in Shoe Cove, Newfoundland. Recently, the United States sharply increased the station fees and restructured these in a manner which makes it very difficult to justify the continued operation of two LANDSAT reception facilities. Thus, CCRS is examining the following options: LANDSAT recording at Shoe Cove would be discontinued. To obtain maximum Canadian coverage from Canadian facilities, a receiving station could be built in Churchill, Manitoba. Present plans call for keeping the processing facilities at Prince Albert. NOAA recording and processing would remain at PASS and SCSS. The savings in capital not required to upgrade the SCSS would be applied toward the move to Churchill and the addition of SPOT readout capability.

Figure 8 shows the schedule for availability of LANDSAT-D and SPOT data in various forms from the Canadian facility. MSS and NOAA data will be available continuously. Limited amounts of raw TM data will be available from a transcription facility in Ottawa shortly after the launch of LANDSAT-D in the fall of 1982. Bulk TM data products, with systematic error correction will be provided in limited quantities through MDA in Vancouver commencing early in 1984. Fully geometrically and radiometrically corrected data will be available in 1986 from PASS. The development for SPOT data will follow that of TM data, but about one to two years later.

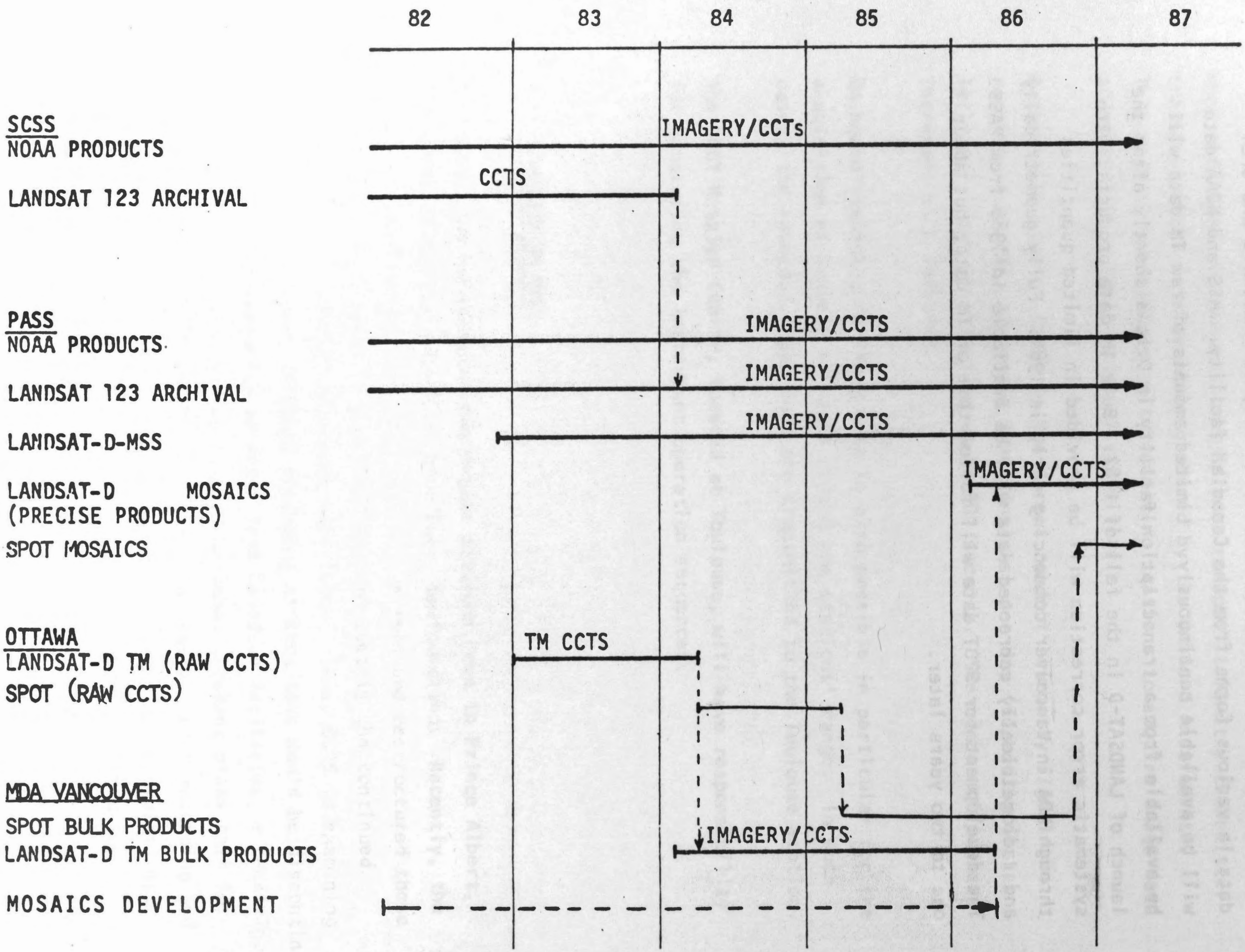


Figure 8 Data Processing Capability

RADARSAT - CANADA'S NATIONAL RADAR SATELLITE PROGRAM

R.K. Raney[1]

1 Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario K1A 0Y7

1. INTRODUCTION

Canada is embarked on a national program to plan, design, and implement a remote sensing satellite system whose prime sensor is a synthetic aperture radar (SAR). Perhaps unique in the world, Canada requires weatherproof operational environmental monitoring over vast regions, a requirement that can be met effectively only with a high resolution microwave imaging sensor such as a SAR. The driving need for this capability stems from the anticipated resource development activities in the Arctic Archipelago. This article outlines information needs and benefits as perceived by Canada, and describes the RADARSAT project as one response. It is anticipated that other radar satellites will be launched over the next decade (notably the European and the Japanese initiatives). Canada plans to use these opportunities as well for complementary remotely sensed data sources. All satellite radar data received in Canada will be processed in near real time, and suitably made available to users for operational purposes.

2. WHAT IS THE NEED?

Arctic Transportation

The most important application area in Canada for a spaceborne SAR is high resolution imagery of the Arctic available rapidly and under all weather conditions, particularly for resource development and shipping. This application is now of urgent concern in Arctic and East Coast centres because of two major marine transportation projects planned by industry in the 1980's.

The Arctic Pilot Project, sponsored by Petro-Canada, Nova, Dome, and Melville Shipping, plans to build two Arctic Class 7 icebreaker LNG tankers to bring gas from Melville Island through the Parry Channel, Davis Strait, the Labrador Sea to a port in Quebec or Nova Scotia. Sufficient gas reserves have been proven to maintain a schedule of 15 voyages per ship a year for a period of 20 years. A system study (1) by the sponsors on the needs of ice information to these ships have concluded that a radar satellite and radar equipped support aircraft are required. Hearings for the Arctic Pilot Project by the National Energy Board of Canada are in process and a decision is expected in Spring 1982. The sponsors are requesting a start-up of tanker traffic by 1986.

