REMOTE SENSING OF WETLANDS

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16. Abstract

The concept of using remote sensing to inventory wetlands and the related topics of proper inventory design and data collection are discussed.

It is evident that remote sensing has special advantages for studying wetlands over traditional ground-based methods because of the limitations imposed on field work by the poor trafficability of most wetlands. The advantages of remote sensing include economy, timeliness, a favorable viewing perspective, synoptic observation, and the creation of permanent graphic records.

The material presented shows that aerial photography is the form of remote sensing from which the greatest amount of wetlands information can be derived. For extensive, general-purpose wetlands inventories, however, the use of LANDSAT data may be more cost-effective. Airborne multi-spectral scanners and radar are, in the main, too expensive to use -- unless the information that these sensors alone can gather remotely is absolutely required.

Multistage sampling employing space and high altitude remote sensing data in the initial stages appears to be an efficient survey strategy for gathering non-point specific wetlands inventory data over large areas.

The operational role of remote sensing in supplying inventory data for application to several typical wetlands management problems is illustrated by summary descriptions of past ERIM projects.

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FOREWORD

Remote Sensing of Wetlands is a special technical
report designed to provide the potential user with a basic
understanding of the information gathering capabilities of
remote sensing technology relative to wetlands, and the need
to critically consider and match up the key factors of wet-
lands inventory design related to remote sensing in order to
effect its optimal implementation.

Preparation of the report was performed as part of an
effort to summarize the findings of a five-year program at
the Environmental Research Institute of Michigan (ERIM)
aimed at applying remote sensing technology to land use and
resource management problems of concern to the people of
Michigan. The inventory and mapping of wetlands was a
significant aspect of the overall program and the knowledge
and experienced gained in the process forms the basis of
much of the material and many of the recommendations found
in this report. This program was made possible by a grant
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ERIM is a state sponsored non-profit research corporation
established on January 1, 1973 as successor to the Willow
Run Laboratories of the University of Michigan's Institute
of Science and Technology.

ΣERIM

ACKNOWLEDGMENTS

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INTRODUCTION

In the face of increasing competition for undeveloped
land, federal and state governments have recognized the
need to provide wetlands with the protection and environ-
mentally sound management they deserve. Before the programs
designed to carry out these policies can be implemented,
however, a great deal of baseline inventory data about
wetlands must be collected or updated. Remote sensing
promises to be one of the most valuable tools available for
accomplishing this task because it provides a practical way
to collect the large volumes of data required and reduce it
to information in a period of time short enough for the
information to still be relevant to decision making.

1.1 ADVANTAGES OF REMOTE SENSING

The basis of the cost-effectiveness of remote sensing
lies in the fact that its special advantages substantially
reduce the amount of field work required to conduct a wet-
lands inventory. Reducing the proportion of total inventory
effort taken up by field work is beneficial in general terms
because field work is typically the most expensive and time
consuming activity associated with an inventory of natural
resources. Reducing the amount of field work required in
connection with a wetlands inventory is of particular value,
however, because wetlands are some of the most difficult
environments in which to do survey work. The obvious reasons
that wetlands are hard to work in are 1) their poor trafficability,
2) their general lack of topography which prevents obtaining
any overview of an area, and 3) large amounts of dense and
frequently tall vegetation (see Figure 2). An additional
factor which compounds the difficulty of the inventory task

FIGURE 2. PROBLEMS ASSOCIATED WITH USING FIELD SURVEY METHODS IN WETLANDS.
Dense vegetation makes it hard for this biologist to obtain a repre-
sentative impression of this marsh. Since he must travel by canoe,
he is restricted to observing primarily that vegetation which occupies
sites adjacent to stream channels and other patches of open water.

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is that many types of wetlands are floristically very dynamic, so that actually several surveys must be carried out (either seasonally or annually) to obtain an accurate portrait of their vegetative composition.

Briefly, the special advantages of remote sensing that make it so well suited for use in wetland inventories are:

1. Economy. The cost of obtaining inventory information via remote sensing data collection and analysis is typically much lower than the cost of obtaining the same type of information through field work. Thus, a given survey can be performed less expensively, or a larger area can be inventoried for the same cost.

2. Timeliness. Remote sensing can provide the user with timely information in two important ways. First, airborne remote sensing systems have a quick reaction potential, so that data can be collected and made available for analysis in response to an urgent or special need in a very short period of time or on short notice. Secondly, the speed with which remote sensing data can be gathered makes it possible to acquire inventory data under nearly constant environmental conditions, which improves the quality of the inventory and makes more accurate data interpretation possible.

3. Favorable Viewing Perspective. Most remote sensing data are collected with the sensor viewing the terrain from vertically overhead. When processed, data collected in this fashion resembles a map-like view of the ground. Observing a scene from this vantage point usually makes identifying the boundaries between different terrain features easier, which, in turn, also makes it easier to determine their location and relative abundance (see Figure 3). Furthermore, if the presentation of

FIGURE 3. AERIAL VIEW AIDS WETLAND IDENTIFICATION AND ANALYSIS.
Several important features of this wetland complex in southeastern
Michigan are far more readily apparent in this early spring oblique
air photo than they would be to someone standing on the road which
runs through the area. For example, the upland/wetland boundary is
quite distinct, and several different physiognomic classes of vegetation
are easily discernible.

the data is truly planimetric, certain measurements, such as area and perimeter, can be made more easily and perhaps even more accurately from the remote sensing data than on the ground.

4. <u>Synoptic Observation</u>. The ability to observe a very large area on high altitude photography or spacecraft imagery under uniform illumination is an important aid to identifying the important components of a landscape and in judging the significance of their spatial relationships. Stratification of an area can often be made more accurately and precisely as a result. Better stratification, in turn, will result in more effective application of inventory procedures at reduced costs by isolating those areas that need detailed study while eliminating those that don't.

5. <u>Permanent Graphic Records</u>. One of the most effective ways to evaluate how well a resource management technique is working, or what the results of a current inventory mean, is to compare existing conditions to those of the pre-treatment past. Using data from previous field work for this purpose is often less than desirable for at least two reasons: 1) the bias introduced by the person that did the work is often unknown; and 2) precisely the right type of data may not have been collected; e.g., plot locations may not be correct; not exactly the right parameters were measured; or not enough data were collected. Remote sensing overcomes these obstacles because its data can be efficiently stored in its raw (i.e., uninterpreted) form.

Then, when a comparison study is to be made, the old remote sensing data can be retrieved and interpreted in such a fashion that the needed historical environmental data will conform exactly to what is required for comparison with the current environmental data.

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1.2 LIMITATIONS

In spite of all the advantages just listed, there remain circumstances under which other methods are better for inventorying wetlands, and remote sensing should not be regarded as a panacea. Under some conditions field work is still the most economical or accurate way to collect wetlands inventory data. This is obviously true when very detailed environmental information is required, e.g., the complete floristic make-up of a plant community.

Another potential limitation is that, although remote sensing data <u>collection</u> is often quite inexpensive, the <u>interpretation</u> of that data can be both more expensive and more time-consuming than the cost of producing the same data by field work if the inventory is poorly designed or an inappropriate type of remote sensing used. Furthermore, the use of remote sensing data requires an agency to either contract the work out or to build up an in-house capability to collect and analyze remote sensing data, which can also be very expensive.

Finally, there is the issue that remote sensing derived inventory data is often not equivalent to traditional types of inventory data, and thus does not perform well in existing user decision models. This means that either the existing models must be modified or new models developed before the full value of the remote sensing data can be realized.

Nevertheless, even with these few drawbacks, remote sensing is one of the most powerful tools available to those interested in gathering information about wetlands. By careful analysis of information needs, proper inventory design, and consideration of how the data are to be used, these few pitfalls can be avoided and the many benefits of remote sensing fully realized.

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1.3 SCOPE OF REPORT

This report is designed to bring together in one place the information essential to understanding the operational use of remote sensing for the inventory of wetlands. Its purpose is to provide the potential user of this technology with a practical introduction to the range of remote sensing techniques that are operationally available and to provide guidelines for identifying generally which technique will best satisfy a specific set of wetland inventory information requirements.

It is not the intention of this report, however, to go into a step-by-step description of how to apply remote sensing techniques. Rather, the material presented focuses on explaining the aspects of the different techniques that make them best suited for certain jobs. From this starting point the user can then begin to make personal judgments as to their relative effectiveness for meeting the various information requirements associated with a specific inventory task. Those interested in a detailed treatment of the technology and implementation of remote sensing are referred instead to the Manual of Remote Sensing (1975), published by the American Society of Photogrammetry.

1.4 ORGANIZATION OF REPORT

The material contained in this report has been selected to provide the reader with four basic types of information: 1) the benefits of using remote sensing to inventory wetlands; 2) the classes and accuracy of wetlands description data that are obtainable using remote sensing; 3) the special factors that must be considered in designing an inventory using remote sensing; and 4) some general

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information about how remote sensing data are generated
and processed and how data collection over wetlands can
be optimized.

