RESOURCE SATELLITES AND REMOTE AIRBORNE SENSING FOR CANADA

REPORT NO. 13

OBSERVABLES AND PARAMETERS OF REMOTE SENSING

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CONTENTS

FOREWORD

The original purpose of this report was to develop a listing of observables and parameters of remote sensing that would be useful to the designers of instruments and sensing systems. The basic data were derived from the literature and personal interviews with users in a broad range of disciplines. During the course of this work, the writer became increasingly aware of the need to establish some frame of reference within which both observables and parameters could be viewed in perspective, relative to the management and control of resources and environments. Although the writer's search and knowledge of the vast literature on remote sensing was admittedly limited, an attempt at a systems engineering approach to the application of remote sensing for management was not uncovered. For this reason, the original theme of the report was recast in an effort to develop such a framework, and thus provide more meaning to the lists of observables and parameters appearing in the Appendices.

The result is no more than a first effort to bring together the various elements of remote sensing activities into an interactive flow sequence that couples with the decision processes of management. The writer has been quite arbitrary in certain terminology, and while an attempt was made to standardize terms that are commonly used in the remote sensing community, many persons will unquestionably take exception to the use of some. Furthermore, the writer acknowledges that several of the concepts need further development and refinement. They have been presented in a somewhat cavalier fashion in places principally to provoke discussion and debate. If it succeeds, it will have accomplished the purpose for which it was intended.

This report is submitted as a discussion paper, and reflectes only the views of the writer. In no way does it necessarily represent the position, beliefs or policy of the Canada Centre for Remote Sensing, or of its Director.

1. INTRODUCTION

This report examines the processes whereby resources and environments are managed, and attempts to portray the role played by remote sensing. While the ultimate destiny of remote sensing is in its use as a management tool, there are many other "users" of the technique including scientists, interpreters, engineers and planners. During the course of studies conducted by the user working groups, covered in reports Nos. 2 to 8 inclusive in this series, it became evident that there was a need to relate the user to the remote-sensing-system designer, because the two groups often use different language and concepts. The user thinks in terms of parameters that will fit the model of the process he is managing or studying, whereas the remote-sensing-system designer has to work with the observables that can be derived from instrument measurements. Thus there is a need to form a bridge between these two groups.

This report is written principally for instrument designers and inventors - those concerned with data acquisition, and those involved with the planning and marketing of remote-sensing services. It has certainly not been written for the user working groups who prepared the other reports in this series - those concerned with data interpretation. However, their contributions have been used extensively and the writer acknowledges with appreciation the time contributed by the user group Chairmen in personal interviews.

The writer had great difficulty in dealing with such a wide range of disciplines. Unquestionably, their treatment in the appendices leaves much to be desired, but there must always be some trade-off between completeness and time consumed. Furthermore, the main purpose of the report is not to develop long, protracted lists, but rather to establish concepts and develop a framework for future planning of remote-sensing systems and services.

As a result of recent Treasury Board directives, government departments are becoming more and more benefit oriented. Remote sensing is particularly well suited for benefit analysis because, when it is used as a management tool, it is usually possible to quantify the resulting benefits directly in terms of dollar cost savings. In the long haul, benefits from remote sensing only accrue when applied to the management of resources or environments. Thus the study starts by examining resource and environmental management.

For the present purposes management is defined, somewhat arbitrarily, as the process whereby decisions are reached to alter the future condition of a resource or environment by human action or decree. To make these decisions rationally, it is necessary to forecast the most likely effects that will result from a number of possible decision alternatives. For this reason, managers employ models in some form or other.

A model provides a mechanism for predicting the future condition of a resource or environment, and can be thought of as consisting of an arrangement of parameters that define its physical state. The arrangement or model can be represented mathematically, physically or even mentally; but it is so designed that the manager can derive quantitative information from it in a form that is meaningful and helpful in arriving at decisions for action - such information has been termed "decision variables".

Parameters of the model, in turn, must be derived from observables - those physical quantities that can be measured directly or derived from imagery. In general, observables can be accepted by the model directly, and thus become parameters without the need for conversion. These concepts of models, parameters and observables are central to the study.

Figure 1 portrays, in block-diagram form, the flow of information involved in most management processes. It employs terminology developed and used in this report. The study focusses on those concepts embodied in the diagram, and the reader is invited to refer to it as required. Following a description of resource and environmental management in Section 2, in which several examples are presented, models for management are examined as to their alternative forms and the various ways in which they are used by managers. Parameters and models are treated next which leads to the key problem of parameter conversion - the principal bottleneck and impediment to the more widespread use of remote sensing. Then the entire management process is studied in order to gain a better understanding of the interaction among all the elements. Data acquisition, handling and interpretation are treated individually, in line with the major activities of the Canada Centre for Remote Sensing (CCRS).

The use of remote sensing usually involves relatively large capital investments, and Section 6 in this report is devoted to economic considerations wherein benefit criteria are used to establish priorities for the Centre. The promotion of remote sensing among users is a "marketing" activity of CCRS, and a benefit-conscious approach is advocated in Section 7.

Finally, Section 8 summarizes the salient points of this report. Seven appendices list the main parameters and remote-sensing observables under each of seven discipline groups.

2. RESOURCE AND ENVIRONMENTAL MANAGEMENT

Essentially, resource and environmental management is the process whereby decisions are reached to alter the present state of a resource or environment by human action or decree. As will be seen from the examples presented in this Section, it can assume almost an infinite variety of forms. Such management functions exist in both the public and the private sectors of our economy, and can involve a tremendously wide range of disciplines. In order to execute the management function, information is required in two forms. One form is the present and predicted physical state of the resource or environment - arbitrarily termed decision variables. The other is the economic and socio-political impact of the resource or environment on society - arbitrarily termed decision factors. In general, decision variables can be quantified; whereas decision factors normally cannot be presented numerically unless they exist in the form of laws or regulations.[1]

To help fix ideas, a few examples are given - chosen from among the disciplines covered in the present series of reports:

1. <u>Agriculture</u> - An example in the field of agriculture could be the management of a crop pesticide spraying program. Here the decisions involve what pesticides to spray, when, where and how; and they cannot be reached until there has been an assessment of *variables* such as pest infestation - type and extent, species and vigour of the crop to be sprayed, its stage of growth, soil, water and weather conditions, etc. Some of the *factors* that could influence the decision would be the environmental impact of spraying, the economic plight of farmers in the areas to be sprayed and the cost of spraying.

2. <u>Geography</u> - A significant example would be the management of land use for urban expansion. Here there is a very complex web of cross-disciplines involved, but the decisions take the form of zoning bylaws and land appropriations for public projects such as airports, utilities, government buildings, etc. The decisions depend on a variety of *variables* such as topography, drainage, soil type and trafficability, proximity of housing and other ecumene, and local climate. Obviously, political and sociological *factors* enter the decision process and often dominate the entire issue.

3. <u>Atmospheric Constituents</u> - The management of air pollution levels in an urban area is a typical case. The decision to order the closing down of industrial air polluters depends upon *variables* such as particulate and gaseous pollutant counts, derived from on-line monitors using either immersion or remote-sensing devices, and atmospheric conditions. Other *factors* could alter or affect the decision, such as the economic losses incurred by the industries involved, and the loss of time and income incurred by workers. However, laws normally exist that set the criteria for closing down polluters, and so the law becomes the major factor influencing the decision.

4. <u>Forestry, Wildlands and Wildlife</u> - The complete management of a pulpwood forest involves a host of decisions such as when, where and what to cut and re-seed, what fires to fight and where, how and where to irrigate or alter water courses, where to locate mills and townsites, roads and powerlines, etc. The decision *variables*

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1. Decision factors and variables are shown in Figure 1 entering the block entitled "Decision Process".

would include present and predicted inventories, assessments of hazards and damage, and data such as land and soil conditions, watershed status and weather predictions. As before, other *factors* enter the decision process such as legal limitations and requirements, environmental impact of each decision, and the socio-political pressures arising from within and from neighbouring jurisdictions.

5. Water Resources - The management of water levels in a system feeding a major shipping channel is an interesting situation. The decisions take the form of dam control in each of the feeding systems, and the decision *variables* are the water levels in the channel, and the storage volumes available in the feeding systems translated into their influence, as a function of time, on the water level in the channel. A major *factor* influencing such decisions could be the political pressures brought to bear by cottage-owners on the lakes feeding the system, who wish their water levels to remain stable.

   A second example in water resources is an interactive management situation involving a government, a company and a community. The decision was whether or not to close a paper mill because it was polluting the river on which it was situated. In this case the pollution was despoiling the environment, the local wildlife and, of course, the biological processes in the river. By law, the plant should have been closed. The decision *variables* were the biological and chemical states of the river - but here, other *factors* were much stronger. The entire community depended on the mill for its existence - closing it would have been tantamount to destroying the community. In spite of the law, the community decided to keep the mill open. In this case, decision variables had virtually no influence on the decision. There are many resource and environmental management situations where decision variables play a minimal or zero role in the ultimate decision process.