The Beaufort Sea Project is planning to spend $40 billion developing the oil and gas fields in the Beaufort Sea by 1990. Its sponsors, led by Dome, predict (2) an oil production rate of 500,000 barrels per day from two fields, Tarsuit and Kopanoar, by 1990. The oil would be transported by Class 10 ice-strengthened tankers year round to the Eastern seaboard. Their schedule calls for one tanker in 1986, and 8 active by 1990 with approximately 50 support and drilling vessels.

Whereas the industry development scenario for Beaufort oil may be optimistic, this is an important future source of domestic oil and every effort must be made to bring it into production. A recent estimate by Canada's Department of Energy, Mines and Resources of oil supply and demand for the 1980's projected 50 thousand barrels a day from the Beaufort Sea starting in 1988 rising to 150 thousand by 1990. This would call for one Arctic oil tanker operating in 1988 and 3 by 1990, somewhat less ambitious than industry estimates. Safe and economical navigation in ice-infested waters requires the ability to distinguish and map ice types and conditions over a sufficiently large area to permit effective strategic routing of the tankers. The Environmental Assessment Panel for the Arctic Pilot Project considers that a centralized source of information and control is essential to permit ships to navigate safely in the North-West Passage, especially on a year round basis.

Industry studies claim that the data is needed at least daily over the entire shipping route. The operational use of satellite SAR data to meet this need for near real time ice data is expected to confer benefits to shipping of some $90-$152 M per year by 1990, and $110-$182 M per year by 1994 through reducing shipping time, reducing operating and maintenance costs, as well as reducing costs (e.g. insurance) related to shipping hazards and environmental damage (3). This benefit does not include that realized by the tactical support that would be provided by aircraft and helicopters. The benefits suggested are based on the assumption that only the Arctic Pilot and Beaufort Sea projects will generate traffic over the expected five year life of the satellite. If production increases, the benefits attributed to SAR data would increase accordingly.

Land Applications

A wide range of information needs for agricultural, forestry, and water resource management could be met by SAR data from an operational satellite system (4). The visible and infrared sensors on LANDSAT and future satellites provide a wealth of information in several spectral bands. The SPOT sensors are scheduled to reach 10 m in resolution. However, these sensors can be hampered by cloud cover, thus impeding the monitoring of dynamic changes such as crop growth and hydrologic processes.

The microwave sensor is not affected by clouds and can complement visible/infrared data for applications which require reliable repetitive periodic coverage. This complementary feature as well as the unique characteristics of SAR allow a preliminary projection of $150 M in annual benefits to land resource management applications in Canada for satellite SAR data based largely on the extensive cost-benefit analyses that have been done for LANDSAT applications.

While SAR data may contribute this level of value to land resource management there is a wide variance in preferred radar frequency and coverage among the many potential applications. In view of the compromises that may result from the RADARSAT mission requirement studies, a lower figure, perhaps one-third or less of the $150 M annually, would be a more likely expectation by 1990. The highest benefits accrue to agriculture, for which management and inventory practices are more and more relying on remotely sensed data. Use of SAR data in conjunction with more conventional sensors provides the all-weather reliability required for operational use of these tools. There are major benefits expected in forestry as well, not only for Canada, but on a worldwide basis. Clearing and burning of tropical forests has potential implications for global climatic change so that monitoring the forests is of interest to all nations who may be able to stimulate improved resource management practices.

A need for new sources of geologic information for mineral and energy exploration can be met by SAR data with significant economic benefit. SAR data has been proven to be successful in highlighting geologic structures through topographical sensitivity. For example, gas field structures can be defined from associated surface fracture zones revealed by SAR. Since the data for most geologic applications requires only one set of data, geologists could use a single coverage of Canada by one satellite for many years after the satellite had ceased to function, allowing long term benefits to be derived. These could be in the range of $100 M based on the success rate for exploration using current practices.

Oceans

Relatively little research compared to the vastness of the field has been done on the application of SAR data to oceanography problems. There are some applications, however, where SAR data is expected to yield an economic return (5).

The deep water and heavy seas of the East Coast create difficult design problems for offshore platforms. If local wave conditions can be better understood through the use of SAR data then the design of the structures can be altered accordingly. A reduction of one foot of structure height would save about $1 M per platform, for example (4).

Small scale current features that would be measured by SAR will affect oil spill drift, sea ice movement and ship routing. If this special application is successful, the benefits to shipping activity could increment those gained from ice mapping by another $10 M annually. If development of Canadian East Coast energy proceeds rapidly this could increase to $50 M annually by the end of the five year lifetime of the satellite.

Other applications include the mapping and monitoring of "internal" waves that generate subsurface currents that present serious problems to the drill stems of drilling ships, and the monitoring of wave refraction and subsurface shoaling in areas of planned harbour construction and shoreline stabilization.

The total benefits of oceanographic applications to Canada is estimated at $75 M over the satellites' lifetime (4).

3. WHAT IS THE FINANCIAL BACKING?

The Treasury Board of Canada approved participation in ESA's Remote Sensing Preparatory Program on March 27, 1980 and a co-operative R & D program is now underway. In July 1980, Cabinet approved funding to conduct with NASA mission requirements and mission definition studies for a bilateral surveillance satellite program. The program is known as FIREX in the United States. A Letter of Understanding was signed with NASA in November 1980, and an interim report on U.S. and Canadian mission requirements was received on June 5, 1981. In April 1981, the Canadian Minister for Space Planning and Policy announced "a $17 M radar satellite preliminary development program which could lead to the provision of a remote sensing satellite using a new sensor which would provide day and night and all weather information on land and sea conditions.

Such a satellite would be particularly important in the provision of ice and sea state information required for safe efficient navigation in ice-infested Arctic and coastal waterways."

Thus, the RADARSAT program is solidly underway in the Phase A stage of development, and is encouraging bilateral and multilateral participation in this and related initiatives.

4. WHAT IS THE PROJECT?

There are three elements to the current project: mission requirements definition supported by aircraft SAR experiments; a Phase A concept study which analyses spacecraft and ground system alternatives that respond to the user requirements; and research and development of radar technology.

The objectives of the project are to:

Perform the Phase A technical and economic studies necessary to define a radar satellite implementation program that would provide a limited operational capability to supply timely ice information for selected Arctic or east coast operations, and provide research data and operational data to meet selected land and ocean requirements. The satellite payload consists of an imaging radar plus one or more of the following secondary sensors: scatterometer, optical imager, scanning microwave radiometer and altimeter.

Develop Canadian industrial expertise in spaceborne radar technology through a research and development program, so that a radar satellite including radar systems and major subsystems in space and ground processing can be built in Canada.

Develop program options for the satellite radar and secondary sensors, including international cooperation with other space agencies or companies, and cost sharing arrangements with domestic and foreign data users.

While the principal mission motivation for the program is sea-ice reconnaissance, other applications will not be neglected as highlighted. Both the Canadian and U.S. groups are working to define the applications that can utilize radar satellite data and to recommend complementary sensors for the mission based on knowledge gained from previous microwave satellite and aircraft experiments. A final report on the team's recommendations is to appear early in 1982. In addition, an economic study is underway to determine the ice and oceans operational requirements of government and industry and to recommend policy alternatives for sharing ongoing operating expenses of the program.