Chapter 2, which follows, is offered as a brief review
of the basic operating characteristics and the differences
and similarities of the basic remote sensor systems for
those who might be unfamiliar with this background infor-
mation.

In Chapter 3, the information-supplying capabilities
of remote sensing are discussed. Both the range of
information classes and the accuracy with which they can be
obtained are surveyed.

In Chapter 4, the integration of remote sensing into
wetland inventory design is considered. The discussion
begins with a brief look at the basic types of wetland
inventories and then proceeds to analyze user information
needs and inventory design constraints in terms of option
selection for the different components of an inventory.
The interrelationships among inventory components are
stressed. General recommendations are made regarding the
sensor system and survey strategy most appropriate for
each of the basic inventory types mentioned earlier.
At the end of this chapter the benefits of using a combina-
tion of sensors in a multistage sampling approach to large
area inventory are discussed.

In Chapter 5, the practical integration of remote
sensing into a variety of operational inventory situations
is illustrated through several short project descriptions.
Each project summary has two important themes; a data
application demonstration and a sensor system performance
description.

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Chapter 6 presents a summary and conclusions. For those desiring additional material of a tutorial nature describing remote sensing data generation analysis techniques, costs, and recommendations for optimizing data collection over wetlands, several appendices have been included containing information on these topics.

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BACKGROUND: REVIEW OF SENSOR SYSTEMS

Remote sensing is the process of measuring and recording the spatial pattern of the intensity of electromagnetic radiation reflected and/or emitted from a scene.

The use of remote sensing to assist in the inventory of wetlands is not a new idea. Biologists, planners, and managers began using black-and-white aerial photography for cover type mapping and improving area measurements before World War II, (e.g., Dalke, 1937; Leedy, 1940; and Dobie and Johnson, 1951). Following the war, the appearance of color and color-infrared films greatly improved the level of information detail obtainable and accuracy of photo interpretation. Then, about ten years ago, airborne multispectral scanners and radar -- sensors that can detect radiation in spectral regions beyond the photographic -- were developed for civilian use. These latter two sensors have made the collection of certain heretofore very difficult to obtain information a routine matter; e.g., it is now possible to make "heat maps". The most significant event of the of the past few years, however, has undoubtedly been the launch of Landsat 1 and 2. These two orbiting earth resources inventory satellites make it possible to obtain a low-cost look at any given area in the continental U.S. as often as every nine days, provided it is cloud free.

In its simplest form, a remote sensing system consists of 1) a data collection platform, 2) a sensor, and 3) a data processing facility (see Figure 4). In this section of the report, the characteristics of the three basic types of sensors that have demonstrated a feasibility for wetlands
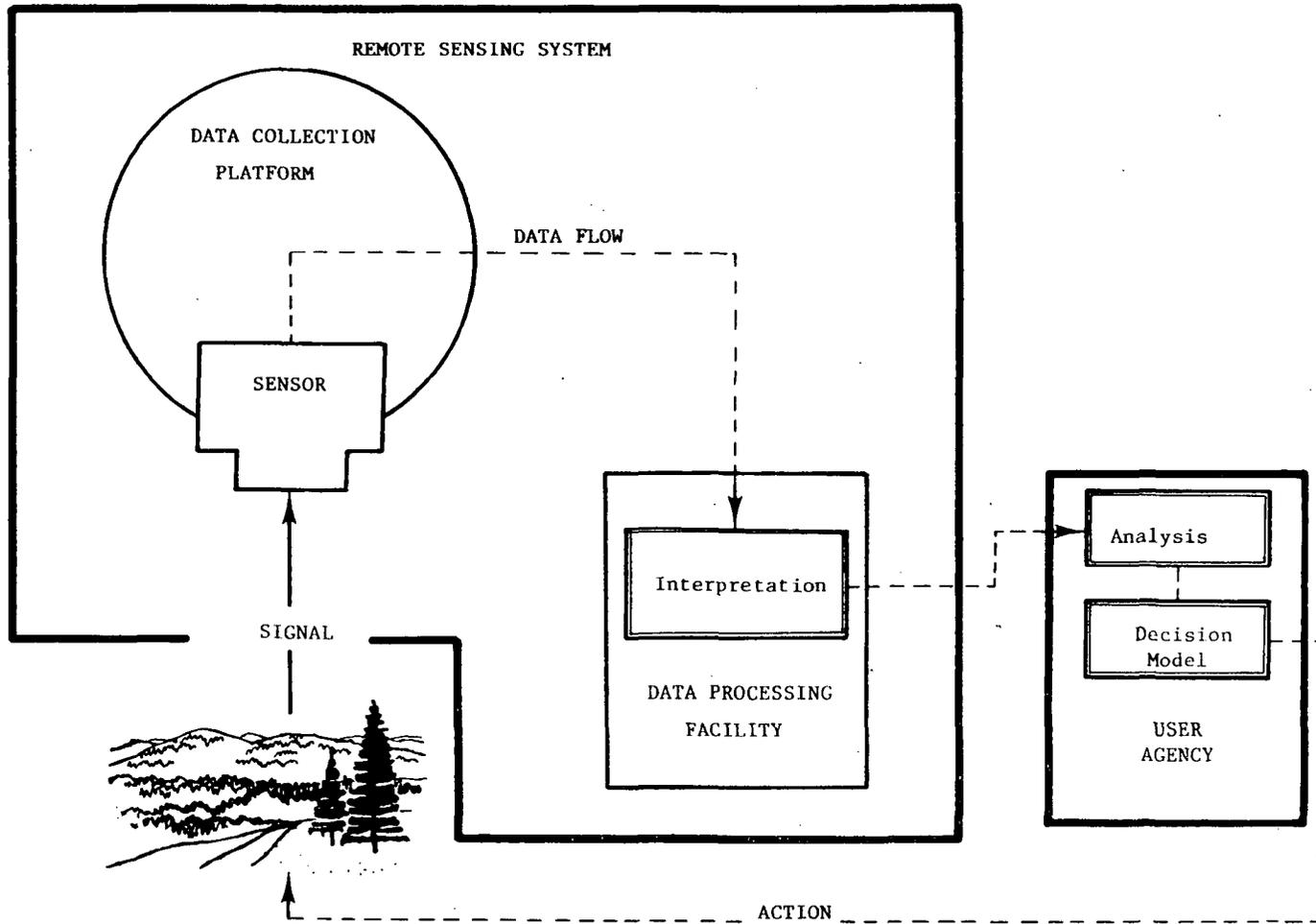
FIGURE 4. BLOCK DIAGRAM OF A TYPICAL REMOTE SENSING SYSTEM AND ITS INTEGRATION
INTO RESOURCE MANAGEMENT.

(cameras, multispectral scanners, and radar) will be examined. The discussion here will focus primarily on the similarities and differences between the type of data each sensor collects. How the data is generated, processed, and the associated costs are covered in appendix A. Differences in sensor performance as a function of being mounted in either a spacecraft or aircraft are considered at the end of the section.

2.1 PHOTOGRAPHIC SYSTEMS

Aerial photography is the most familiar form of remote sensing. In comparison with scanners and radar it has several important advantages. First, photographic systems have better resolution. Thus, from a given altitude more detail will generally be observable in a photograph than in an image produced by the other sensors. Second, photographs taken with metric quality cameras have excellent spatial fidelity. This facilitates accurate mapping and areal measurements. Third, from an interpretation standpoint, a photo provides the interpreter with a representation of the ground that appears essentially the same to him as if he were flying over it looking down. This familiar view of things greatly facilitates object identification and makes photo interpretation relatively easy to learn. Lastly, photography is easily obtained from several sources. Photos taken for government agencies are available for nominal fees. Many aerial survey firms also exist which specialize in photo collection. In addition, many resource management agencies have an in-house capability to collect aerial photography.

Photographic systems also have some limitations. The most serious limitation is probably the fact that cloudfree weather is needed to collect useful data. In many parts of

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the country completely cloud free days do not occur very
often, especially at certain times of the year. Several
cloud free days in a row, which would be needed for a large
aircraft survey project, are of course an even rarer occur-
rence, and waiting for good weather increases data collection
costs.

Another factor that may be considered a drawback is
that photo analysis and interpretation is essentially a
manual process. This means that trained photointerpreters
must be available. Furthermore, in many projects, unique
interpretation keys must be developed for use with the
specific photography available. On the other hand, more
information can typically be obtained by an experienced
interpreter than by an automated data processing system.

In addition, photographic systems are more limited than
multispectral scanners in the portion of the spectrum over
which they can detect radiation. Further, unlike radar which
can penetrate vegetation to some degree, photographs show
only the appearance of the first surface nearest to the
camera that reflects light. This means that in air photos
only the upper surface of the plant communities in wetlands
can be seen. Thus, even though one might also be interested
in knowing if there was water underneath the vegetation, it
would be impossible to tell this by observation of the photos
alone.