These examples of resource and environmental management have several features in common:

(a) The primary output of management is a decision to alter the present state of the resource or environment by human action.

(b) Management receives two primary inputs on which it must base its decisions - decision variables defining the present and predicted future state of the resource or environment, and decision factors reflecting the economic and socio-political impact of the resource or environment as judged by society and its laws.

The art of such management is to blend the two principal inputs into the decision process so as to achieve stability and maximum satisfaction to those who have designated and empowered the management authority.

This report deals principally with the derivation of the decision variables, and the ultimate role to be played by remote sensing. The next section shows that decision variables must be derived from some model of the resource or environment - and model building is a key element in the whole management process.

3. MODELS FOR MANAGEMENT

Managers need to know the physical state of the resource or environment for which they have responsibility. Such information must be in terms that relate directly to the factors over which they have control. We have called such quantities "decision variables". In some cases they can be measured directly, such as in local air pollution control; but generally, they must be derived or inferred from a knowledge of the mechanisms at work (physical, chemical or biological), and the physical qualities that can be measured readily.

For example, in controlling the water level in a shipping channel, it is necessary to understand how it is influenced by water levels and flow rates in the storage system. In this case, the relationships between individual dam heights and flow rates, and their future effect on channel depth, are mechanisms that must be understood thoroughly for water-level management to be effective. Such mechanisms become extremely complicated, and man must resort to some form of model to assist him in understanding the inter-relationships that exist between dam heights and water level in the shipping channel as a function of time.

3.1 Types of Models

The model can take many forms. If the mechanisms are relatively simple, it need be no more than a mental understanding of the processes involved. The manager develops a physical "feel" of the situation, often acquired over years of experience, and performs an effective job without the need to build elaborate models of the resource or environment he is managing. Perhaps most present management practices in the resource field involve this form of model.

When the mechanisms become too complex for a mental model, frequently it can be depicted mathematically or physically. A mathematical model can be stored readily in a computer; this becomes absolutely essential when the model is used in association with high data rates. Physical models are small-scale replicas of the resource or environment, and often have the advantage of not requiring a thorough knowledge of the mathematical relationships between the various characteristics or parameters. Often, however, there is a danger in scaling physical processes without a thorough scientific understanding of the physics, chemistry and biology involved. Furthermore, many phenomena cannot be replicated in small scale.

Whatever form the model takes, its degree of perfection usually is a function of its complexity. In the water-level management situation described in Section 2, the model could be either mathematical or physical. If physical, it could be as simple as a geometric (three-dimensional) replica of the water basin system feeding the channel. But no matter how perfectly such a model depicts the topography, it likely would not be feasible to include hydrological processes such as groundwater ingress into the system and meteorological effects resulting in precipitation. Thus such physical and mathematical models will almost always fall short of simulating the real world.

Just how imperfect the model will be is an engineering decision - a trade-off between modelling costs and adequacy for practical management purposes. In the past, such decisions have erred on the side of simplicity, for environmental impact was not taken into consideration in many management decisions. Environmental modelling recently has beome a major undertaking by many resource management agencies, and such models must be woven integrally into the fabric of future resource models.

3.2 How Models are Used - The Need for a Data Bank

Models have a temporal aspect that is important to recognize. Principally, models are built in order to predict the future. The management function is a future-oriented activity - the generation of decisions to take action and thus alter the future state of the resource or environment. Thus models are used to answer "what if..." questions posed by various decision alternatives. For example, the model for water-level management could answer the question, "What would the channel depth be at specific times in the future if a certain dam in the storage system were lowered by two feet?"

Such questions are continually being asked in the management process, and the model is used to provide the answers. The validity of the answers can only be established by real-time experience - and when there are serious deviations, the model must be altered, extended or up-dated. Thus integral with model-building is the need to store past data derived from real-time experience. A repository for such information, termed a data bank, is an essential ingredient of any model for management.

For mental models, the data bank is the manager's memory - derived from his experience. For mathematical and physical models, such data can be stored in a form suitable for a computer, or in tabular or graphical form on paper. In the case of water-level management, the data bank could store such historical information as:

a) Previous year's precipitation amounts and patterns in the water basin.

b) Storage water-level variations with time for previous years.

c) Dam height - flow relationships over the range of seasonal variation for the existing dams in the system.

By and large, predictions must be developed from past experience, and real-time data must be smoothed in the process of extrapolation. Thus data withdrawn from the data bank and used in the model must be smoothed by criteria determined by the model.

3.3 Inputs and Outputs

We define as parameters the physical quantities used by the model as inputs. In general, they are the independent variables which, when combined by the model, define the physical state of the resource or environment. The decision variables normally are the dependent quantities derived from the model as outputs. In some management situations, the job is to control one or more of the parameters in accordance with externally-set or arbitrary criteria. Such parameters, or combinations thereof, become "control variables".[1] In the water-level case, water levels in the storage regions, past and predicted precipitation and runoff are the parameters, whereas dam heights are the decision variables and channel depth is the control variable.

In summary, managers use models in two ways: to predict the future state of a resource or environment and thus establish values for the decision variables, and to derive control variables when the management mission entails a regulatory or control function. Essentially, models are specific arrangements of parameters that define the state of the resource or environment in a form acceptable to the model. Parameters are stored in a data bank associated with the model from which they can be withdrawn to develop decision and control variables. In turn, parameters are derived from observables that can be measured by instruments. We now turn to the processes whereby measurable observables can be converted into parameters.

4. PARAMETERS AND OBSERVABLES - PARAMETER CONVERSION

Parameters have been defined as those physical quantities that can be accepted by the model. For this reason, the model becomes central to the entire information structure of the management system. In the case of the pesticide spraying program described in Section 2, the model is derived from the biological processes involved with each species of crop. The parameters for such a model include species identification and stage of growth, location and extent of pest damage, type of pest, soil, and water and weather conditions. Some of the parameters also become decision variables in this case, along with the type of pesticide and timing for each crop - derived from the biological model which probably uses all or most of these parameters.

4.1 Types of Observables

Parameters have to be derived from physical quantities that can be observed either directly or sensed by instruments located within or some distance from the resource or environment. Such quantities are defined as observables. Direct observation, as sensed by man located at or within the resource or environment, is commonly termed "ground truthing". Whereas most ground truthing utilizes man's sight as a primary sensor, some parameters require other senses to come into play, for example, the classification of soils requires the use of the observer's sense of feel.

Instruments located within or at the resource or environment fall into the general classification of "immersion sensors" and can be grouped with direct observation or ground truthing. Both are characterized by a relatively low data rate, in contrast with remote sensing where the measuring instrument is located on a platform some distance from the resource or environment. In remote sensing, the instrument is usually capable of providing data covering large areas in relatively short periods of time, and thus it is characterized by a high data rate. Data rates become an extremely important aspect of any management system as will be shown.

Although observables can take the form of spatial or temporal variations of a single physical quantity (such as spectral radiance in a narrow wavelength band, surface temperature or water levels), by far the majority of remote-sensing observables consist of some form of imagery.[1] Various types of cameras, multi-spectral scanners and side-looking radars are the principal instruments now in use to create such imagery. Thus, observables can take the form either of imagery or calibrated graphical and tabular data.

4.2 The Nature of Parameter Conversion

Some observables are directly usable as parameters, for example, water levels as measured by a radar altimeter for the water-

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[1] In Figure 1 decision and control variables are shown as outputs of the model. In some management situations, parameters and even observables become decision or control variables without the need for a model. For example, pollution counts in air management are decision (and control) variables that are measurable directly.

[1] Although it is recognized that observables are extracted from imagery through the perceptive abilities of the interpreter, for convenience we have used imagery as a generic class of observables where the physical quantities derived therefrom depend on the skill of the interpreter.

level management problem. Most parameters, however, need to be converted from one or more observables. A common example of parameter conversion is the interpretation of imagery. Here the interpreter develops a skill in recognizing subtle variations in film density as specific physical characteristics of the object that has been imaged. Often, a parameter results from the combination of a number of observables, as in the case of identifying, for example, tree species in a wildlands region. Crown shape, height, image texture and spectral characteristics are among the many observables needed by an interpreter to identify and map specific types of trees.