The overall concept for the Canadian radar satellite (RADARSAT) program is shown in Figure 1. It is an end-to-end system that starts with a satellite in an inclined polar orbit transmitting signals from its wide swath SAR to ground receiving stations, where the data is converted into digital images. The image data is relayed via communications satellite (ANIK) to an ice-information centre, where other data such as from aircraft SAR or weather satellite is incorporated to provide a forecast of ice conditions. The forecast is again relayed by communications satellite to the tankers and other users in the form of annotated images.

The spacecraft will consist of a 3-axis stabilized platform with sufficient power and weight capacity to carry a C-band or L-band SAR and complementary microwave or optical sensor. In addition the transponder for search and rescue missions might be carried. Preliminary studies of existing spacecraft buses have shown that there are several which could be adapted for this mission. The spacecraft would be designed for a 3-5 year life, with further spacecraft launched depending on the user needs and success of the program. Three or four satellites would be needed to provide an operational service from 1990-2000. The baseline parameters (6) for the radar payload are a swath of 150 km or greater with a resolution of 25 to 30 meters at 4 looks and an incidence angle of 30o to 45o. Preliminary orbit studies have shown that with this swath width it is possible to obtain twice-daily coverage over the primary Arctic transportation corridor, the North-West Passage. Figure 2 shows coverage obtained from the preferred orbit.

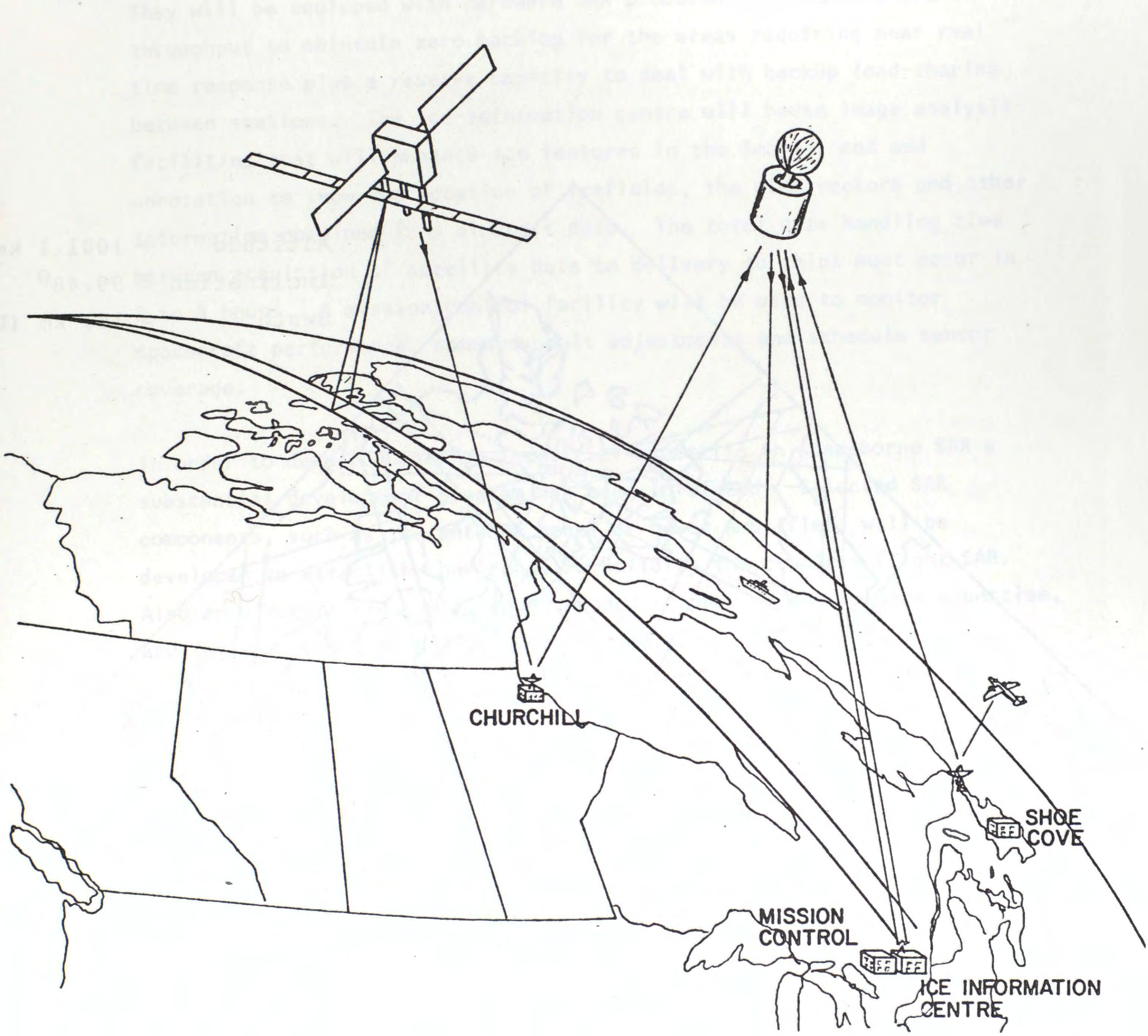
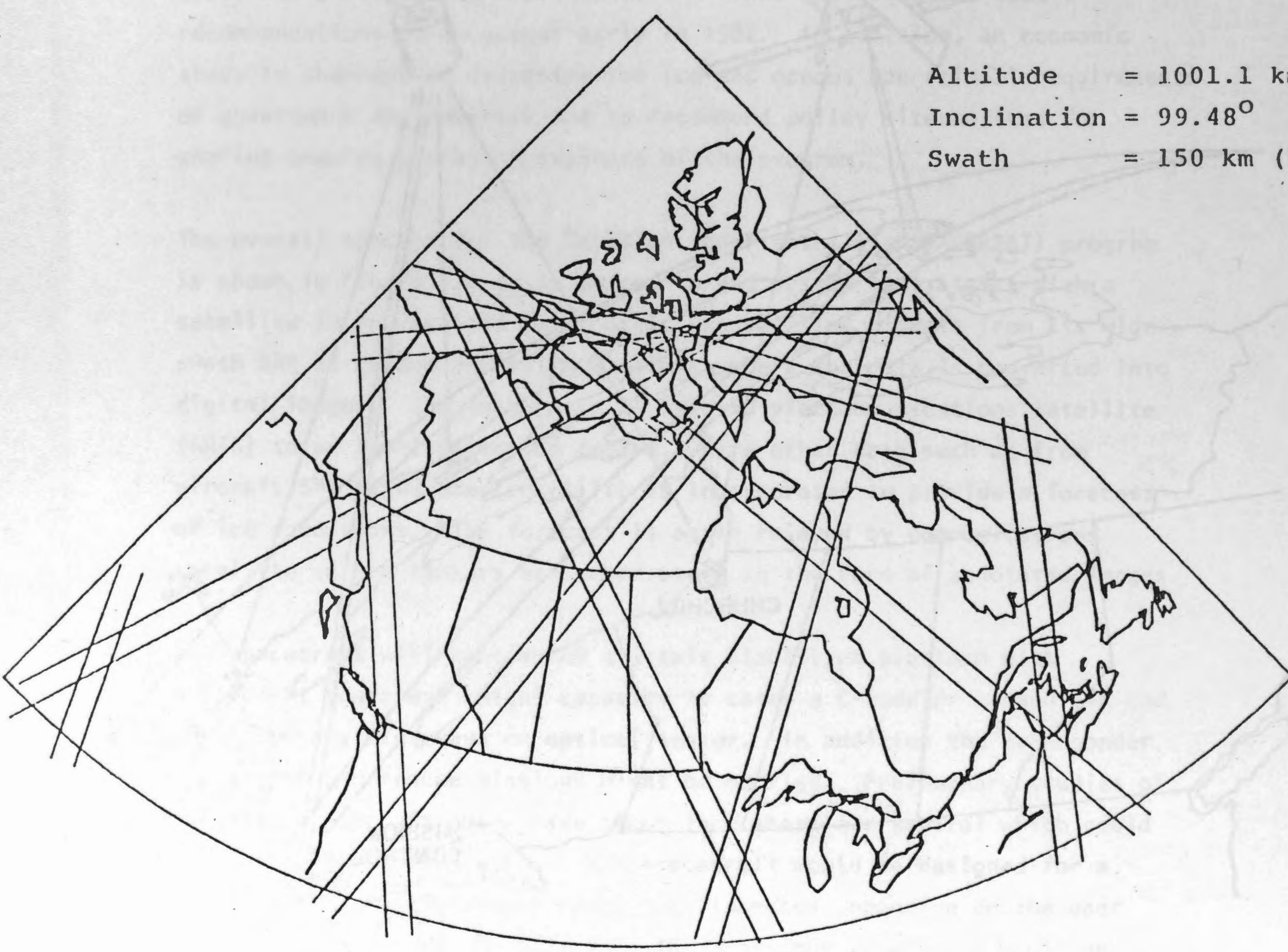