2.2 MULTISPECTRAL SCANNERS

The multispectral scanner (MSS) is the newest of the
three sensors considered and was developed in the early
1960's for two basic reasons: 1) to extend the spectral
data gathering capabilities of remote sensing techniques
beyond that which is possible with strictly photographic

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techniques; and 2) to reduce the time and effort required
to analyze the large quantities of data that this approach
dictates collecting by making the data computer-compatible.

MSS systems have several important advantages. First,
they can detect radiation over a wide portion of the spectrum
where many natural materials exhibit diagnostic spectral
reflectance patterns that can be used to identify important
terrain features of which they are a part. This wide range
of spectral sensitivity includes both <u>reflected</u> and <u>emitted</u>
radiation. Thus, an MSS is the <u>only</u> remote sensor that can
detect heat[1]. Secondly, scanner data can be calibrated fairly
simply and accurately. Thus, maps can be made which accurately
portray the nearly <u>instantaneous</u> apparent reflectance or
temperature of ground features over large areas. The other
major advantage of the MSS is that the data are recorded in
computer compatible form. This means that machines can be
used for data processing and subsequent user analysis. For
example, computer-generated ground feature recognition maps
can be plugged directly into computerized resource management
data bases; or this same information used to derive survey
statistics; or two such maps of different dates can be
compared to detect changes that have occurred during the
interval between the acquisition time of the two data sets.

There are also disadvantages connected with using MSS
systems. One is that an accurate cartographic presentation
of aircraft scanner data is difficult and expensive to produce.
Aircraft MSS data collection costs are also high and only a
limited number of organizations are prepared to do it. On the

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[1]Not all scanners have both capabilities, however. Those that
do not sense thermal radiation are called scanning spectrometers.
Those that only detect heat are simply referred to as thermal
scanners.

other hand, a large amount of Landsat data is available at very reasonable costs. Another drawback is that computer processing of MSS data usually involves large fixed costs that makes doing small areas economically infeasible.

2.3 RADAR

Radar is an acronym for Radio Detection And Ranging. Radar systems have several unique capabilities that make them very useful remote sensing devices. First of all, they operate in a portion of the spectrum that makes data collection possible during cloudy weather. Secondly, because radar provides its own source of scene illumination (this is discussed in detail in appendix A) it can operate at night as well. Third, resolution is independent of range, so very large areas (50-80 km/30-50 mi swaths) can be imaged at a constant level of detail. Fourth, longer wavelength radars make it possible to tell something about the surface conditions under a canopy of herbaceous vegetation because they can penetrate the canopy. Finally, for bare soil the relative soil moisture content of the first few centimeters below the soil's surface can also be imaged.

Radar also has some disadvantages. One of the most significant is that military restrictions limit civilian use to only resolutions greater than 1.5 m in range and 2.1 m in azimuth (5x7 ft, respectively). Second, a radar image appears "grainy" which may hinder interpretation. Third, the production of large scale, cartographically accurate maps is difficult becuase it is hard to acquire enough positional information during data collection to rectify the image properly. Fourth, there are few trained radar image inter- preters available; and, lastly, there are also very few commercial sources of radar data collection.

TABLE 1. CHARACTERISTICS OF REMOTE SENSING SYSTEMS

SENSOR	DATA PRODUCT	RESOLUTION	SPECTRAL RANGE	SPECIAL CAPABILITIES	APPROX COST OF DATA COLLECTION FOR 777 SQ.KM. (300 SQ.MI.) AREA	INTERPRETATION MODE & COST	COMMERCIAL AVAILABILITY
Photographic	Photograph	Best of all sensors; e.g.; 1 m. (3 ft.) at 1:20,000	.4 - .9 µm	Stereoscopic viewing possible	$2-4/sq km ($6-10/sq mi), when resolution = 1 m/ 3 ft.	Manual interpretation: $3-6/sq km ($8-15/sq mi)	1. Aerial survey firms 2. Government agency archives
Airborne MSS	1. Video Image 2. Electronic signal on computer tape	Approximately 20 times less than a photographic system at the same altitude	.33 - 14 µm	Can record mid-and far-(heat) infrared radiation	$3-5/sq km ($7-13/sq.mi), when resolution= 8m x 8m (25ft x 25 ft.)	Image interpretation: $3-6/sq.km ($8-15/sq mi) Analog processing: $1-2/sq.km ($3-6/ sq.mi.	Several domestic sources
LANDSAT	1.Video image 2.Computer tape	0.4 hectares (1.1 acres)	.4 - 1.1 µm	Large area coverage from space	Color Composite image= $15/ 9in frame; Digital CCT's = $200/frame	Digital processing $.20-.60/sq km ($.50-1.50/sq mi*)	EROS Data Center
Airborne Radar	Video image	Best available is 2.1 m x 1.5 m (5ft x 7ft) due to military restrictions	3.2 - 23 µm	Penetrate cloud & some herbaceous vegetation; Resolution independent of range	$10/sq km ($25/sq mi), when resolution = 3 m x 3 m	Image generation and manual interpretation $11-14/ sq km ($30-35/ sq mi)	2-3 domestic sources

*There is a high fixed cost for digitally processing Landsat data; thus it would not be practical to process an area much smaller than 1/2 of a quarter-frame (3900 sq km/1500 sq mi).

A summary of sensor characteristics and performance parameters is presented in Table 1.

2.4 DATA COLLECTION PLATFORMS: AIRCRAFT VS SPACECRAFT

Both aircraft and spacecraft have advantages for remote sensing data collection depending on the intended use of the data. Spacecraft, in contrast to aircraft, can 1) obtain coverage of large areas very quickly, 2) provide repetitive coverage on a frequent and regular schedule, 3) use sensor systems with narrow viewing angles which minimize changes in viewing geometry and facilitate interpretation, and 4) provide data which is essentially in orthographic form upon collection and thus facilitates cartography.

Aircraft, in contrast to spacecraft, can 1) be dispatched quickly to collect data in reaction to a crisis or to create a record of a situation under a fleeting set of interesting environmental conditions and 2) collect data at several levels of resolution using the same sensors by flying at different altitudes. Also, the best resolution is obtainable from aircraft systems. Table 2 compares the resolution ERIM photo interpreters have found characteristic of good quality aerial photography with that cited for space photos and Landsat images.

When detailed interpretation of photography is planned, another important advantage of an aircraft platform is that the best stereo vision is obtainable when remote sensing from aircraft altitudes.

TABLE 2. RESOLUTION OF PHOTOGRAPHIC SYSTEMS AND LANDSAT FOR MEDIUM CONTRAST OBJECTS

Sensor System	Scale	Object Size		Area Coverage	
		m. /	ft	sq km /	sq mi
1. Aerial Photography (9 in sq format)	1:6,000	.30 /	1	1.9 /	0.7
	1:12,000	.60 /	2	7.5 /	2.9
	1:16,000	.75 /	2.5	13.7 /	5.3
	1:20,000	.90 /	3	20.2 /	7.8
	1:40,000	1.4 /	5	84.2 /	32.5
	1:60,000	2.4 /	8	187.3 /	72.3
	1:80,000	3.4 /	11	336.7 /	170.0
	1:120,000	5.2 /	17	748.5 /	209.0
2. Space Photography (Belew and Stuhlinger, 1973) SKYLAB					
S190A Multispectral photographic camera (70 mm sq format)					
Color Film	1:3,000,000	23.8 /	78	25,921 /	10,000
Color Infrared	1:3,000,000	57.0 /	187	25,921 /	10,000
Black & White Infrared	1:3,000,000	68.0 /	223	25,921 /	10,000
S190B Earth Terrain Camera (4.5 in sq format)					
Color Film	1:936,000	15.2 /	50	11,881 /	4,624
Color Infrared	1:936,000	30.2 /	99	11,881 /	4,624
3. LANDSAT (NASA-GSFC, 1972)					
Singleband images	1:1,000,000	86.0 /	282	32,018 /	12,362
Color Infrared Composites	1:1,000,000	159.1 /	522	32,018 /	12,362

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WETLAND INVENTORY DATA DERIVABLE FROM
REMOTE SENSING

To set program goals intelligently wetlands managers
need several types of information; among these are 1)
resource description (including wetland abundance, distri-
bution, and condition), 2) change and trend information,
and 3) data on surrounding land-use. To obtain these types
of information the manager must carry out surveys and
inventories. As has already been pointed out, the special
advantages remote sensing possesses over field survey tech-
niques make it one of the most cost-effective ways to obtain
much of this data. It has further been stressed that proper
data collection can improve the quality of the raw remote
sensing data and make the extraction of information easier,
more accurate, and even less expensive. Finally, it has
also been pointed out that remote sensing is not a panacea
and that there are some types of information that it is not
suited to provide, or cannot provide at all.

In this section of the report the level of information
detail and accuracy that can be obtained using different
types of remote sensing is discussed in terms of the types
of information wetlands managers most often need to know.
In order of discussion these are 1) vegetation, 2) water,
3) soil characteristics, 4) wetland boundaries, and 5) land use
surrounding wetlands.

3.1 VEGETATION

The performance of the three operational sensor types
described in Chapter 2 will be discussed with regard to
vegetation mapping in the following order: photography,
multispectral scanners, and radar.