Parameter conversion normally requires a detailed understanding of the physical, chemical and biological properties of the object being observed; in which case the observables, and combinations thereof, can be used as surrogates or proxies for the parameters, once the relationships are established. Such conversion processes should not be confused with modelling, where the model's validity does not depend on the quality of the input. Instead, they are algorithms of one form or another, normally limited in respect to the magnitude of fluctuations of the observable, and subject to calibration defects of the instrument measuring it. For example, the interpretation of an uncorrected aerial photograph depends on the tip and tilt of the film plane, performance of the lens, spectral response of the emulsion, gamma of the film, incident illumination, angle of view and the atmospheric conditions between the terrain and the camera. Even if some of these effects are compensated for in the photograph during data processing, the remaining defects and circumstances during the flight must be known by the interpreter. Thus the algorithm for parameter conversion depends on the characteristics of the input. The validity of a model, by its very nature, usually does not depend on the characteristics of its parameters. Nevertheless, it is a truism that a model will yield erroneous decision or control variables if its parameters have been incorrectly interpreted.

4.3 The Significance of Parameter Conversion

We have suggested that observables are obtained through two methods: remote sensing and immersion sensing (in which we have included ground truthing). Most observables are not in a form that can be accepted by a model, and so it is necessary to perform a parameter conversion - the interface between the instrument designer and the user.

This interface is so important that it merits special attention. As in the past, and until remote sensing really takes hold, immersion sensing will be the principal form of data collection in most resource or environmental management systems. For immersion sensing, there is little need to go through the formalism developed so far in this report. For one thing, the "immersed" observer can usually establish or measure the model parameters directly; and more often than not, he can get at the decision and control variables without the need to construct a model. In any event, his models usually are quite simple, such that they need not take on a physical or mathematical form. More importantly, however, is that the data rate for immersion sensing is characteristically low; and the time scale permits relatively crude methods of data handling and processing.

The high data rates associated with remote sensing place severe requirements on the information handling capacity of any management system employing it, and the concept problems relating to the flow of management information have led to this epistemology. It is likely that imagery will continue to be the principal form of remote-sensing observable. So far, image interpretation has required human sensory skills, so that parameter conversion will remain as the bottleneck until automated image interpretation becomes more practical. Furthermore, manual interpretation of the newer types of multispectral imagery, and even traditional black-and-white aerial photography, is still in its infancy. Thus it is not surprising that many users remain sceptical about the ability of remote sensing to assist the management process in a cost-effective fashion.

4.4 Disciplinary Listing of Parameters and Remote-Sensing Observables

In the appendices of this report, an attempt is made to list some of the main parameters, together with their associated remote-sensing observables. The discipline headings follow those covered in reports Nos. 2 to 8 in this series. Within each discipline, parameters are classified under arbitrary subgroupings that appear to contain some degree of technical unity, or that relate to specific management missions. An effort was made to eliminate redundancies, and minimize the number of repetitive parameters appearing under different disciplines. Such efforts were only partially successful, and some parameters appear more than once because they are common to several disciplines (e.g., many of the water and meteorological parameters).

A striking feature of these lists is the number of occasions when the relevant observable is in the form of some kind of imagery. Reference has already been made to this fact. Also, it should be emphasized that the lists are far from complete, and that some parameters may have been given too strong an emphasis, whereas other more important parameters may have been excluded altogether. The range of disciplines is so broad that such lists should really be prepared by experts in each field. In many cases the relevant observables are purely conjectural, and indeed there are some parameters for which there are no known remote-sensing observables at the present time.

We return now to a broad overview of the entire management process and attempt to portray the foregoing concepts in the information flow diagram. Such an approach helps to fix ideas and lends itself to a sub-division of the various activities associated with resource and environmental management, along the functional lines of the Canada Centre for Remote Sensing.

5. THE MANAGEMENT PROCESS

The concepts generated in the previous sections of this report can be tied together conveniently in a block diagram. Figure 1 is an information flow system intended to show how the management processes operate. For convenience and generality, the resource or environment being managed is shown as a double-lined block in the centre of the diagram. There is a management mission to be accomplished, and such missions usually fall into one or more of the following categories:

(a) Control of one or more physical characteristics of a resource and/or environment.

(b) Engineering projects associated with the building of the nation.

(c) General management of renewable and non-renewable resource exploitation.

(d) Conservation and environmental protection.

The role of management, shown as a dotted block at the right of Figure 1, is to arrive at decisions for human action or decree that will alter or affect the future condition of the resource or environment. The management function consists of the processes involved in reaching such decisions. In order to perform this function, the manager needs to know the consequences of each possible decision alternative. For this he has two sources of information:

1) Decision and control variables derived from the model and its associated data bank.

2) Decision factors provided by society (who vested in him the management authority) and by its laws.

Let us deal with 2), depicted by the bottom block in Figure 1. The present or planned future state of the resource or environment will have an economic and socio-political impact on society which will result in some form of pressure on management, arbitrarily called decision factors. Generally, they will be non-quantitative unless they appear in the form of laws or regulations. Quite often, such factors are the main determinant in any management decision. The case cited in Section 2 of the decision not to close the paper mill polluting the local river, is an example where local economic and political pressures outweighed the technical fact that the river pollution was despoiling the environment.

Decision and control variables are the other principal inputs to management. Decision variables are developed by postulating a series of model parameters that represent possible alternative future courses of action. The model and its associated data bank, in which is stored historical data and local cause/effect relationships, then is used to establish the decision variables. The historical state of the resource or environment is measured either by immersion or remote sensors, shown as the block at the upper left in Figure 1, and provides raw sensing data which must be processed into a form suitable for parameter conversion or data bank storage - what we have called "observables". Parameter conversion, described in Section 4, creates the parameters stored in the data bank.

A control variable is a category of decision variable that is measured by this process, but in real time. It is used in the first category of management mission listed as (a) where the task is to control some physical quantity on a pre-set schedule (e.g., channel water-level control, and local air-pollution control). In this case, the upper loop in Figure 1 becomes an automatic control system (with one of its major "disturbances" represented by the bottom loop).[1]

The second category of management mission (b) involving engineering projects, deserves special mention because of the role remote sensing must have in the future development and building of our nation. An excellent example is the management of land use for urban expansion (described in Section 2 under Geography). In this case, it is possible for the manager to postulate a series of alternative land use patterns using such known and stored parameters as topography, drainage, soil type and trafficability, and climate. Then, he must test each alternative with his model to establish the technical consequences of each, and thus narrow the alternatives down to those that are physically feasible. Many of these parameters also become decision variables, because it is necessary to relate the proximity of housing and other ecumene to the economic and socio-politcal factors entering the decision process. The manager must bring all of the facts to the people in order that decisions in the form of zoning laws (decrees) and land appropriations for public projects (action) can be effected.

The third and fourth mission categories, (c) and (d), include activities that are combinations of the types described in the examples for (a) and (b).

The dotted line boxes across the top blocks of Figure 1 represent the planned functional structure of the Canada Centre for Remote Sensing (CCRS). Figure 1 shows how they interact with the management processes and with each other.

5.1 Data Acquisition

Data acquisition covers the gathering of raw sensing data and involves four principal activities:

1) The development, testing and acquisition of new remote sensors (the present program is described in Report No. 10 of this series).

2) Platforms on which remote-sensing instruments are mounted:

    (a) Mobile trailers or vans located at strategic vantage points.

    (b) Aircraft.

    (c) Balloons (see Report No. 16 of this series).

    (d) Satellites (see Report No. 17 of this series).

3) The data-gathering program (see reports Nos. 11, 19 and 20).

4) Immersion sensing and ground truthing.

These principal activities are covered elsewhere so there is no need to describe them in detail here. Raw sensing data includes such items as unprocessed film, magnetic tape, oscillograms, strip charts, and instrument readings, together with calibration and environmental "housekeeping" data recorded at the time and location where the measurements were made.

5.2 Data Handling

Within this division fall all aspects of data transmission processing, computation, storage and retrieval. In the management information context of Figure 1, it includes the processing of raw sensing data into observables, the parameter conversion process, and the data bank associated with the resource or environment model.

Data processing is the conversion of raw sensing data which, for photography and scanner data (usually recorded on magnetic tape), results in imagery of a form ready for interpretation, together with detailed housekeeping information such as spectral response, range and atmospheric conditions, gamma, and geometry of image plane. Non-imaging sensor data is processed into a form most suitable for parameter conversion or storage, and includes calibration data, instrument non-linearities and dynamic response as well as other necessary housekeeping data.

While the algorithms for parameter conversion must be developed by the interpreter, the treatment of quantified observables and the parameter computation is a data handling problem. So also is the data bank, but it should be stressed here that the storage requirements will vary considerably from model to model, and for each management situation. (For this reason, the data bank is also included in the dotted line block labelled "management" at the right of Figure 1.)

The data handling aspects of CCRS include far more functions than are described in this report. For example, among its activities are the past operations of the Air Photo Production

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[1] As a control system, the dynamics of these two loops become critical. Thus time constants and finite delays associated with each function are important not only to the control problem, but also to the general management role. A treatment of the dynamics of the management process is beyond the scope of this paper.