Figure 1   The Radarsat System



ELEVATED SUN SYNCHRONOUS ORBIT/C-BAND RADAR
1 DAY OF ASC. PLUS DESC. PASSES - 3 DAY SUBCYCLE

Figure 2 Optimised Arctic Coverage - Sun Synchronous

Direct telemetry will be sent to three Canadian ground stations. They will be equipped with hardware SAR processors, with sufficient throughput to maintain zero backlog for the areas requiring near real time response plus a reserve capacity to deal with backup load-sharing between stations. The ice-information centre will house image analysis facilities that will enhance ice features in the images, and add annotation to show the location of icefields, the wind vectors and other information obtained from aircraft data. The total data handling time between acquistion of satellite data to delivery to ships must occur in 2 to 4 hours. A mission control facility will be used to monitor spacecraft performance, command orbit adjustments and schedule sensor coverage.

In order to develop Canadian industrial expertise in spaceborne SAR a substantial development program has been initiated. Selected SAR components, such as the antenna panel or power amplifier, will be developed to establish confidence in building the complete flight SAR. Also an aircraft radar will be developed to provide SAR systems expertise, and for use in the satellite support role.

5. WHAT IS THE BACKGROUND?

Since 1976 a serious effort has been made in Canada to concentrate on synthetic aperture radar (SAR) as the primary sensor to provide information over the frozen and open oceans bordering Canada, and in support of information needs in forestry, geology, hydrology and agriculture.

During the period 1977 to 1979 through its SURSAT project, Canada participated in the NASA SEASAT program, acquired the ERIM multi-channel SAR, modified it, and installed it in a Convair 580 aircraft. Despite the early failure of SEASAT, 35 SAR orbits were recorded at Shoe Cove and 80 SAR orbits obtained over western Canada from U.S. recording stations. The aircraft flew over 530 hours in fulfilling the data acquisition needs for approximately 100 experiments. The majority of the aircraft SAR data was optically processed.

The project supported the development of the MDA (MacDonald Dettwiler and Associates Limited) digital SAR processor, which continues to set the standard of excellance for SEASAT SAR imagery world-wide.

6. WHAT ARE THE TECHNICAL ISSUES?

There are two dominant technical concerns facing the project: data processing and technology development.

The driving requirement for the project is operational, which implies that the time required to process to high quality imagery from raw data received in real time should be no slower than 4 times real time. This appears to be a feasible objective; there is currently a contract with MDA (Canada) to produce a detailed design of the required processor, with plans to build a subswath prototype processor within the next two years.

The frequency of the radar was selected in January 1982 to the C-band (wavelength of 5.7 cm), based on studies by users of the C-band and L-band data available from the CCRS airborne radar, and on a cost/risk study by industry of the relative merits of the two alternative frequencies. There now remains the task of developing the detailed system design and required spaceborne technology to support the mission. Whereas it is now known that a C-band system is feasible at only moderate risk, a great deal of work is yet to be done to bring the project into maturity.

7. **OUTLOOK**

The current project is planning for a RADARSAT launch in 1990, with an estimated cost on the order of $300 M. This is an ambitious program and unlikely to reach fruition unless there are offsetting contributions from industry and other international initiatives. The project is actively talking to ESA, NASA, other nations and the oil and gas industry in Canada to negotiate satisfactory cost sharing. Early indications are promising. The results of these negotiations will be incorporated in the Phase A documentation late in 1982, which will form the basis of Phase B development and final project definition in 1983 and following years.

REFERENCES

1. LNG Tanker Strategic Routing Study, Ivatech Resources Limited, and Leigh Instruments Limited, April, 1981.

2. Development of Beaufort Sea Hydrocarbons - An Opportunity for Canadian Industry, M.B. Todd, Dome Petroleum Limited, "Frontier Oil and Gas - The Decade Ahead", Montebello, April, 1981.