3.1.1 PHOTOGRAPHY

3.1.1.1 Space Photography

In a study of coastal wetlands in Delaware Bay using Skylab S190A color infrared (CIR) photography collected in September 1973, Klemas, et al (1975) found that Spartina alterniflora communities and open water could be correctly identified 78% and 98% of the time, respectively, using standard photo interpretation techniques. In comparison, the same investigators found that computer processing of Landsat data resulted in recognition of Spartina alterniflora that was 16% better than the photo interpretation results, but that recognition of open water was poorer by 5% using the automatic technique.

3.1.1.2 Aerial Photography

Cowardin and Meyers (1974) feel that the most useful results are obtained from photographic remote sensing when:

1) the data collection mission is planned to answer a specific question;

2) the flight is properly timed;

3) multispectral photography is collected and analyzed.

In terms of the accuracy to which different physiognomic forms of vegetation can be recognized on photography, Aldrich (1966) found that at photo-scales of 1:1,584 or larger all tree species could be identified to an accuracy of 90% or better. At scales greater than 1:1,200 Losee (1953) concluded that tree identification is based more on crown shape than on tone.

The traditional scales for forestry photo interpretation, 1:10,000 to 1:20,000, are also useful for the identification of some tree species, but in general are more valuable for the classification of groups of commonly associated tree species (Avery, 1966). At scales between 1:20,000 and 1:50,000 stand mapping can usually be done, if the right film type is used
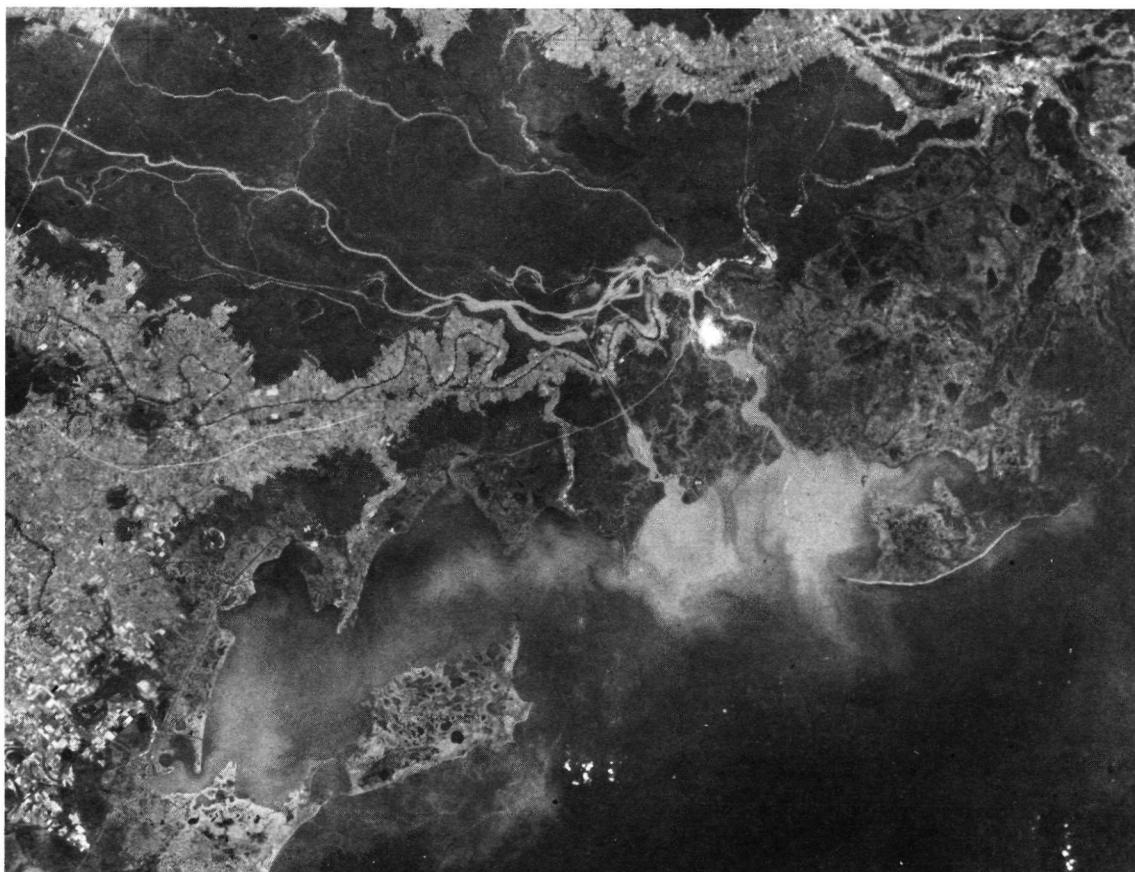
FIGURE 5. SPACE PHOTOGRAPHY OF LOUISIANA WETLANDS. The bayous, fresh-water swamps and salt marshes that surround the Atchafalaya River before it empties into the Gulf of Mexico show up clearly in this S190A color infrared photo taken from SKYLAB.

and the photography is collected at the right time of year.
The basic use of photos with scales larger than 1:50,000
is for forest vs. non-forest land surveys. Klemas et al
(1975) reports classifying forest land correctly 88% of the
time using 1:3,000,000 space photography.

For identifying the smaller life forms of inland wetland
vegetation accurately, in general, larger scales and color
photo are necessary. For example, D. Olson (1964) found that
for herbaceous wetland vegetation in Maine, a very significant
10% increase in accuracy came with an increase in scale from
1:20,000 to 1:12,000. An additional 5% increase in accuracy
was observed from 1:12,000 to 1:5,000. Seher and Tueller (1973),
found a 12% increase in classification accuracy in Arizona
wetland vegetation types between the scales of 1:10,000 and
1:1,000 (77% to 89%).

Very detailed vegetation mapping requires both large
scale photography and ground checking. Using 1:4,000 scale
CIR photography Enslin et al (1973) increased their mapping
accuracy from 77% to 94% for 14 classes of emergent vegeta-
tion found at Pointe Mouillee, Michigan when transects were
run in the study area and the occurrence of both mixed plant
and single plant communities correlated with their photo
appearance.

In coastal wetlands, however, Reimhold, et al (1973) found
that adequate identification of three herbaceous species groups
(Juncus sp; Distichlis sp; and Spartina sp) as well as four
density classes of Spartina could be made equally well from
1:20,000 or 1:40,000 scale color infrared photography,
although the most accurate interpretation was done at a scale
of 1:5,000. Undoubtedly, the fact that such species tend
to grow in fairly large homogeneous stands contributes to
their identifiability at the smaller scales.

Similarly, Schneider (1966) found that freshwater marsh and brackish marsh could be distinguished in the Everglades on the basis of characteristic vegetation at scales of from 1:20,000 to 1:57,000.

If two sets of photography can be exposed on a single data collection mission, emergent and submergent vegetation can be distinguished by using film sensitive to the visible spectrum in one camera and film filtered to the near infrared (NIR) portion of the spectrum in the other (Cowardin and Meyers, 1972). Only the emergent vegetation will appear on the infrared photos. The appearance of very sparse emergent vegetation can be further enhanced by overexposing the near infrared photography. If the use of two camera systems is not possible, color infrared film which combines the spectral sensitivity of both of these film types would be a good alternative approach. Its only drawback is that its exposure might be difficult to adjust to show the very sparse emergent vegetation without sacrificing information in the visible part of the spectrum.

In general, little difference in accuracy of marsh vegetation has been noted between results obtained using color infrared or color film, when both are flown at low altitudes (Seher and Tueller, 1973; Reimhold et al 1973); but, when data are collected at an altitude of over 15,000 feet color infrared film with a 15G filter seems to provide more information for the interpreter. It is also the opinion of several others that color film is a better choice for use by inexperienced interpreters. Film/filter combinations that have proved effective for specific wetland vegetation detection are listed in Appendix C.

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3.1.2   MULTISPECTRAL SCANNERS

3.1.2.1   Landsat

Several studies have investigated the useful-
ness of Landsat data for wetlands mapping. Much of the
interest behind these studies has come from the fact that
if wetlands can be accurately mapped with Landsat data
then the periodic coverage provided by this sensor would
provide an effective monitoring system for assessing wetland
changes.

In the coastal wetlands of Delaware, Kelmas et al (1975)
found that Spartina alternifolia could be mapped to an
accuracy of 93.7% and S. patens to the 87.0% level. Open
water was also mapped correctly 93.5% of the time. July
data was used.

In the Atchafalaya River Basin of Louisiana, Cartmill
(1975) found that some wetland plant species could be mapped
better using Landsat data than with aircraft MSS data.

Percent Accuracy

Category	Landsat	Aircraft MSS
Cypress-Tupelo	93	67
Willow	73	63
Water Hyacinth	96	90
Marsh	89	61
River	69	68
Lake	71	83

Part of the explanation for this performance is that the
varying canopy illumination seen by the aircraft scanner
confused the classifier. In the satellite data, however,
because of its very narrow view angle, scene illumination
was essentially constant.