Unit and the National Air Photo Library, together with recently acquired facilities associated with ERTS data reduction and an expanding aircraft program. Details are covered in reports Nos. 1, 9, 12, 15 and 18 of this series.

5.3 Data Interpretation

Perhaps the most under-developed and misunderstood part of the entire management process, at least insofar as remote sensing is concerned, is that associated with interpretation. It is the process whereby the observables are converted to decision variables, and in Figure 1 is shown to include parameter conversion, the model and its associated data bank. All of which are described in some detail elsewhere in this report.

It is important to recognize, however, the interfaces between interpretation and data handling on one side, and management on the other. It is the function of the interpreter (and instrument developer) to define the algorithms for parameter conversion, develop the model and identify the parameters and observables to be stored in the data bank. The interpreter must also interact with the sensor people, for it is the role of data acquisition to provide meaningful observables to the interpreter.

The management interface is extremely important. Both the model and its data bank are common to both groups, because the model must relate to the specific resource or environment being managed. Thus there is a highly regional flavour in most models, and indeed the model builder needs to possess a profound knowledge of the region for which his models are intended. It is for this reason that the establishment of regional interpretation centres across Canada is being encouraged by CCRS.

The same arguments apply to parameter conversion when the observable is imagery, but ultimately this activity should reduce to fixed algorithms once the methodology is established. In the foreseeable future, however, it will be necessary to arrange for "grass roots" interpreters to work both at CCRS and in their local regions to develop parameter conversion techniques that ultimately can be automated.

In Section 4 it is suggested that remote sensing (as opposed to immersion sensing) is characterized by very high data rates. One has only to examine the volume of data resulting from one hour of flying, or the tremendous volley of bits spewed out by ERTS every second it is transmitting, to be overwhelmed by the data handling problems. These data rates can only be handled by automatic equipment and computers. The days of manual data handling are clearly numbered. Thus costs become a major consideration, and criteria for investment decisions are needed.[1] We turn now to economic matters, and ask the question, "On what basis should decisions be made to invest in remote sensing?"

6. ECONOMIC CONSIDERATIONS

The rapid data rates associated with remote sensing imply high capital equipment costs, which in turn involve large investments. Thus it behooves us to search for investment criteria. Treasury Board has been examining such matters for some time, and has endorsed the concepts of benefit analysis.[2] Remote sensing could be amenable to such an approach, because it should be possible to quantify benefits so derived in terms of cost savings.

Benefits can accrue in several ways. First of all, there are the main benefits that accumulate from performing the entire management process more efficiently. Higher data rates covering more parameters enable better predictions of the future state of a resource and/or environment, and thus provide for more rational and effective decisions. Such extended management visibility should minimize or even eliminate past mistakes, and thus it should be possible to identify certain marginal benefits resulting from improved predictions provided by remote sensing. Not all such benefits can be quantified in terms of cost savings. For example, it is not possible to equate directly to dollars the environmental improvements resulting from better management through remote sensing, but attempts could be made to accomplish it indirectly.

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[1] It has been suggested that a remote-sensing information network might emerge as a national "utility". While this might be possible, it is the writer's view that, like the computer, individual management groupings, both private and public, will be prepared to make their own investments in remote sensing hardware and systems because of the highly favourable cost/benefit ratios involved, and their desire for confidentiality.

[2] Benefit-Cost Analysis Guide - Fifth Draft, Planning Branch, Canadian Treasury Board Secretariat.

A second type of benefit is that which accrues to the private sector. Industries involved in sensor development and manufacture, data processing, aerial surveying and management services all receive benefits in terms of profits resulting from the sale of their products or services. Over a period of several years, such benefits can be substantial.

A third form of benefit results when remote sensing is used as an engineering tool to develop and build the nation. Its marginal contribution to national prosperity could be quantified by studying how it has been used in the past. For many years, engineers have been using aerial photographs for planning purposes. Benefits resulting from improvements in quality, delivery time and coverage should be measurable; as would be any extension in the number and type of parameters that could be made available.

In order that future investment decisions can be made with greater wisdom, it is clear that a data base must be established which identifies and tabulates the benefits resulting from earlier remote-sensing programs. At the present time, a thorough study is being conducted by CCRS on the whole question of benefit analysis and prediction.

Benefit concepts help to maintain a sequence of priorities in planning a national program for remote sensing. The newer methods are neither known nor well understood by a large segment of the potential user community and so a marketing program is essential. We now examine some of the marketing issues, and attempt to use benefit concepts to set priorities.

7. MARKETING CONSIDERATIONS

In this section, we consider marketing matters only insofar as they relate to the national program conducted by CCRS. It is almost trivial to suggest that the major efforts should be directed to areas of largest payoff in terms of benefits. Nevertheless, it is far easier to follow the path of least resistance and respond to requests for services from those already fully "converted" to the use of remote sensing. Unfortunately, such converts are not always associated with the areas of largest payoff.

Unquestionably, the most important benefits will result when remote sensing is used in the management process. But existing managers not now using remote sensing have built-in resistance mechanisms in the form of fixed or stringent budgets. Thus a "hard sell" is required in order to convince the manager that he must either abandon or supplement his existing information sources (usually some form of immersion sensing) in favour of more expensive methods. Resistance to change is also a difficult phenomenon to combat. In such instances, benefit analysis becomes an effective, if not the only, marketing tool. CCRS is in a position to provide convincing demonstrations to potential users at minimum cost to them. It is the writer's view that such demonstrations should be given the highest priority, because they are most likely to yield the largest benefits.

Second in priority is the effort needed to eliminate impediments to the use of remote sensing. Specifically, the major bottleneck in the entire management process is parameter conversion - particularly the interpretation of imagery. Also, this is where the major interface exists between instrument designer and user. Even though improving interpretation must be near the top of the priority list, the benefits resulting therefrom cannot be measured until the improvements have been incorporated into some management system.

Although better methods of parameter conversion are the principal ways of enhancing CCRS's ability to market remote sensing, the remaining elements of the process should not be neglected. Improved sensors, less costly and higher capacity data handling systems and more precise models, together with more effective methods of gauging economic and socio-political impact, all contribute to ease the marketing problem.

A third area where there is a measurable payoff is in the involvement of the private sector. Companies receiving their initial support from CCRS programs will often be in a position to generate further sales to outside agencies, industry and other countries. When such new businesses attain viability, new jobs and profits are generated thus resulting in benefits that can be attributed to the initial investment by CCRS. For this reason, CCRS should be assisting the private sector (for example, the sensor, data processing, survey and service industries) that has been funded by the Centre in marketing its products and services externally. Furthermore, the same arguments can be used to urge CCRS to place as much of its work as is practicable in the private sector, for it is only there that such benefits can accrue and be assessed.

Finally, a word of caution would not be out of place under the subject of marketing. As stated earlier, many of the "converted" who would utilize the services of CCRS are involved in fields that have much less likelihood for payoff than in the areas suggested. Many research workers, accustomed to the use of advanced technology, will likely want to avail themselves of the Centre's facilities. In the context of Figure 1, such researchers are usually involved in developing better models related to their individual disciplines. The benefits resulting from early work of this type are difficult to foresee, and often the research worker is not prepared, or is reluctant to reveal his data and his successes until he is in a position to publish.

It is not being suggested here that such activities should be rejected by the Centre. Indeed, it is quite possible that the Centre could contribute to new scientific "breakthroughs". However, there should be mechanisms established whereby at least marginal costs incurred by CCRS can be recovered from such research support. What is being advocated is that the Centre should set its expenditure priorities on the basis of payoff criteria. In general, this means that CCRS will have to posture itself in an "active" mode and market its services to a reluctant user (management) community, as opposed to the easier "reactive" mode where the Centre could sit back and respond to its "customer". They may provide more interesting and even more challenging scientific programs, but such fascinating activities could well be of the wrong kind.

While benefit criteria can set the stage for marketing priorities, the selection of specific programs and investments should be based on risk assessments. Quite often large potential benefits are associated with relatively high investment risks. Thus, there is an incentive to find ways of generating benefit/risk indices to aid in decisions for committing the Centre's resources. But it is unlikely that such sophisticated approaches will replace fully the traditional "seat of the pants" methods that have worked well in the past.

8. CONCLUSIONS AND RECOMMENDATIONS

Throughout this report we have attempted to develop a very generalized approach to remote sensing, and how it fits into the process of managing a resource or environment. Undoubtedly, some readers will be able to identify certain management situations that cannot be fitted perfectly into the patterns and paradigms outlined here. Nevertheless, the key elements must always be present - the model and its parameters. The greatest single impediment to more widespread use of remote sensing will continue to be the conversion of observables into parameters. This is the watershed - either side it is downhill all the way.