3. Potential Benefits of Satellite Radar Data in Support of Arctic Activities, A. McQuillan, 1981.

4. RADARSAT Preliminary Mission Requirements Document, June, 1981.

5. Oceanography from Space, Edited by J.F.R. Gower, Plenum Press, New York, 1981.

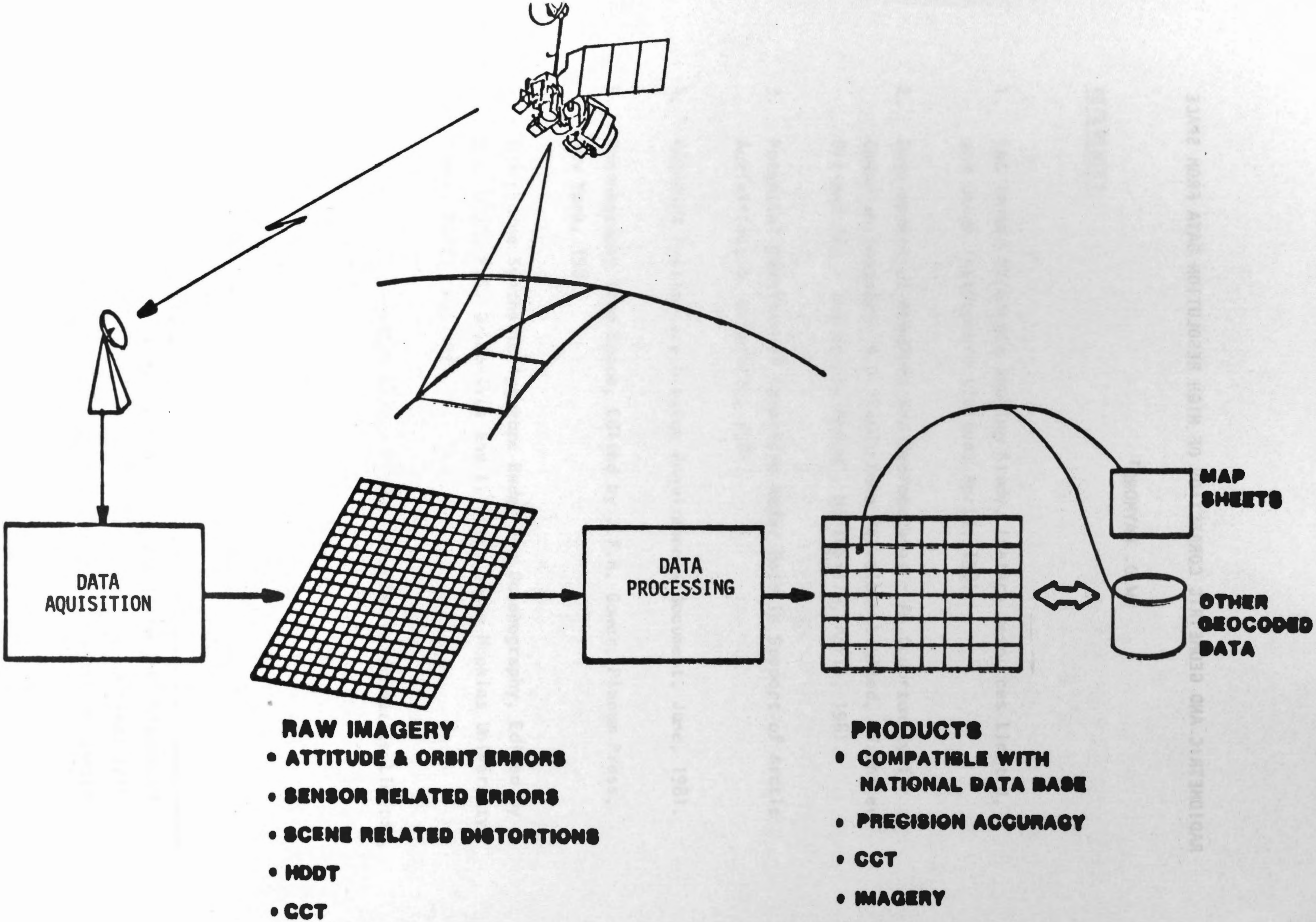
6. Spaceborne Synthetic Aperture Radar for Oceanography, Edited by R.C. Beal, P.S. DeLeonibus and I. Katz, Johns Hopkins University Press, Baltimore, 1981.

7. SURSAT - A Conceptual Design Study, Canadian Astronautics Limited, March, 1980.

RADIOMETRIC AND GEOMETRIC CORRECTION OF HIGH RESOLUTION DATA FROM SPACE

W.D. HAYMOND[1]

1 MacDonald, Dettwiler and Associates Limited
3751 Shell Road
Richmond, British Columbia V6X 2Z9


DATA AQUISITION
RAW IMAGERY
• ATTITUDE & ORBIT ERRORS
• SENSOR RELATED ERRORS
• SCENE RELATED DISTORTIONS
• HDDT
• CCT
DATA PROCESSING
PRODUCTS
• COMPATIBLE WITH NATIONAL DATA BASE
• PRECISION ACCURACY
• CCT
• IMAGERY
MAP SHEETS
OTHER GEOCODED DATA

LEVELS OF CORRECTIONS

1. Radiometric Corrections

2. "Bulk" Geometric Corrections

   - resampling in the along-scan direction only

3. "System" Geometric Corrections

   - two dimensional resampling

   - geometric transformation calculated using spacecraft orbit, onboard attitude measurement system and sensor characteristics known prior to the pass

4. "Precision" Geometric Corrections

   - two dimensional resampling

   - geometric transformation calculated using ground control points in addition to other available data

5. Terrain Corrections

   - requires digital terrain model

1. RADIOMETRIC CORRECTIONS

1.1 Logarithmic Decompression

- If sensor data is logarithmically compressed on the spacecraft prior to transmission, then it must be decompressed during ground processing.

1.2 Sensor Non-Linearity

- Detector response is approximately linear. Deviations are corrected by using a look-up table derived from pre-launch test data.

1.3 Absolute Detector Calibration

- One detector per band is adjusted using data from the calibration signal.

1.4 Radiometric Striping Removal

- Histograms are collected and corrected to remove non-linear effects (saturation).

- All other detectors in the band are adjusted to match the absolutely calibrated detector, using the histograms.

1.5 Sun Angle Correction

- Sun elevation varies with latitude and with the season, and affects the intensity of the light radiated by the ground.

1.6 Haze Removal

- Atmospheric haze (including pollution) may add a bias to the received light intensity.

1.7 Failed Detector Compensation

- Final image quality may be poor due to failure of one or more detectors. It may be necessary to compensate for a failed detector by substitution of other detector data.

1.8 Film Gamma Correction

- Image data to be recorded on film is adjusted to compensate for radiometric non-linearities in the film recorder system.

2. "BULK" AND "SYSTEM" GEOMETRIC CORRECTIONS

2.1 Spacecraft Position

- Image framing is performed using the station time code track recorded on HDT. This requires that spacecraft position be accurately known as a function of time.

2.2 Band-to-Band Misregistration

- The detectors for different spectral bands are physically separated in the spacecraft sensor array. Due to this, the first pixel from one band represents a different point on the ground than the first pixel of another band, and cannot be overlaid.

2.3 Detector Delay Within a Band

- Within a spectral band the detectors are sampled at different times and may also be physically displaced. Due to this, they represent slightly different points on the ground.

2.4 Scan Line Length Variations (MSS, TM)

- The electronic sampling of the detectors is derived from a quartz crystal which is relatively stable.

- The rocking mirror in the sensor may change frequency slightly during operation due to temperature or aging effects. This results in a change in line length.

- Scan line length may change during a satellite pass (by one or two pixels) or during the sensor lifetime (by five to ten pixels) or from one sensor to another "identical" sensor (by 30 or 40 pixels).