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Anderson and Wobber (1973) found that broad salinity-related vegetative zones could be mapped based on vegetation indicator types in eastern coastal marshes. They recommended locating the landward boundaries of wetlands from the analysis of early spring Landsat data, followed by a second analysis using summer data to look at the vegetation in order to determine the salinity zones.

Carter and Shubert(1974)also found saline marshes could be identified. They mapped three communities: Spartina alterniflora, S. patens, and Iva Fructescens.

In Canada, in the northern clay section of Ontario, Boissonneau and Jeglum (1975) found that four classes of bog could be mapped on the basis of dominant plant physiognomy by level slicing MSS band 5. These include:

1. sedge open bog
2. sedge treed bog: 2 subclasses
3. dwarf shrub open bog: 2 subclasses
4. dwarf shrub - treed bog

In southern Michigan the author (in Sattinger, et al, 1974) found that wetlands corresponding to U.S.F.W.S Circular 39 (Shaw and Fredine, 1956) wetland types could be mapped to the following accuracies using simultaneous multidate computer recognition of March and June Landsat data:

Wetland Type		Accuracy (%)
Type 3	Deep Marsh	95
Type 4	Shallow Marsh	66
Type 5	Open Water	100
Type 6	Shrub Swamp	96

In this same study, the relative performances of several types of automatic recognition of wetlands were also assessed (See Table 3).

TABLE 3. PERFORMANCE OF FOUR AUTOMATED WETLAND INVENTORY
TECHNIQUES APPLIED TO LANDSAT DATA (Sattinger,
et al., 1974).

Mapping Technique	Performance						Comments
	Error in estimating percent relative abundance of wet-lands in scene.*	Percent water correctly identified	Percent marsh correctly identified	Percent swamp correctly identified	Percent overall correct recognition Average of 3 classes	Total Scene	
Single Band Level Slicing of Near Infrared Data	+40%	83	37	70	63	72	Much marsh missed, some called water; some swamp called marsh; much lowland forest called swamp.
Level Slicing of a Red Band Edited Using a Near Infrared Channel	+ 9%	91	60	71	74	78	Some water called marsh. Considerable marsh missed, much lowland forest called swamp.
Single Date Maximum Likelihood Ratio (MLR) Recognition Processing	+ 5%	91	68	82	80	84	Some water called marsh, considerable marsh missed. Some lowlands forest called swamp.
MLR Recognition Processing of Multi Date Data	− 4%	100	75	96	91	96	Moderate amount of marsh missed.

*Positive error indicates overestimates of relative abundance.

3.1.2.2 Aircraft Multispectral Scanners

Very little information is available on the accuracy of wetland vegetation classification using aircraft mounted scanners. An ERIM study in Florida, however, showed that tree islands in the Everglades could be mapped to an accuracy of 90% and that dense stands of sawgrass (75%-100% cover) could be recognized 80% of the time (Thomson, 1970).

In another ERIM study done at Pointe Mouillee, Michigan an aircraft scanner was used to map the emergent plant species of a waterfowl refuge area. Although point accuracies were not determined, the summary statistics of cover types for the area generated by the computer compare well with those determined by photo interpretation, which were known to be 94% accurate (see section 6.2 for further details of this study).

3.1.3 RADAR

Apparently no numerical accuracies have been reported in the open literature for the wetlands mapping capabilities of radar. Orr and Quick (1971) have, however, rated three radar systems in general terms based on wetlands vegetation mapping in a delta area of Louisiana. Their results showed the following:

Vegetation Type	Radar		
	8mm SLAR (Res: 30 m)	3 cm SAR (Res: 15 m)	3 cm SLAR (Res: 30 m)
Marsh	good	good	poor
Swamp	good	good	poor

Poor image quality was the reason given for the poor rating of the 3 cm SLAR system. Whether this was a result of poor

data processing, or a lack of spatial resolution combined with a longer wavelength is not clear.

3.2 WATER

The format of the discussion in this section will be different from that followed in the preceding section on vegetation. Instead of a sensor orientation, an application format will be used.

3.2.1 POND MAPPING

Pond mapping in the midwestern U.S. has been extensively studied at ERIM (Burge and Brown, 1970; Work and Thomson, 1974; Work, 1974; and Work et al, 1974) for the purpose of developing a means of producing an index to annual waterfowl production in the prairies. Conclusions reached were that (1) thresholding of a single near-infrared band of MSS data is more cost-effective than multispectral recognition processing (See Figure 6); (2) in order of preference, the best spectral band to use is 1.5-1.8 μm, 1.0-1.4 μm, and 0.73-0.92 μm; (3) using Landsat data, ponds as small as .4 hectare (1 acre) can be detected, but the threshold of consistent recognition is 1.6 hectares (4 acres); (4) applying proportion estimation techniques[1] to Landsat data improves detectability down to ponds as small as .13 hectare (.33 acre) and the threshold of consistent recognition is lowered to .53 hectare (1.3 acre).

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[1] Proportion estimation is a method developed by ERIM which takes advantage of the added information content of additional spectral channels to estimate the proportion of terrain features within a scanner's instantaneous field of view (IFOV). For a discussion of this methodology see Work and Gilmer, 1975.
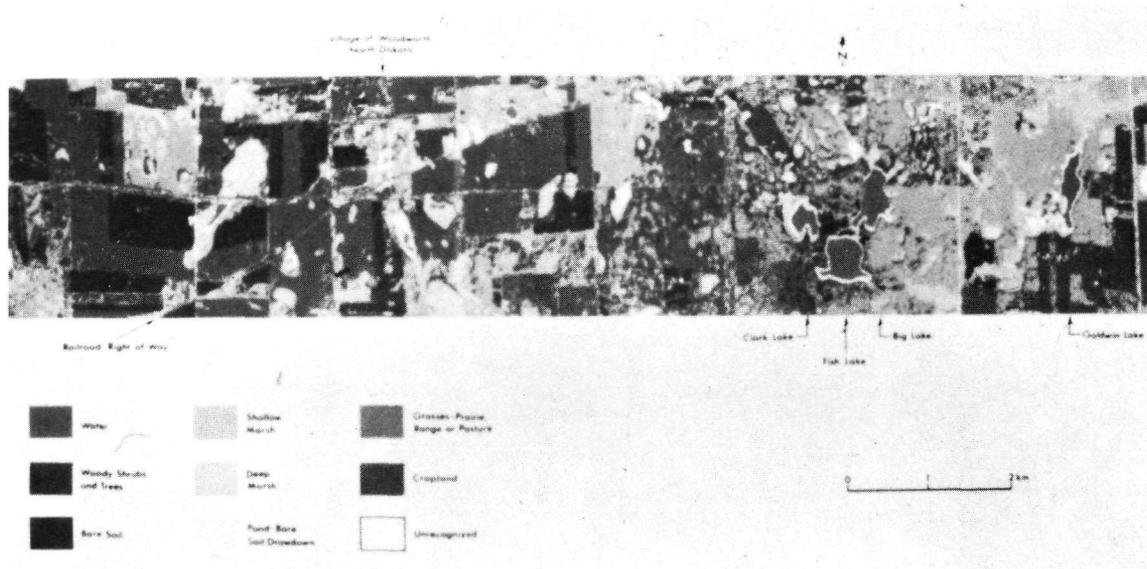
FIGURE 6. POND MAPPING IN NORTH DAKOTA BY AIRCRAFT MULTISPECTRAL SCANNER.
Open surface water was mapped by thresholding a single channel of NIR
data and the results merged with pattern recognition output of vegetation
classification to form the composite map shown. (courtesy of E. Work)

3.2.2 DRAINAGE ANALYSIS

Parry and Turner (1971) found that small stream detection is improved by 37% for second and third order drainage channels using black and white infrared compared to panchromatic film in New Brunswick.

Orr and Quick (1971) also compared the performance of the three radar systems listed in the vegetation section for mapping features associated with drainage systems; their findings were as follows:

	RADAR		
	8 mm SLAR (30 m res)	3 cm SAR (15 m res)	3 cm SLAR (30 m res)
Feature			
Natural levee	Poor	Poor	Poor
Abandoned channel	Excellent	Good	Poor
Point bars	Good	Good	Poor
Spoil banks	Good	Poor	Poor
River bars and Islands	Good	Good	Good

Based on these results it was their feeling that radar data were best utilized at the regional resource analysis level because the radar images provided about the same information for large areas as photo mosaics. For more detailed local analysis the authors concluded that photos were more useful.

3.2.3 WATER QUALITY PARAMETERS

The synoptic observation potential of Landsat for instantaneously monitoring water quality parameters over large areas has generated much interest. Moore et al (1975) found it possible to measure the following parameters

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in a study of a reservoir in South Dakota:

Water Quality Parameter	Correlation of Field Measurements with Landsat Data
Chlorophyll "a"	sometimes
Turbidity	high
Secchi Disc Transparency	high
Water Depth	sometimes

In addition, aircraft multispectral scanners have the potential to produce apparent surface temperature maps of waterbodies. (See Figure 7)

3.3 SOILS, FLOODING, AND FLOODPLAINS

Using Landsat data Bands 5 and 6, Deutsch et al., (1973) were able to distinguish between bare soils which had flooded and upland soils which had not been inundated. Hoyer, et al (1973) subsequently found that the inundated area of a vegetated landscape could be mapped using Landsat band 7 up to five days after recession of the flood waters.