The management decision process is never simple, but in resource and environmental matters it is both confounded and obfuscated by the tremendous intensity of the economic and socio-political factors that affect virtually all decisions. Very little success has been achieved so far by the social scientists in their attempts to evolve social indices along the lines that economists have developed economic indicators. Until more progress has been made, such management will remain as an art to be practised by a select few who have endured the years of experience to gain the wisdom necessary for survival. Remote sensing will not help here (at least not in the foreseeable future), but therein lies another major impediment - most managers problems do not centre on the decision variables, but rather on the decision factors (as defined in Figure 1 and its related text). For this reason, remote sensing will continue to be a "hard sell" to most managers for some time to come.

During the course of this study, several issues have come to light that have altered the writer's views on the matter of priorities related to the three major sections of CCRS. They are dealt with in this Section as recommendations under each activity, and the Section concludes with some general recommendations that arise directly from what has been said previously.

8.1 Data Acquisition

Whereas remote sensing is obviously the central focus of CCRS, the resource or environmental management process does not make a distinction between remote and immersion sensing. In fact, the best data acquisition system for any particular management situation will be the most economic blend of the two. Furthermore, ground truthing is an integral part of the remote sensing process - whether it is required to establish the validity or performance of a sensor, or is used in the normal course of data interpretation. Ground truthing, however, is no more than immersion sensing - in either case the observer must be in contact with or immersed in the resource or environment. It make little difference whether he uses one or more of his senses or an instrument.

Immersion sensing is very closely coupled with the particular discipline involved, and thus CCRS could find itself encroaching on areas outside of its terms of reference, should it include immersion sensing within its ambit. Nevertheless, CCRS must be involved with immersion sensing in order to support its sensor and interpretation work, and be knowledgeable in the field so as to be able to provide advice to managers seeking answers to their data acquisition problems. For these reasons, it is recommended that:

> CCRS maintain a capability in immersion sensing necessary not only to support its own programs, but also to provide advice on a consultative basis.

From the appendices, it is quite evident that the most common observable is some form of imagery. Canada has many regions where there is a consistently high percentage of cloud cover; and the arctic regions, of course, have long periods of darkness. Thus the time during which optical imagery may be obtained from such regions is limited, which suggests that certain types of missions cannot be accomplished without the use of cloud and darkness-penetrating imaging systems[1] (e.g. side-looking radar (SLAR) and other microwave methods). Therefore, it is recommended that:

> CCRS acquire or have access to SLAR equipment as part of its data acquisition capability, and pursue the development of new imaging devices capable of penetrating darkness and cloud.

A very large number of remote-sensing instruments measure the reflected radiation from the terrain. For this reason, Report No. 10 suggests that a major program be launched to create a Canadian Reflection Spectral Atlas. It would be a significant contribution to the art of image interpretation. New technology is rapidly approaching whereby it will be possible to operate high-power lasers at many more optical wavelengths than are now available (for example, using tunable-dye and mode-locking techniques). Thus, the next advance in imaging systems is likely to be the use of active scanners that can produce reflective images of the terrain in very narrow spectral bands. Coupled with the Atlas in the hands of the interpreter, such imagery would become an extremely powerful tool - particularly in the identification of species of all kinds. It is recommended that:

> The Canadian Reflection Spectral Atlas program be initiated as soon as possible, and that CCRS place high priority on technology leading to active, tunable, optical imaging systems.

8.2 Data Handling

The arguments above concerning immersion sensing are also relevant to data handling. The use of re-transmission systems on board satellites, aircraft and balloons for relaying data from immersion sensors in remote locations to central data collection points is a technique that will play an increasingly important role in future management systems. While data retransmission is normally thought of as being related to immersion sensing, more sophisticated systems of the future might well use the technique to relay remotely sensed data from aircraft or balloons via satellite to a central point. Canada is more likely to benefit from the use of data re-transmission than many other developed countries because of its vast remote regions and the large distances involved. For these reasons, it is recommended that:

> CCRS actively promote and coordinate the use of data re-transmission techniques, and undertake studies leading to programs involving their use with aircraft and balloons in planned future data networks.

It has already been stated that remote sensing is characterized by high data rates, and that a principal bottleneck in the whole management process is the interpretation of imagery which is presently accomplished by manual methods. As interpretation technique improves, it will be possible to automate the whole process and thus take advantage of the high data rates available.[1]

Therefore, it is recommended that:

> CCRS audit the long-term trends in automatic image interpretation, and initiate research programs

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[1] Ice reconnaissance in the arctic winter is an example of such a mission.

[1] For example, it should be possible, in some cases, to convert raw sensing data from an imaging system directly into parameters or even decision variables (Figure 1) without the intervening steps.

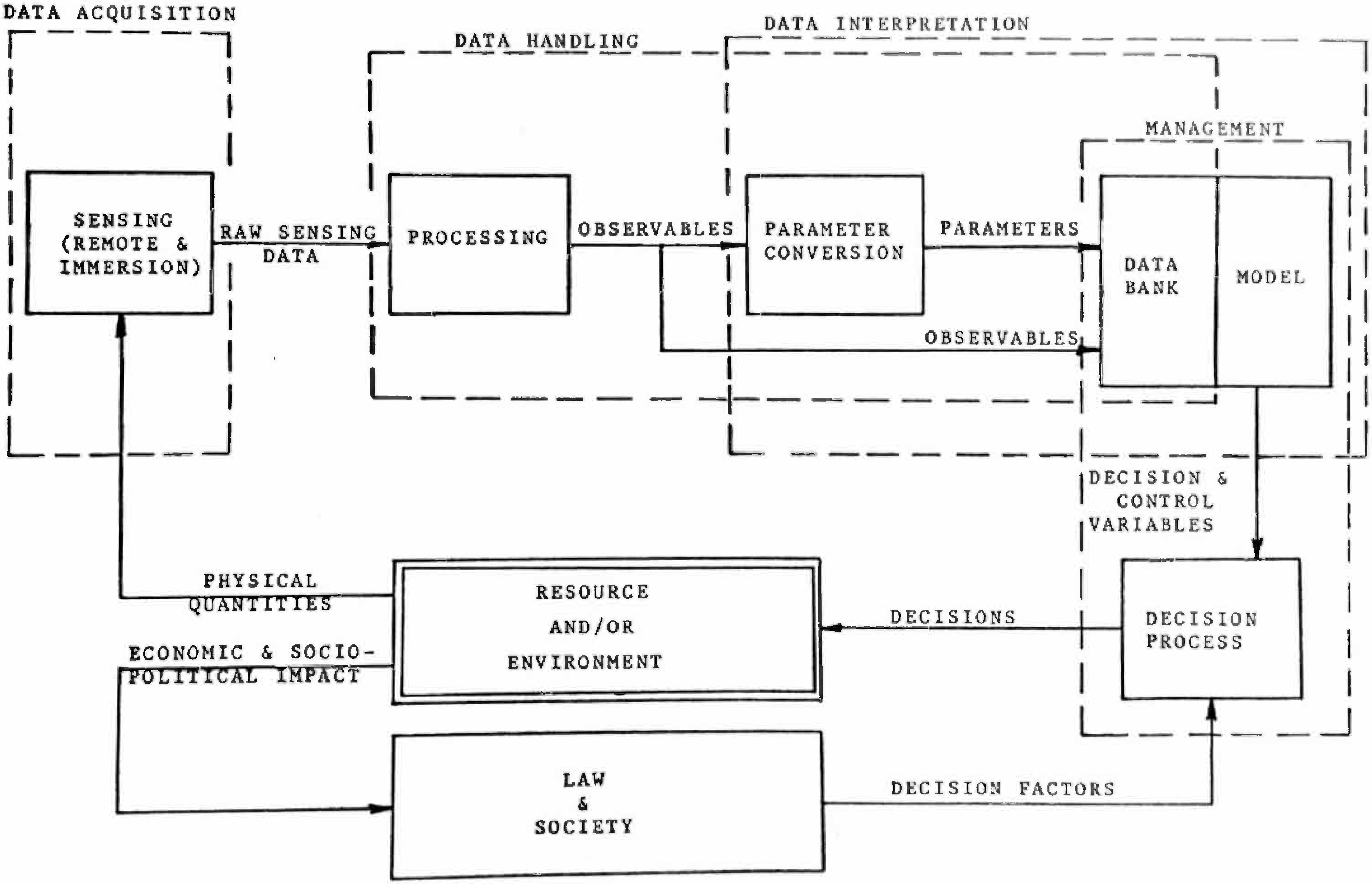

Figure 1. Resource or environmental management

> directed to the optimization of data handling procedures that can cope with the high data rates associated with remote sensors.