2.5 Mirror Scan Non-Linearity (MSS, TM)

- Mirror velocity during the scan is not constant, and has a non-linear profile. This is corrected using a nominal mirror scan profile.

2.6 Panoramic Distortion

- Ignoring earth curvature effects, pixels at the start and end of the scan represent a larger ground area than pixels in the centre of the scan due to the changing observation angle. This is a two-dimensional problem and is sometimes referred to as the "bow tie" effect.

2.7 Earth Curvature

- Due to earth curvature, pixels at the start and end of the scan represent a larger along-scan ground distance than pixels in the middle of the scan.

2.8 Spacecraft Altitude/Velocity

- Changes in spacecraft altitude result in a change in image scale. Altitude changes occur during an orbit due to the oblateness of the earth and can occur gradually over time due to orbit decay or suddenly due to adjustment of spacecraft orbit.

- During an orbit, the oblateness of the earth results in a change in spacecraft altitude between a pole and the equator and causes a corresponding change in spacecraft velocity. This is corrected by changing the along-track scale of the image.

2.9 Earth Rotation

- The earth is rotating during the imaging operation. The combination of the earth's rotation and the inclination of the orbit results in a vertical scale change which remains constant throughout the pass. In the along-scan direction, each scan line is displaced with respect to the next. This displacement is a function of latitude and is maximum at the equator and minimum at the poles. For latitudes in between, the result is a combination of along-scan shift and across-scan scale change.

2.10 Spacecraft Roll

- Constant roll angle has no effect other than moving scene centre.

- Changing roll angle causes a varying along-scan shift of lines and is corrected using one-dimensional resampling.

2.11 Spacecraft Pitch

- Constant pitch angle has no effect other than moving scene centre.

- Changing pitch angle changes spacing between mirror scans in the image. Correction requires resampling in the vertical direction.

2.12 Spacecraft Yaw

- Constant yaw angle causes each scan line to be rotated by a constant amount which results in a skewed image. This distortion is approximately one-dimensional and is corrected by resampling in the along-track direction.

- Changing yaw angle causes each scan line to be rotated by a different amount. This distortion is still approximately one-dimensional and is corrected by resampling in the along-track direction.

2.13 TM Jitter

- Landsat-D has a flexible spacecraft structure which will likely be caused to vibrate by the TM mirror motion. As a result, the point at which the TM unit is joined to the spacecraft will be vibrating, causing a "jitter" in the pointing of the TM sensor. This will show up in the image as a two-dimensional jitter.

- The along-scan component of the jitter will be a smoothly varying pixel displacement which can be corrected by resampling.

- In the across-scan direction, the sixteen sensor lines in a mirror scan will be displaced together. Between scans there may be overlap or a gap of one or two pixels. Since, for large gaps, the ground data is not sampled, true correction cannot be achieved. Only cosmetic smoothing or interpolation is possible.

2.14 TM Stitching

- Forward and reverse scans are not parallel, but follow a zig-zag pattern. For nominal spacecraft altitude, an optical "scan line corrector" will make the forward and reverse mirror scans parallel.

- As the spacecraft deviates from nominal altitude, a residual overlap and gap will occur.

3. "PRECISION" GEOMETRIC CORRECTIONS

3.1. Ground Control Points (GCPs)

- Points indentified in an image for which the map coordinates are known.
- Points are selected based on easy identification both in the image and on the map - highway interchanges, small islands, small lakes.
- There is a residual error which is caused by map inaccuracy, map measurement error and image measurement error.

3.2 Registration Control Points (RCPs)

- Points are used to register one image with a previously processed image.
- Points are selected based on easy automatic correlation - do not need to be identifiable on a map.
- The absolute accuracty of the second image is determined by the absolute accuracy of the reference image plus the registration error.

3.3 Geometric Model Error

- The model parameters are estimated from GCPs and/or RCPs.
- Excluding GCP and RCP errors, there is an error caused by approximations inherent in the model.

4. TERRAIN CORRECTIONS

4.1 Geometric Terrain Correction

- Terrain effects combined with spacecraft look angle result in a pixel displacement in the along-scan direction.

- The pixel displacement appears as a high frequency "jitter" in the along-scan direction.

4.2 Radiometric Terrain Correction

- Terrain effects change the sun angle and increase or decrease the reflected radiation.

- In extreme terrain, shadows occur.

TABLE 4-1 ESTIMATED ACHIEVABLE PROCESSING ACCURACIES (very approximate)

Sensor	Radiometric Accuracy		Relative Geometric Accuracy (excluding terrain error)				Geometric Terrain Error	Nominal Map Scale
	Relative Intraband	Relative Interband	Absolute	Bulk Corrected	System Corrected	Precision Corrected		
MSS-1,2,3,	2%	3%	10%	800m	800m	80m	0-240m	1:250,000
MSS-D	2%	3%	10%	160m	120m	80m	0-320m	1:250,000
TM	0.5%	3%	10%	90m	60m	30m	0-300m	1:100,000
SPOT MLA	1%	3%	10%	100m	100m	25m	0-80m	1:100,000
SPOT LA	1%	N/A	10%	100m	100m	20m	0-1000m	1:100,000

TOPOGRAPHIC MAP REVISION USING SATELLITE IMAGERY

E.A. FLEMING[1]

ABSTRACT

Landsat imagery is being used effectively to provide revision information for 1:250 000 maps and change detection for 1:50 000 maps in the National Topographic Series of mapping. Offshore features such as islands and shoals have been positioned using the CCRS DICS products and this type of digital imagery has been used for the automatic extraction of lake information for small scale maps on an experimental basis.

1. Topographical Survey Division
Department of Energy, Mines and Resources
615 Booth Street
Ottawa, Ontario K1A 0E9

1. INTRODUCTION

Topographic maps are a form of inventory of the earth's surface, and, like any inventory, they must be kept up-to-date if they are to be useful. The map scales for which the Topographical Survey Division is responsible are the 1:50 000 and 1:250 000. The latter scale, with 918 maps, is the largest scale offering complete coverage of Canada. The 1:50 000 series is now 66% complete and total coverage is anticipated by 1992. Considering both scales there are, today, 9491 maps entered into revision cycles and the number is increasing at the rate of about 400 maps per year.

In a country as large as Canada, and with the resources for mapping limited, it is essential that these resources are used in the most effective manner. Many advances have been made in recent years to accelerate the production of new maps, but revision mapping has remained the labourious process of collecting information on change from many sources and obtaining and analyzing new aerial photography. Because of the inability to predict how many changes will be required on a map sheet before all the data are collected, production planning of revision work is difficult.

However radical changes in approach are now on the horizon, as the impact of Landsat imagery analysis on revision planning is being studied in an operational mode for both the revision and the monitoring of revision requirements of Canada's two principal topographic map scales.

In addition, the digital image correction techniques that are now available for Landsat make it possible to use this imagery for positioning offshore features in the U.T.M. coordinate system.

And if one does a little crystal ball gazing, one can foresee the use of this digitally corrected imagery to produce the water separation negatives for small-scale mapping.