Moore and Rusche (1974) found that for a very detailed (field by field) determination of flood levels, an aircraft photographic system was required. They found that successful flood extent could be determined by photo-interpretation of color infrared film to locate debris lines created by the washing up of dead vegetation.

Parker et al (1970) found that both black and white panchromatic and color film can be used to identify the location of flood plain boundaries in glaciated terrain in Wisconsin. Their results showed that while photointerpreted delineations of flood plains agreed perfectly with Corps of Engineers field data at only 28% of their measured cross sections, they nevertheless were within 30m (100 ft.)
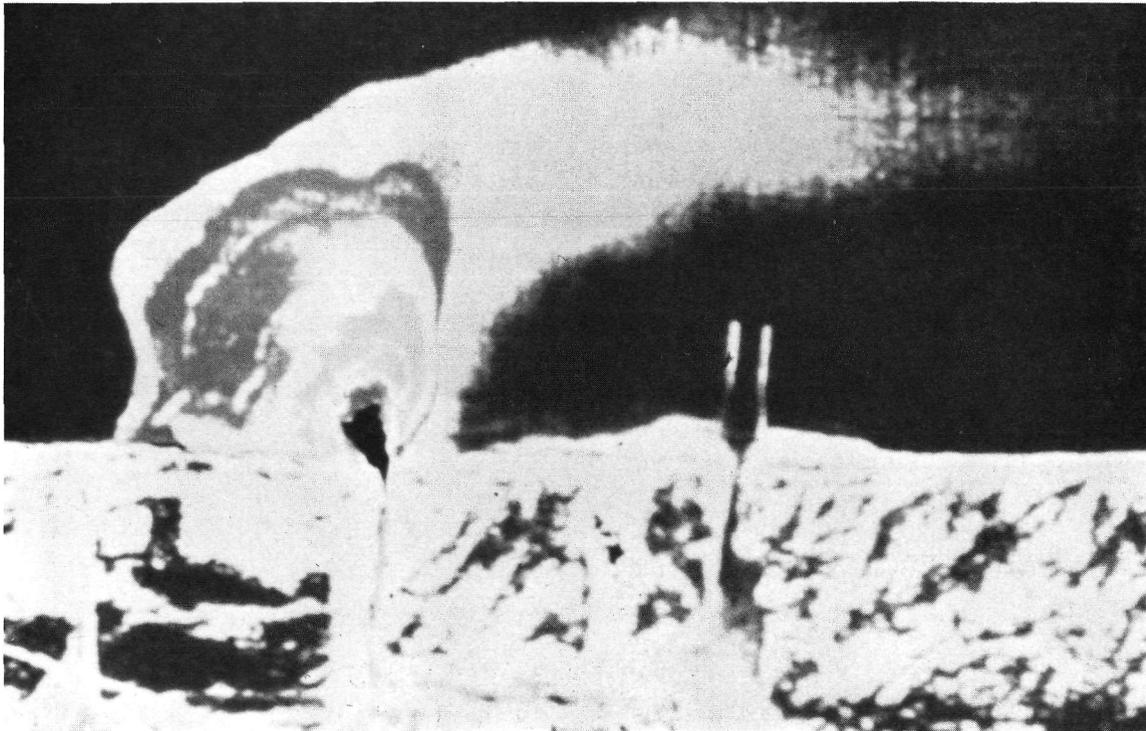
Temperature (°F)	Tone (Proceeding Out From Center of Plume)
80.6	black
78.8	dark gray
77.0–75.2	light gray
73.4	white
71.6	medium gray
69.8	white
68.0	dark gray

FIGURE 7. THERMAL MAP OF POWER PLANT DISCHARGE INTO LAKE MICHIGAN.
A single channel of ERIM aircraft MSS data was level-sliced and
calibrated to surface water temperature using spot field measurements.
The data was collected and processed as part of a study by ERIM to
assess the effects of thermal effluents from nuclear power plants
on local limnology (Stewart and Polcyn, 1970).
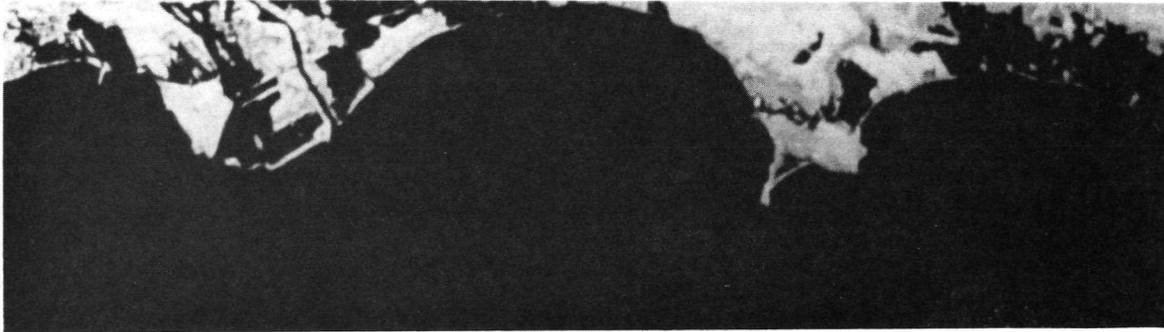
Flooding Severity Class	Tone
open water	black
soil still saturated at surface	dark gray
soil flooded at height of storm	medium gray
unflooded	light gray

FIGURE 8. LAKE ERIE SHORELINE FLOODING ASSESSMENT BY LEVEL–SLICING OF AIRCRAFT MSS DATA. The objective ratings of flooding severity shown here were collected and processed by ERIM and available to civil authorities within 24 hours of the height of the storm which generated the wave and wind conditions responsible for the flooding. The data was useful for disaster relief planning and damage assessment (Sattinger et al, 1973).

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of the engineering data 65% of the time and within 60m
(200 ft.) 95% of the time.

3.4 WETLAND BOUNDARIES

Identification and location of the ordinary high water
level (OHWL) is an important part of wetlands inventory
because many states have chosen to use this as a means of
defining where public and private ownership of wetlands meet.

Since hydrographic verification of OHWL and engineering
plotting of its location on the ground is both time consuming
and costly, other methods must often be relied on to accom-
plish this task. One of the methods used is to estimate
the location of the OHWL by judging it to be located on the
boundary separating wetland vegetation associations which
are known to require periodic inundation and those that are
characteristic of somewhat higher and drier sites.

Good success has been achieved with this technique
under certain conditions. These conditions are that vegeta-
tion indicative of OHWL must vary with 1) hydrologic regime,
2) shoreline gradient, and 3) the region's biogeographic
characteristics (Deeley et al 1975). Best results are
obtained on natural lakes of moderate shoreline gradient
within continuous drainage systems.

Where water levels are artificially controlled, veg-
etation communities will probably be more characteristic
of the induced conditions, so care must be exercised in
the application of this approach.

McEwen et al (1976) found that in practice using 4x enlarge-
ments of 1:80,000 color infrared photos, it takes five days to

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interpret, delineate, and field check the major vegetation associations that are associated with the upper wetland boundary in coastal wetlands on a 7.5 minute USGS map. They found the accuracy of boundary placement to be within 30' of engineering data.

Lukens (1968) found that the positive error of upper wetland boundary placement associated with inland wetlands to be greater, and dependent on flying height as shown below:

Location Error of Upper Wetland Boundary (m/ft)	Flying Height (m/ft)	Scale of Photography
10.7/35	900/3,000	1:6,000
12.2/40	1800/6,000	1:12,000
13.7/45	2750/9,000	1:18,000
15.2/50	3700/12,000	1:24,000

Verification of the correspondence of photointerpreted mean high water level and the real thing has been done by Polis et al (1974) who found that hydrographic measurements of the volume of a wetland basin compared with the remote sensing derived volume estimate within the measurement error of the two techniques.

3.5 LAND USE

Data on land use surrounding wetlands is important for two reasons: 1) cultural practices associated with certain types of land use can directly affect the quality of wetlands -- non-point source pollution of water from agricultural fertilizers and pesticide is an example-- and, 2) the types and arrangement of land use around wetlands can enhance their value substantially with waterfowl,-- for example, the presence of cropland is a definite

attractant since it is an important source of food for
many species of waterfowl.

The role of remote sensing in looking at land use is
two fold: baseline data on existing land use is, of
course, of prime interest, but monitoring changes in land
use is also an important task. From this latter information it may be
possible to identify deleterious trends before they have
completely destroyed adjacent wetlands.

Representative accuracies of Landsat land use mapping
were obtained by Kelmas, et al (1975) on a site adjacent
to Delaware Bay. For four broad categories they could map the
following classes to the accuracies indicated.