8.3 Data Interpretation

It has already been mentioned several times that imagery of some form is the most common observable, and that image interpretation is perhaps the least developed of all of the technologies involved in the management process (neglecting the problem of "measuring" socio-political impact, which is not yet a technology!). A report of this kind could not omit the obvious recommendation that:

> CCRS have as its top R and D priority the advancement of manual image interpretation directed, in the long term, to techniques that lend themselves to automatic methods; and that R and D in data acquisition and handling, supported by the Centre, be dictated by the requirements of the interpreter; but of course, such R and D should not be restricted solely to imagery.

8.4 General

The appendices of this report list a series of parameters and remote-sensing observables under major discipline headings. The writer harbours some doubt as to the usefulness of such lists, except possibly to help the instrument designer devise new sensors through a broader understanding of requirements. Should they prove to be of greater value than envisaged, then it is recommended that:

> The list of parameters and remote-sensing observables be extended and up-dated by the respective experts in each discipline area.

It was mentioned earlier that there is and urgent need on the part of decision makers for measuring the socio-political impact of alterations caused by human action on resources and environments. A tremendous amount of effort is now being devoted by teams of social scientists and economists to the development of social indices, but this work is still in a very embryonic state.[1] Meanwhile, in its marketing program, the Centre must possess an understanding and sensitivity to this element of the manager's environment (as illustrated in Figure 1), which is not directly related to the hard sciences normally associated with the Centre's other activities. For this reason, it is recommended that:

> CCRS maintain a social scientist on staff to assist principally with marketing activities and benefit analyses, and to provide a knowledgeable coupling with potential contributions from the soft sciences.

Benefit analysis will be a continuing activity of the Centre, and a data base is required to assist in methodology and to establish greater credibility in future. Thus it is recommended that:

> Records be maintained of the results from previous CCRS programs - particularly the economic benefits derived by the user, and that a continuing search be performed by the Centre for tangible and documented benefits resulting from remote-sensing programs conducted by other agencies - both within and outside of Canada.

Finally, it has been shown that it will be easy to be diverted from the pursuit of those programs where there is maximum payoff in terms of benefits.

It must be recognized, however, that the largest payoff areas usually are accompanied by the greatest degree of risk, when decisions are made to invest the Centre's resources. Therefore it is recommended that:

> CCRS program priorities be established principally on the basis of benefit and risk assessments, the procedure for which should be developed as fundamental guidelines for the Centre.

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[1] Science, Growth and Society - A New Perspective (The Brooks Report) OECD, 1971, p. 104.

APPENDIX A

AGRICULTURE AND GEOGRAPHY

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
1. SOILS	. Location and mapping of aquifers	. See Water Resources
	. Moisture profile	. Thermal imagery, microwave and IR radiometer output, resistivity
	. Salinity profile	. Resistivity?
	. Temperature profile	. IR radiometer output?
	. Surface features	. Imagery
	. Drainage classes	. ?
	. Profile characteristics - colour - texture - mottles - structure - consistency - roots and pores - clay films - concretions - horizon boundaries	. ?
	. Nutrient status	. Multi-spectral imagery, spectrometer output?
	. Tillage status	. Imagery
2. CROPS	. Identification and map of species	. Imagery of all forms
	. Acreage of each type	. Imagery of all forms
	. Stage of growth	. Imagery of all forms
	. Per cent ground cover	. Imagery of all forms
	. Insect and pest damage	. Imagery of all forms
	. Disease detection and identification	. Imagery of all forms
	. Moisture stress identification and mapping	. Imagery of all forms

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Vigour	. Imagery of all forms
	. Agent responsible for loss of vigour	. Imagery of all forms
	. Yield prediction	. Imagery of all forms
	. Disaster location and mapping	. Imagery of all forms
3. WATER		
	. Aquifer location and mapping	. See Water Resources
	. Location, quantity and flow of groundwater	. See Water Resources
	. Depth of water table	. See Water Resources
	. Extent of surface water and wet/dry boundaries	. See Water Resources
	. Quantity and distribution of snow and ice	. See Water Resources
	. Extent and depth of frozen soil	. See Water Resources
	. Extent and depth of unfrozen soil over permafrost	. Thermal imagery, ?
4. WEATHER	. Forecast (short, medium and long term)	. Standard meteorological variables
	. Rainfall prediction (long term)	. Standard meteorological variables
	. Storm warnings	. Standard meteorological variables
	. Frost and drought risk	. Standard meteorological variables
5. LIVESTOCK		
	. Counts in each field by kind of animal, use, breed, sex, age and vigour	. High-resolution imagery
	. Forage amount, palatability, accessibility and nutritive value by species; need for re-seeding	. High-resolution imagery

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Location and state of repair of corrals and fences	. High-resolution imagery
	. Location of livestock-poisoning plants, noxious weeds, salt grounds and rodent concentrations	. High-resolution imagery
	. Location of springs and portable water for livestock	. High-resolution imagery
6. LAND USE	. Thematic mapping of forms, extent and type of: - vegetation - water, snow and ice - bare soil and rock - permafrost - ecumene (land where man has made his home, and all work areas used for economic purposes)	. All forms of imagery
	. Land topography	. Stereo-photography
	. Land erosion by wind and water	. Multi-spectral imagery
7. BUILDINGS	. Location and density of man-made structures	. High-resolution imagery
	. Classification of man-made structures	. High-resolution imagery
	. Stage of construction of man-made structures	. High-resolution imagery
8. TRANSPORTATION AND UTILITIES	. Location and stage of construction of existing and planned road, rail, pipeline and electrical transmission systems	. High-resolution imagery
	. Navigability of water courses	. High-resolution imagery
	. Trafficability of terrain	. Soil observables and penetrometer data
	. Topography suitable for planning road, rail, gas and oil	. Stereo-photography

pipelines, electrical
transmission systems,
airports and generating
stations

SOURCES

1. Resource Satellites and Remote Airborne Sensing for Canada, Report No. 2, Agriculture and Geography, Information Canada, 1971.

2. Remote Sensing with Special Reference to Agriculture and Forestry, National Academy of Sciences, 1970.

3. Useful Applications of Earth-Oriented Satellites - Summary of Panel Reports, Panel 1, National Academy of Sciences, 1969.

4. Terminology for Describing Soils - compiled by J.H. Day, Proceedings of the Seventh Meeting of the National Soil Survey of Canada, Canada Department of Agriculture, 1968.

5. Papers presented at the Technical Consultation on the Application of Remote Sensing to the Management of Food and Agricultural Resources, Food and Agricultural Organization of the United Nations, September, 1971.

6. Communications with Dr. A.R. Mack, Canada Department of Agriculture.

APPENDIX B

ATMOSPHERIC CONSTITUENTS

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
1. LARGE-SCALE MAPPING OF PARTICULATE MATTER (AEROSOLS)		
	. Suspended particulate levels in stratosphere	. Lidar amplitude polarization, time delay
	. Vertical particulate concentration profiles (ground through to stratosphere)	. Lidar amplitude, polarization, time delay
	. Horizontal mapping	. Lidar network, bistatic Lidar output
	. Vertical flows	. Time-lapse Lidar outputs
	. Horizontal flows	. Time-lapse Lidar outputs
	. Interurban mixing and transboundary flow	. Time-lapse Lidar outputs
	. Composition of particulates	. ?
	. Transmissivity or turbidity	. Photography
	. Height of inversion layer	. Lidar return-time delay
	. Height of dust and haze layers	. Lidar return-time delay
	. Pesticide residue mapping	. ?
2. LARGE-SCALE MAPPING OF GASEOUS POLLUTANTS		
	. Three-dimensional spatial distribution with following priority order: - carbon dioxide - oxygen - water vapour	. Infrared radiance: 2-3 microns CO, CO_2, CH_4 3-5.5 microns CO, NO_2, CH_4 5.5-20 microns $CO_2, NO_2, SO_2, NH_3, CH_4$

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	- carbon monoxide - sulphur dioxide - hydrocarbons - nitrogen oxides	with sun as source below 3.5 microns and earth thermal emission above 3.5 microns up to 7 km. altitude as observed by: - Correlation and scanning spectrometer outputs flown at various altitudes, interferograms from various altitudes, and ground chopped sensor for shorter wavelengths - Lidar (tunable) frequency, amplitude, polarization and possibly phase using Raman and Raman resonance scattering, fluorescence scattering or differential absorption and scattering
	. Plume mapping	. As above
3. METEOROLOGICAL PARAMETERS OF IMPORTANCE TO ATMOSPHERIC CONSTITUENTS		Meteorological observables normally measured by immersion sensing
	. Wind profiles	. ?
	. Air turbulence	. ?
	. Vertical air mass movement	. ?
	. Profile of relative humidity, dew point	. ?
	. Radioactivity levels	. ?
4. MISCELLANEOUS		
	. Air pollution damage to vegetation	. Multi-spectral imagery
	. Precipitation composition and its vertical profile	. ?