2. REVISION REQUIREMENTS: 1:250 000

The 1:250 000 map series for Canada was completed in 1970 with an updating program already in effect. The rate of updating maps has never kept pace with the rate prescribed by revision cycles for urban (10-year), rural (15-year) or remote (30-year) areas.

In remote areas where the bulk of the maps lie (685 maps) changes will tend to be limited to the development of settlements and the construction of roads, pipelines, power lines or reservoirs. Many sheets will show no change whatever in a 30-year interval. It is in this area that the use of Landsat imagery can have its greatest impact.

In 1980, a two-year development contract was awarded to Gregory Geoscience Limited who had done the Landsat interpretation on an initial test (Moore, Gregory 1979). The purpose of this contract, which is being carried out in close cooperation with the staff of Topographical Survey, is to develop operational techniques leading to the revision of 1:250 000 maps from Landsat data.

To move from feasibility studies to operational techniques means that many things aside from the interpretation of the Landsat imagery must be considered, although this also requires extended consideration. It is known for example that change detection is reliable where some type of forest cover exists, but as the vegetative cover diminishes it seems likely that the reliability of Landsat as the primary source of revision information will also diminish. It is therefore necessary to classify the terrain areas of Canada where Landsat is effective before it is possible to incorporate these techniques in revision programs on a long term basis.

The information extracted from Landsat must also be coded in a consistent manner that is meaningful to the map compiler, and the completeness and accuracy of the final revision must be verified. Although this is a routine process for 1:50 000 mapping, techniques for carrying out such work over the area of a 1:250 000 map have not been considered in the past. Again, new standards and effective procedures must be evolved before this change in revision method can be considered operational.

Landsat Revision Techniques, 1:250 000

During 1980 two 1:250 000 maps were revised using Landsat data as the primary source of information.

The first step in this process was to obtain the latest and best imagery of the area, both MSS and RBV, black-and-white and colour. These were interpreted by optical projection of the imagery on to the map base to detect and delineate change. Simultaneously all published 1:50 000 maps were examined for changes that could be derived for the 1:250 000 map. Combining the data from both sources lead to a composite revision overlay of new roads, power lines and clearings. The information from the rather spotty coverage of the 1:50 000 maps confirmed the Landsat interpretations and helped identify features.

The revision overlays were field checked by an interpretation team from both Gregory Geoscience and Topographical Survey. The check was carried out primarily by light aircraft. Since the test sheets were in the coastal area of British Columbia it was found that the full-time attention of one interpreter was required to keep track of the exact location of the aircraft in the mountain valleys and to guide the pilot, while the other interpreter checked the completeness of the revision and identified features where necessary. The flying was done at 1500 ft above ground, this being a reasonable compromise between having enough time to see things and still being close enough to verify their identity. From this on-the-spot verification road classes could be determined, uncertainties of interpretation resolved, and any more recent changes incorporated in the revision.

With the experience gained from these two maps, the application of the technique is being tested in other regions having different geographic characteristics. These include coastal areas, interior rangeland, mountains, Precambrian Shield country and forested lowlands. In all, revision is being attempted on 58 additional maps during 1981. Eleven of these are within the 15-year cyclic revision area and 47 are in a 30-year cycle.

3. REVISION REQUIREMENTS - 1:50 000

At present there are in the neighbourhood of 900 maps in the 1:50 000 map series that are passed their scheduled revision date. The current rate of map revision is sufficient to prevent this number from increasing but not sufficient to reduce the backlog and bring the total series on-cycle. The development and operational application of Landsat change detection techniques will enable Topographical Survey to markedly increase the number of maps revised each year, to such an extent that it is expected to have the series on-cycle within 5 years.

4. MAP REVISION APPROACH USING LANDSAT - 1:50 000

In the change detection study carried out in 1979 it was found that although 1:50 000 maps could not be fully revised from Landsat data, the change detection was complete for this scale. This information alone can provide those planning map revision programs with a powerful two-pronged tool. It is immediately possible to separate those maps which require new aerial photography for revision from those maps in which no change has taken place and where new photography would serve no useful mapping purpose. Additionally, since change detection was complete in the test area, it is possible to re-validate the maps to the date of the Landsat imagery on which no change was detected.

As with the use of Landsat for 1:250 000 mapping the completeness of the change detection will vary with the geographical area, and those areas where change detection will be most profitably carried out must be delineated for 1:50 000 mapping. Figure 1 shows the present assessment of the areas in Canada where Landsat can be used for revision mapping purposes.

Revision Planning Techniques - 1:50 000

To study the impact that Landsat change detection could have on 1:50 000 map revision planning, Gregory Geoscience undertook to carry out change detection analysis of 535 maps in 1980 prior to their inclusion in the 1981 revision program. This analysis (Moore et al, 1980) was completed in 4 months, including the time required to obtain Landsat imagery. Forty-four maps were dropped from the project because of delays in obtaining imagery, but of the remaining 491 sheets, it was found that 222 evidenced no change whatever, 70 maps had localized or linear changes for which revision information could be obtained by strip photography and only the remaining 199 maps evidenced enough change to warrant full photographic coverage.

By using this information in planning the 1981 photographic requirements it is possible to concentrate efforts where the photography is most needed. This is particularly important since many of these maps lie in an area of notoriously poor photographic weather where in the normal course of events it takes several years to complete block coverage.

The areas selected for this evaluation were those where change detection was known to be effective due to the vegetative or forest cover. The maps that evidenced no change are therefore justified in having their validity dates changed to the date of the Landsat images used in the study.