Land Use Category	Accuracy (%)
Forest	81.5
Wetlands	97.8
Water	87.9
Agriculture	90.2

The dependence of automated Landsat data processing
performance upon the time of year of the data is illustrated
by Kalensky's results (1974), in which he mapped forest
and agricultural land in Ontario.

| Land Use Categories | % Accuracy | | | |
	SEP	JUN	OCT	All 3 Dates
Agriculture	81	66	68	80
Coniferous Forest	85	82	89	91
Deciduous Forest	80	63	48	75
Average Accuracy	81	69	67	83

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The very poor accuracy of decidous forest mapping in October can be attributed to the leafless condition of the hardwood forest.

The author (in Sattinger et al, 1974) also used multi-temporal recognition processing of Landsat, this time to make a land use map of a part of southern Michigan. The results were as follows:

LAND USE	% Accuracy
urban/residential	51
agricultural	84
brush	73
deciduous forest	93
coniferous forest	92
schrub swamp	96
shallow marsh	66
deep marsh	99
lakes and rivers	100

In spite of these good accuracies for Landsat data processing, for general land use information high altitude aerial photography is the best remote sensing system. The reason for this is that activity, as well as land cover, can be inferred from photointerpretation, thus making a better (i.e., more versatile) sensor to use than Landsat which classifies things strictly on spectral information which is primarily indicative of cover. Typically, accuracies of 90% or greater are possible down to level II of the USGS Publication 671 land use classification system, which can be improved upon even further by the use of ancillary information.

In general terms Anson (1966) found that color and color infra-red film were 20 and 22% more accurate respectively for land use mapping than black and white panchromatic film, and that

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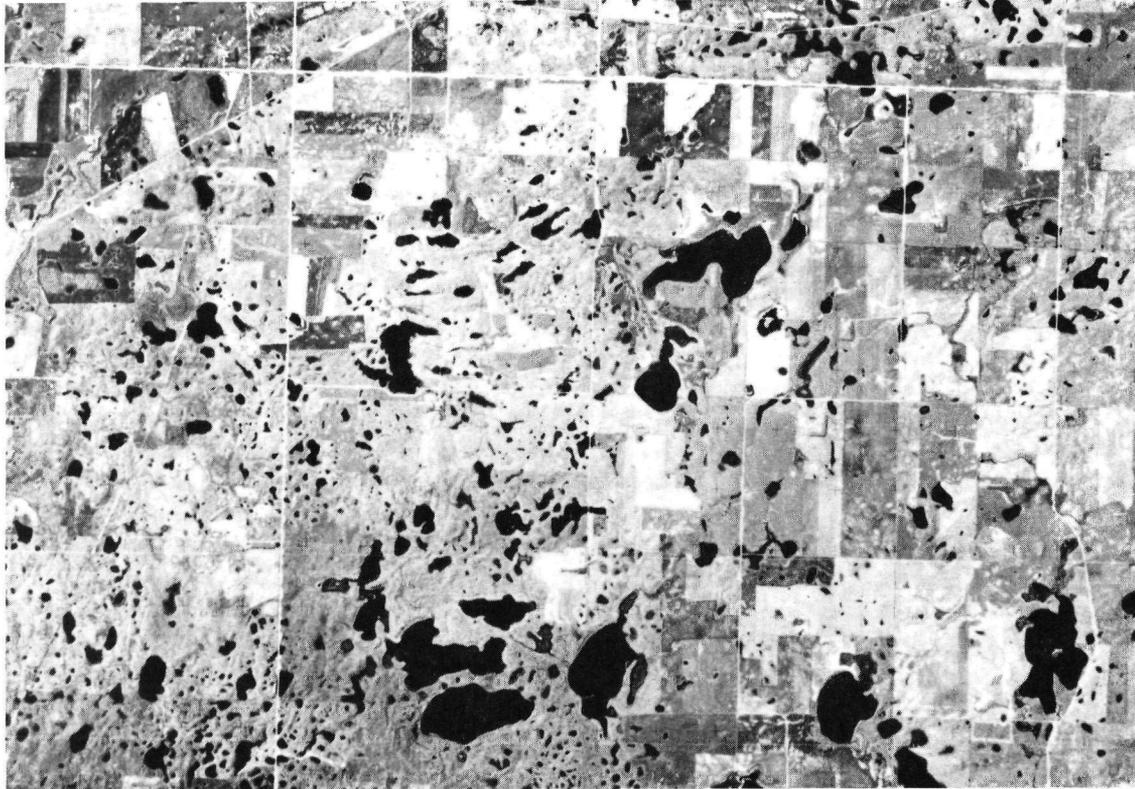
FIGURE 9. AGRICULTURAL LAND-USE SURROUNDING PRAIRIE WETLANDS. This
high-altitude NASA color infrared photograph of an area outside Wood-
worth, North Dakota shows the intimate association between food pro-
duction and waterfowl habitat in the U.S.'s "duck factory". The red
fields are mostly small grains, while blue fields, are bare soil-
formerly in wheat. Natural prairie vegetation is generally greenish,
while wetland vegetation is reddish. Such information on surrounding
land use was valuable for assessing the performance of ERIM's automated
pond mapping techniques during their developmental stages (Work et al,
1974).

color infrared film was better for mapping vegetation and drainage, but that color was better for soils and cultural features.

Land use mapping has been an important part of ERIM wetland studies in both Michigan and North Dakota. Our experience confirms Anson's conclusions. Figure 9 is included to illustrate the detail of land use information that can be interpreted from high altitude aerial photography. The area shown is part of ERIM's pond mapping test site (See Section 3.2.1).

4

INVENTORY DESIGN CONSIDERATIONS
RELATED TO REMOTE SENSING

For a given set of inventory design components to yield
a desired inventory output product, these same components
must, when taken together, form a sufficient basis for
successful information extraction and output product
generation. Each of the components in the inventory design
must, therefore, be consistent with, and appropriately
suited to the other components with which it is combined,
if a successful outcome is to be insured.

The key inventory components that must be jointly developed
are 1) a wetland classification system, 2) sensor and data
processing technique, 3) survey strategy, 4) supporting field
work, and 5) cartography (if maps are a desired output product).
Figure 10 graphically illustrates how closely interelated all
these inventory components actually are. An appreciation of
the significance of these interelationships is probably best
achieved by understanding the manner in which each component
influences the others through common technical parameters such
as scale, accuracy requirements, phenological event timing, etc.

The intent of this chapter is to develop this under-
standing. Accordingly, each of these five key inventory
components listed above will be treated individually. Before
doing this, however, it is desirable to provide a context
in which to base the discussion. The following section (4.1)
provides this frame of reference by analyzing the basic
types of wetland inventories and describing their output
products and operational characteristics.
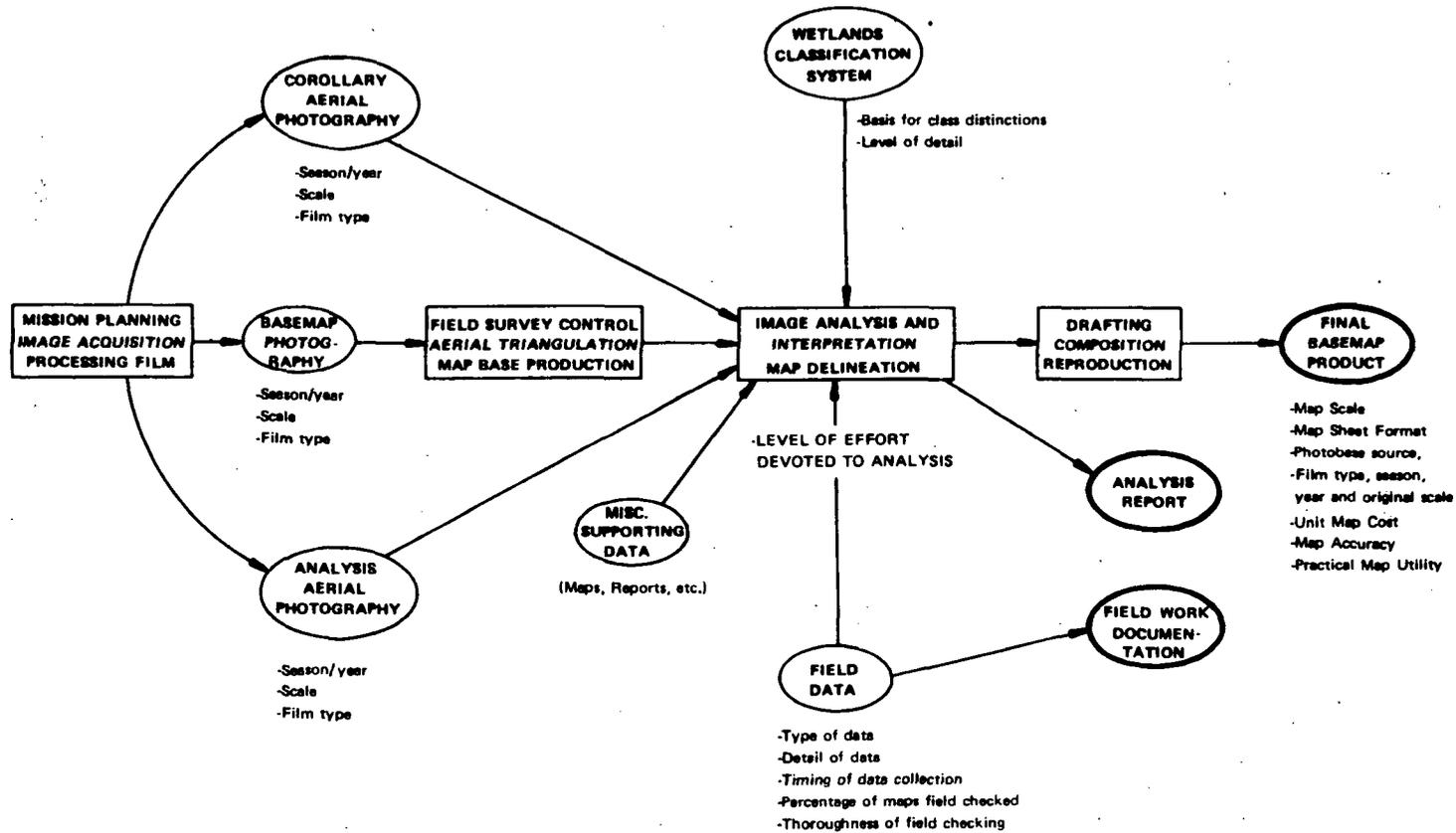
FIGURE 10.   SCHEMATIC DIAGRAM OF A REMOTE SENSING WETLAND INVENTORY SYSTEM
(After Deeley, et al 1975)