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	Scavenging mechanisms for air pollutants	?
	Long-term effects of pollutants on climate	General meteorological observables

SOURCES

1. Resource Satellites and Remote Airborne Sensing for Canada, Report No. 3, Atmospheric Constituents, Information Canada, 1971.
2. Air Pollution Measurements with Remote Sensing Correlation Spectrometer, Barringer Research.
3. Communications with:

   a) Dr. A.I. Carswell, York University.
   b) Mr. B.C. Newbury, Environment Canada.

APPENDIX C

CARTOGRAPHY AND PHOTOGRAMMETRY

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
1. VERTICAL CONTROL		
	. Vertical distance to terrain	. Radar or laser pulse delay time
	. Geodetic coordinates of isobaric surface	. Atmospheric pressure sensor
	. Geodetic coordinates of sensor platform	. Inertial acceleration and coordinates of initial position, airspeed and meteorological conditions for compensation . Output of a platform-tracking radar at a known location
2. HORIZONTAL CONTROL		
	. Latitude and longitude of sensor platform and navigation	. Characteristics of electro-magnetic field created by ground stations at known locations . Inertial acceleration and coordinates of initial position, airspeed and meteorological conditions for compensation . Output of a platform-tracking radar at known location
3. PHOTOGRAMMETRY		
	. Angular tip and tilt of sensor relative to vertical	. Output of vertical gyro or pendulum
	. Direction of apparent vertical relative to true vertical	. Angular displacement between short period and Schuler-tuned pendulums

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Linear displacement of sensor relative to platform (vibration)	. Output of displacement pickoffs on camera mount
		. Photograph of sensor from platform-fixed camera
		. Output of accelerometers or vibrometers mounted on sensor
	. Image correlation and identification	. Geometric patterns of film density variations
	. Terrain radiance	. Tonal and colour densities of film
	. Location of man-made and natural features under trees and other vegetation	. SLAR output?
	. Location of man-made structures, pipelines underground or under surficial material	. Thermal imagery?

SOURCES

1. Resource Satellites and Remote Airborne Sensing for Canada, Report No. 4, Cartography and Photogrammetry, Information Canada, 1971.
2. Useful Applications of Earth-Oriented Satellites, Report No. 13, Geodesy-Cartography, National Academy of Sciences, 1969.
3. Communications with Mr. R.E. Moore, Canadian Dept. of Energy, Mines and Resources, and Dr. J.M. Zarzycki, Terra Surveys Ltd.

APPENDIX D

FORESTRY, WILDLANDS and WILDLIFE

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
1. FOREST and WILDLANDS INVENTORY		
	. Population by species and location	. High-resolution multi-spectral imagery
	. Size of trees and stands, average size per tree (stem diameter and height), timber volume per acre	. High-resolution multi-spectral imagery: crown canopy density, mean crown area, tree height, average height of canopy
	. Distribution of trees - density (stems per acre) mix of sizes and species, density of undergrowth	. High-resolution, multi-spectral imagery
	. Amount of cull and decay in a stand (percentage of wood in an area that is sound)	. ?
	. Growth rate	. Time-lapse imagery
	. Area of cut trees and dead trees	. High-resolution, multi-spectral imagery
2. FOREST and WILDLANDS PROTECTION and DAMAGE ASSESSMENT		
	. Fire detection	. Thermal imagery, storm tracks
	. Fire periphery map	. Thermal imagery
	. Burned areas	. High-resolution imagery
	. Insect and pest infection	. High-resolution, multi-spectral imagery
	. Flooded areas	. Imagery
	. Physical damage	. Imagery
	. Vigour and agent responsible for loss of vigour	. High-resolution multi-spectral imagery

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
3. LAND and SOIL		
	. Surficial geology	. Imagery
	. Soil types (see Agriculture)	
	. Moisture	. ?
	. Trafficability	. Bearing strength
	. Topography	. Imagery
4. WATER		
	. Quantity and distribution of snow and ice	. Imagery + ?
	. Water levels, temperature and quality of lakes, streams and ponds	. Thermal imagery + ?
	. Times of freeze-up and break-up	. Imagery
5. WEATHER		
	. Fire, frost and drought risk by region	. ?
	. As in Agriculture	. Standard meteorological variables
6. WILDLIFE		
	. Population by species and location	. Imagery
	. Migration and flyways mapping	. Imagery
	. Arctic and alpine snowpack	. Imagery
	. Snow depth - ungulates and game birds	. Imagery
7. PHENOLOGY		
	. Time of leaf-out, blooming, etc.	. Imagery
	. Seasonal changes	. Imagery

SOURCES

1. Resource Satellite and Remote Airborne Sensing for Canada, Report No. 5, Forestry and Wildlands, Information Canada, 1971.
2. Forest Management Institute, Program Review 1967-69, Canada Department of Fisheries and Forestry.
3. Useful Applications of Earth-Oriented Satellites, Summaries of Panel Reports, National Academy of Sciences, 1969.
4. Applications of Remote Sensors in Forestry, Joint Report by Working Group, International Union of Forest Research Organizations, Section 25.
5. Remote Sensing - with Special Reference to Agriculture and Forestry, National Academy of Sciences, 1970.
6. Air Photo Interpretation in the Development of Canada, Proceedings of the 2nd Seminar held at Ottawa, March 13-15, 1967, Queen's Printer, 1968.
7. Communications with Dr. L. Sayn-Wittgenstein, Forest Management Institute, Environment Canada.

APPENDIX E

GEOLOGY

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
1. IDENTIFICATION		
	. Rock type	. Imagery, geophysical variables such as: permeability, conductivity, spectral luminescence and fluorescence, radioactivity
	. Mineral composition	. As above; presence of vapours such as mercury in the atmosphere
	. Colour	. Colour photography, multi-spectral imagery
	. Granularity and texture	. Imagery
	. Induration	. Imagery
	. Porosity, permeability and fluid content	. Imagery, radiometry
	. Fossils	. Imagery?
2. SPATIAL ARRANGEMENT		
	. Outcrop area	. Imagery
	. Elevations and rates of change	. Stereo imagery
	. Foliation and lamination	. Imagery
	. Bedding and banding	. Imagery
	. Depth to bedrock, permafrost, water table	. Geophysical variables, thermal imagery
	. Concordance of rock units	. Imagery
	. Attitude of planar structures	. Imagery, hologram?

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Joints, faults and shears	. Imagery, resistivity
	. Folds	. Imagery, resistivity
	. Striations, grooves, linear features	. Imagery, resistivity
	. Morphology and structure	. Imagery, resistivity
	. Rates of erosion and sedimentation	. Imagery
3. GEOTHERMAL AREAS		
	. Location	. Surface temperature, resistivity
4. GEOLOGIC HAZARDS		
	. Landslide regions	. Imagery
	. Erosion regions	. Imagery
	. Volcanism	. Surface temperature, thermal imagery
	. Earthquakes	. ?

SOURCES

1. Resource Satellites and Remote Airborne Sensing for Canada, Report No. 6, Geology, Information Canada, 1971.

2. Useful Applications of Earth-Oriented Satellites, Report No. 2, Geology, National Academy of Sciences, 1969.

3. A.R. Barringer, Remote Sensing Techniques for Mineral Discovery, Ninth Commonwealth Mining and Metallurgical Congress, Institution of Mining and Metallurgy, 1969.

4. A.R. Barringer, Airborne Exploration, Mining Magazine, Vol. 124, No. 3, March 1971.

5. Communications with Dr. A.R. Gregory, Geoscience Consultant, Ottawa.

APPENDIX F

ICE RECONNAISSANCE AND GLACIOLOGY

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
1. ICE RECONNAISSANCE		
	Sea ice/water boundaries	Imagery
	Amount of open water in sea-ice areas	Imagery
	Pattern of different ice types	Imagery, laser profiler
	Open water near shoreline	Imagery
	Thickness of sea ice (including pressure ridges)	Radiometry, hologram (HF), resistivity
	Thickness of lake and river ice	Radio sounding, resistivity
	Ages of sea ice - above sea surface	Multi-spectral imagery
	Ice surface texture (roughness, size and orientation of ridges and hummocks)	Imagery, laser profiler
	Surface temperature of sea ice or snow on sea ice	IR thermometry
	Albedo of sea ice (regional and detailed)	IR radiometry
	Degree of ice fracturing	Imagery
	Extent, nature and rate of drift of large pressure ridges	Time-lapse imagery
	Ice jams and hanging ice dams in straits and channels	Imagery
	Floe and pack movement (during storms)	Time-lapse imagery (radar?)
	Salinity profile of sea ice	?