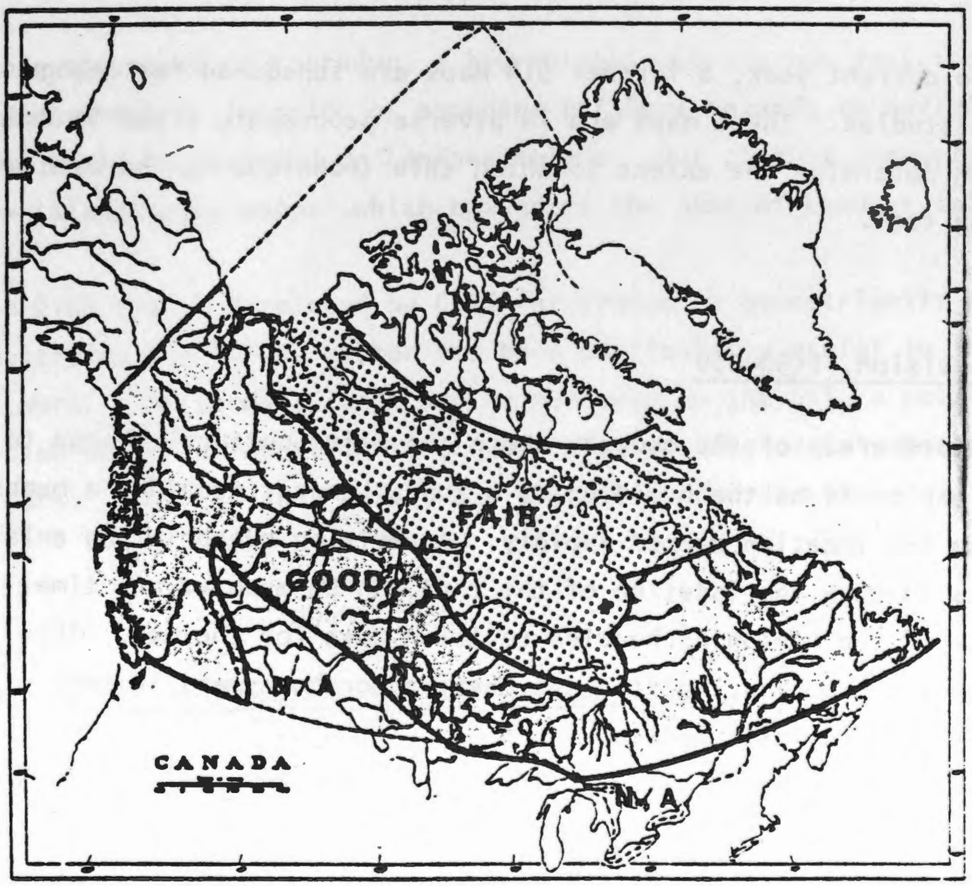


Figure 1

Suitability of Landsat Imagery to Revision Mapping

N/A Landsat techniques are either not applicable or are questionable

There are inevitable compromises that must be made in this approach to re-validation. One of these is the mapping of isolated habitations - cabins, houses or buildings. Changes in these features would never be detected on Landsat imagery and perhaps not even on aerial photography. Thus the correctness of these features after re-validation cannot be relied on, and marginal map notes will acknowledge this fact.

During the current year, a further 514 maps are scheduled for change detection studies. These maps are in diverse geographic areas in order to further determine the extent to which this technique can be used as a planning tool.

Interim Revision, 1:50 000

In the remote areas of the country where the major cultural change to affect a map could be the building of a road, Landsat provides a means of getting its location mapped rapidly. A revision overprint on existing map stocks to show the location of the road can be made at any time, regardless of the nominal scheduled revision date for the map. This then becomes a practical approach to keeping northern maps current between lengthy revision cycles.

5. ISLAND LOCATION USING DICS

Positioning offshore features by stereophotogrammetry presents problems because of the water gaps involved. The broader picture and the essentially orthogonal projection that can be achieved with a Landsat image has provided a fresh approach to this mapping problem.

As a result, islands in Ungava Bay have had their locations revised, the islands in Dubawnt Lake have had their positions verified for the new 1:50 000 mapping, The azimuth of a small island in the Bay of Fundy was checked, in the forlorn hope that, instead of falling at the intersection of four 1:50 000 maps, it might be swung off at least one of them.

Along the coast of Labrador, a hydrographic survey was assisted by the photogrammetric location of apparent offshore hazards to navigation that could be detected on Landsat images. Out of this survey came a new island to be mapped which now bears the name of Landsat Island.

The DICS system developed by CCRS for producing geometrically corrected imagery in the U.T.M. system has been particularly useful in this type of work. The Landsat image can be observed on the CRT, a point can be picked which is identifiable on the corresponding aerial photograph, a cursor moved to that point, and the U.T.M. coordinates of it printed out.

6. AUTOMATIC FEATURES EXTRACTION FROM LANDSAT

Space imagery is digital. In this form it can be readily manipulated for feature extraction. It is now possible to select a map feature such as water, produce a DICS computer tape of this feature by contrast stretching, which can then be used to operate a scanning microdensitometer or raster scanner that automatically produces a water separation negative for a small scale map. This would make it possible for us to correct the quite erroneous portrayal of the water areas of Canada as they currently exist on our small scale maps.

7. CONCLUSIONS

Operational methods for the effective use of Landsat Imagery in the map revision programs of Canada's two major topographic map series are being successfully developed.

The 1:250 000 scale map series can now be revised independently of the 1:50 000 series for many parts of the country. The planning of aerial photography can be optimized so that those 1:50 000 maps showing most changes are given the highest priority, and by reducing the total amount of photography in any one area, the probability of completing it in a single photo season increases.

In addition, improvements in the positioning of islands have been achieved, and automatic feature extraction for mapping is on the horizon.

REFERENCES

Fleming, E.A., "The Use of Satellite Photography in the National Topographic Mapping Program of Canada". Commission IV W.G. 2 of the proceedings of the X111 Congress of the International Society for Photogrammetry, Helsinki, July 1976.

Fleming, E.A., "Positioning Off-Shore Features with the Aid of Landsat Imagery". Photogrammetric Engineering and Remote Sensing, Vol. 43, No. 1, January 1977.

Fleming, E.A. and Lelievre, D.D., "The Use of Landsat Imagery to Locate Uncharted Coastal Features on the Labrador Coast". Proceedings of the Eleventh International Symposium on Remote Sensing of Environment. ERIM, 1977.

Fleming, E.A., "Change Detection by Landsat as a Guide to Planning Aerial Photography for Revision Mapping". Commission IV W.G.4 of the Proceedings. 14th Congress of the International Society for Photogrammetry, Hamburg, July 1980.

Moore, H.D., Gregory, A.F., "The Use of Landsat Images for Revising Topographic Maps". Prepared under EMR Contract OSQ79-00018. December 1979, Ottawa.

Moore, H.D., Jeffery, C., Turner, A., and Thirlwall, S. "Change Detection with Landsat Images as a Guide for Acquiring Aerial Photography to Revise 1:50 000 Topographic Maps". Prepared under EMR contract OSQ80-00060, December 1980, Ottawa.

REFERENCES

Fleming, E.A., "The Use of Satellite Photography in the National Topographic Mapping Program of Canada", Commission IV-WG 2, of the proceedings of the XIII Congress of the International Society for Photogrammetry, Helsinki, July 1976.

Fleming, E.A., "Positioning Off-Shore Features with the Aid of Landsat Imagery", Photogrammetric Engineering and Remote Sensing, Vol. 43, No. 1, January 1977.

Fleming, E.A. and Lelievre, D.D., "The Use of Landsat Imagery to Locate Uncharted Coastal Features on the Labrador Coast", Proceedings of the Eleventh International Symposium on Remote Sensing of Environment, ERIM, 1977.

Fleming, E.A., "Change Detection by Landsat as a Guide to Planning Aerial Photography for Revision Mapping", Commission IV W.G.4 of the Proceedings, 14th Congress of the International Society for Photogrammetry, Hamburg, July 1980.

Moore, H.D., Gregory, A.F., "The Use of Landsat Images for Revising Topographic Maps", Prepared under EMR Contract 04SU-OSS73-00018, December 1979, Ottawa.

Moore, H.D., Jeffery, C., Turner, A., and Thirlwall, [illegible] Detection with Landsat Images as a Guide for [illegible] Photography to Revise 1:50 000 Topographic [illegible] contract 05080-00060, December 1980, [illegible]