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Degree and extent of scouring by ice islands and icebergs	. Colour photography?
	. Location and extent of rafting	. Imagery
	. Extent of permafrost under the sea	. ?
	. Thermal conditions of sea bottom	. ?
	. Times of freeze-up and break-up	. Imagery
	. Iceberg population, density of numbers and location	. Imagery
	. Iceberg dimensions shape (above and below water) and mass	. Imagery
	. Iceberg movement - tracks and velocities	. Time-lapse imagery
	. Navigability of channels and straits for ships (pack ice conditions)	. Imagery
2. GLACIOLOGY		
	. Calving and surging glaciers	. Photography
	. Ice-rock, ice-gravel or ice-water boundaries (terminus, moraine limits)	. Photography
	. Ice and snow surface profile of major ice caps and small glaciers	. Stereo-photography
	. Thickness of glaciers	. Radio sounding
	. Ice-snow boundary (firn line)	. Imagery
	. Snow edge (regional and detailed)	. Imagery
	. Snow surface temperature	. IR thermometry

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Free water content in uppermost 5m. of glaciers	. Radiometry
	. Snow depth on glaciers	. Radio sounding
	. Water equivalent of glacier snowpack	. Radiometry
	. Snow avalanches (occurrence, size and characteristics)	. Imagery
	. Presence of pollution on ice and in ice-infested water (hydrocarbons - foreign chemicals, sediment load, local thermal disturbances)	. Multi-spectral imagery, fluorosensor
	. Discharge of glacier - dammed lakes	. Imagery
	. Formation of river ice (aufeis)	. Imagery
	. Location of avalanche deposits under naturally deposited snow	. Imagery

SOURCES

1. Resource Satellites and Remote Airborne Sensing for Canada, Report No. 7, Ice Reconnaissance and Glaciology, Information Canada, 1971.
2. Manual of Standard Procedures and Practices for Ice Reconnaissance, Third Provisional Edition, Meteorological Branch, Canadian Department of Transport, 1965.
3. Communications with Messrs. H. Hengevelt and E. Stasyshyn, Environment Canada.

APPENDIX G

WATER RESOURCES

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
1. PHYSICAL STATE OF WATER		
(a) Inventory - Lakes, rivers, streams, wetlands, potholes, tundra and beaver ponds		
	. Water levels	. Stereo imagery, laser and radar altimetry
	. Areas, perimeters and shapes	. Orthophotography
	. Volumes	. Radiometry,?
	. Depths	. ?
	. Changes (seasonal, floods, seiches, droughts)	. Time-lapse imagery
	. Age and permanence	. Time-lapse imagery
	. Distribution of geo-potential of water bodies	. Laser and radar altimetry, stereo imagery
(b) CHARACTERISTICS - on terrain		
	. Temperature - surface	. IR thermometry, imagery (8-14 micron)
	. Temperature - vertical profiles	. ?
	. Snow cover areas	. Imagery - visible
	. Snow cover depths	. Radar, radioactive attenuation
	. Water equivalent of snow pack	. Radiometry data, resistivity
	. Ice thickness	. Holography, radiometry
	. Ice texture (top and bottom)	. Holography, ?, radar
	. Water/ice boundaries	. Imagery - visible IR
	. Plumes and patterns of turbidity	. Multi-spectral imagery

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Opacity and other optical properties	. Laser beam penetration, multispectral
	. Commercial movements and storage (e.g. logs, boats etc.)	. Imagery
	. Phenology (freeze-up, break-up)	. Time lapse imagery
(c) CHARACTERISTICS - atmospheric (hydrometeorology)		
	. Rainfall and snowfall rate and accumulation	. ?
	. Storm tracks	. Spherics
	. Wind factors	. ?
	. Precipitable water vapour content (profile)	. Radiometry, temperature profiles, IR spectrometry
	. Evaporation rate over water bodies	. Energy balance
	. Evapo-transpiration rate of vegetation	. Energy balance
	. Cloud climatology	. Photography?
	. Cloud water content	. Radiometry, lidar data
	. Atmospheric optical properties (e.g. transmissivity, scatter, etc.)	. Lidar data
(d) GROUNDWATER - (hydrology)		
	. Location and mapping of aquifers	. Thermal imagery, resistivity, other geophysical variables, hologram (LF)?
	. Soil moisture	. ?, radiometry, resistivity
	. Discharges (as springs) into lakes and rivers, changes with season	. Thermal imagery

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Permafrost location and boundaries	. Thermal imagery, resistivity
	. Permafrost progressive destruction by construction, vehicular use, pipelines, etc.	. Thermal imagery
	. Holes in permafrost - revealing regions of good sub-surface conductivity associated with mineralization	. Thermal imagery
	. "Sensing" phenomena:	
	- Phreatophytes (deep-rooted, water-loving plants)	. Multi-spectral imagery
	- Concentrations of floral growth and temporal variations	. Multi-spectral imagery
	- Salts (calcium and sodium sulphates and carbonates) deposited on surface by evaporated ground water	. Multi-spectral imagery
	. Sink holes - small regions of localized land collapse	. Multi-spectral imagery
(e) WATER/LAND BOUNDARIES		
	. Run-off boundaries	. Photography
	. Irrigation patterns	. Photography
	. Underwater topography	. Colour photography, multi-spectral imagery
	. Coastline geomorphology	. Stereo colour photography, multi-spectral imagery
	. Coastal maps (chart maintenance)	. Orthophotography
	. Beach morphology	. Stereo-photography
	. Sediment motions and accumulations	. Multi-spectral, time lapse imagery

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Damage assessment from floods, frost, ice flows, wave action and erosion	. Photography
	. Locations for gauging stations	. Stereo-photography
	. Sites for reservoirs and dams	. Stereo-photography
2. DYNAMIC STATE OF WATER		
	. Current and turbulence mapping	. Photography injected dye traces (e.g. Rhodamine) by laser
	. Flow speeds	. Stereo time-lapse photography
	. Volumetric flows	. ?
	. Waves and swells - heights, periods, sea states, energies	. Photography, E-M scattering, magnetometry
	. Tides and tidal currents	. Photography, E-M scattering, magnetometry
	. Breakers and surf characterization, undertow warning	. Photography, E-M scattering magnetometry
	. Ice movement and break-up patterns	. Time-lapse photography
	. Rate of snow melt	. Energy balance
	. Characteristics of convergences (merging of water masses)	. Thermal mapping
3. CHEMICAL STATE OF WATER		
	. Salinity mapping	. Resistivity-surface
	. Salinity profiles	. Resistivity-profile
	. Nature, extent and movement of oil slicks	. Multi-spectral imagery. Fluorescence signatures, microwave radiometry data, SLAR data
	. Nature, extent and diffusion of industrial waste plumes	. Multi-spectral imagery, injected dye traces by Laser and photography

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. Nature, concentrations, extent and movement of other contaminants and pollutants (e.g. heavy metals such as lead and mercury, synthetic organic chemicals such as DDT)	. Multi-spectral imagery
	. Estuarine salt water intrusion	. Resistivity?
	. Dissolved oxygen content	. ?
	. Presence of radioactive materials, principally tritium	. Gamma-ray spectrometer output
4. BIOLOGICAL STATE OF WATER		
	. Detection, mapping and movement of plankton	. Multi-spectral imagery, specific vapour concentrations
	. Detection, mapping and movement of algae	. Multi-spectral imagery, spectrometer data, specific vapour concentrations
	. Detection, mapping and movement of benthic forms (plants or animals living on sea bottom)	. Colour photography, multi-spectral imagery
	. Nutrient content - eutrophication	. Multi-spectral imagery
	. Bacterial and virus content and concentrations	. Multi-spectral imagery,?
	. Underwater plant growth mapping	. Colour photography multi-spectral imagery
	. Detection and concentrations of chlorophyl	. Spectral response
	. Fisheries:	
	- Identification and locations of fish schools	. Photography

CLASSIFICATION	PARAMETERS	R/S OBSERVABLES
	. "Sensing" phenomena for fish tracking:	
	- Mapping of fish oil in surface slick	. Spectral response
	- Bird concentration	. Photography
	- Sources of fish food	. Iodine vapour concentration
	. Spawn mapping	. Multi-spectral imagery
	. Lake productivity	. ?

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3. Useful Applications of Earth-Oriented Satellites, Summaries of Panel Reports, National Academy of Sciences, 1969.

4. A.R. Barringer, Airborne Exploration, Mining Magazine, Vol. 124, No. 3, March, 1971.

5. A.R. Barringer, Detecting the Ocean's Food (and Pollutants) from Space, Ocean Industry, May, 1967.

6. Communications with Dr. R.K. Lane, Canada Centre for Inland Waters, and early drafts and working papers of Working Group on Water Resources (Ref. 1 above).