4.1   TYPES AND CHARACTERISTICS OF WETLAND INVENTORIES

ERIM;s experience has shown that wetland inventories can be grouped into four broad classes on the basis of their objectives.   These are:

1.   Baseline environmental reconnaissance and monitoring
2.   Program support
3.   Data base for land use planning and regulation
4.   Research

The characteristics we have found to be associated with these four inventory types are shown in Table 4.   Several trends are noticeable in the table.   For example, as the agency involved becomes more local, the need for detailed information increases, the area of interest becomes smaller, and the time available to complete the survey becomes shorter.

Another point to note is that nearly all users require both maps and statistics as output products.   The importance of good maps should not be overlooked.   As the length of time from the date of the survey increases, more and more emphasis will be placed on the maps and less and less on the statistics unless they are updated.

The discussions in the following sections will take into account the criteria listed here and the conclusions presented will reflect this influence.   At this point it is also appropriate to state that it is not the intent of these discussions and this chapter to cover the general theory and practice of natural resource inventory design. This has already been done well by others (e.g., Shelton and Hardy, 1975).   Instead, only those factors that are specifically related to the conduct of the remote sensing part of the inventory process are treated here.

TABLE 4

CHARACTERISTICS OF THE BASIC TYPES OF WETLAND INVENTORIES

INVENTORY TYPE	USER	PHYSICAL AREA	INVENTORY DATA REQUIRED	LEVEL OF DETAIL	PERFORMANCE PERIOD	OUTPUT PRODUCTS	ANALYSIS	DECISIONS
1. Baseline Environmental Reconnaissance and Monitoring	Federal, State agencies	U.S., Multi-State Regions, States	1. Resource description 2. Geographic location	General	2-5 years	Maps, statistics	Change detection	Policy formulation: new protection and acquisition requirements
2. Program Support Functions	Federal, State agencies	State-sized areas	1. Resource description 2. Geographic location 3. Resource ondition	General to Moderate	1-3 years	Maps, statistics	Trend analysis, cause-effect	1. Identify priority acquisition, pre-servation and Treatment sites
3. Land use Planning and Regulatory Data Base	State, County and Township organiza-tions	Counties, Townships and Individual Wetlands	1. Resource description 2. Geographic location 3. Resource condition	Moderate to Fine	2 months to 2 years	Maps, statistics, zoning ordiances, permits, boundary locations	Environ-mental impact	Wetland use regulation
4. Research	Resource Management Agencies, Land-owners	Individual Wetlands	1. Resource description 2. Resource Condition	Fine to Very fine	1 week to 6 months	Maps, statistics, biological indices	Cause - effect, treatment evaluations	1. Revised manage-ment plans 2. Research guidance

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4.2 WETLAND CLASSIFICATION SYSTEM

Where wetlands occur in definite basins and valleys or
are bordered by impervious materials or structures, their
boundaries are often quite distinct and easy to identify
from remote sensing data. Where slopes are gradual, however,
the transition between the wetland and upland is more in
the nature of a continuum. In this situation there is no
point at which everyone will agree that the wetland obviously
ends and the uplands begin. Yet, because it is often necessary
in order to get something done to have some reference
point, many users have developed a set of criteria which
define for them a locatable wetland/upland boundary. This
has led to the profliferation of a great many different
definitions of wetlands. As a result it has often been
difficult until recently to communicate about wetlands
because 1) there is a wide natural variability in wetlands
types within a region, and the significance of wetland types
varies between regions; 2) few persons are familiar with
the total range of variability within and between wetland
types; and 3) the terminology is very confused. The same
wetland names often refer to different wetland types in
various regions of the U.S.

To remedy this situation one function of the National
Wetlands Inventory Project of the U.S. Fish and Wildlife
Service has been to develop a new wetland classification
system for the U.S. This new classification system has
been designed with three primary objectives: 1) to group
together ecologically similar habitats, so that value
judgments concerning them can be made; 2) to provide a
consistent set of criteria for wetlands inventory work;
and 3) to foster a uniformity in concepts and terminology
throughout the U.S.

Insuring compatibility between the class identification
criteria of the new natural wetland classification system and
the data obtained from remote sensing has been an important
consideration in the design of this system since its in-
ception. Thus, in general, unless there is a good reason
to use another classification system, most users would do
well to use the new national system. By doing so, users
would realize several benefits: For example, their work could be
used to update or expand federal records or vice versa; the
compatibility of future surveys would make change detection
in wetlands easier; and, data from others areas would be
directly comparable.

In the event a decision is made to use a classification
system other than the new federal wetlands classification
system, it should be made only after serious consideration
of the effects this will also have on the remote sensing
data interpretation process and the nature of the final
inventory output product. Because choice of the classifi-
cation system determines what data will be collected and,
hence, what information the entire project can furnish, it
is essential that agreement as to what information is desired
govern the selection process. Care should be exercised to
pick the system that provides the required data but which
is not unwieldy or that includes a large amount of extraneous
data. The costs of interpreting raw survey data will be a
major part of the project's financial outlay and the more
streamlined the process is, the more cost-effective the
project will turn out to be.

Application of a too generalized classification system
at a large map scale would not make effective use of the
detailed information that could be interpreted from a

remote sensing system like large scale aerial photography.
Conversely, application of a too detailed classification
system at a very small map scale would result in a need to do an
excessive amount of field checking if a sensor that provides only
generalized synoptic coverage like Landsat is used.
The best designed inventory is the one in which a very
fine balance is achieved between fiscal, manpower, and time
limitations on the one hand, and necessary and adequate
inventory data on the other. To achieve this balance,
prior to beginning the inventory design, an outline resource
management plan should be drafted and used as a framework
to determine the data that will actually be needed to
justify the plan's premises and optimize its implementation.
What is typically found at this stage is that the type and
resolution of resource description data needed varies
with the level of government involved in the management
process and the type, intensity, and rate of land-use devel-
opment in the area of concern.

If the goal of the inventory is to provide all these
users with some information, or to conduct an open-ended
inventory in which the lower levels of government can
expand the inventory in detail at a later date, ERIM has found
another important aid to effective inventory is to use a
classification system that is hierarchical in nature.

Hierarchical classification systems are the most
flexible type of classification system because they permit
combining different levels of information detail and survey
intensity without any loss of data. Furthermore, a
hierarchical classification that has been specifically
designed to make use of remotely detectable parameters in
the classification process is the best type of classification

system to use, because it permits the maximum amount of information to be obtained from the data processing with a minimum amount of field work.

To illustrate this point, consider that if a single level (non-hierarchical) classification system is used, any survey unit that cannot be positively identified must be either left unclassified or labelled with a less than desired level of confidence (and probably accuracy). Unless, there is also some way to indicate this confidence factor in the labelling scheme then a map of uneven classification accuracy is the result. If this is not acceptable, then the unclassified areas must be field checked, which quickly runs up inventory costs if there are many such areas.

In a well designed hierarchical classification system all the classes at a given level are interpretable to about the same level of accuracy so the problem described above does not occur. Thus, hierarchical systems still permit making detailed classification through the use of successive levels, while also making it possible to produce a map of uniform confidence and accuracy. Figure 11 shows an ERIM example of how increasingly finer classifications of a resource are made at successive levels of a hierarchical classification system.

Once user information needs have been defined and a classification system that will supply this information selected, the next logical step in inventory design is to identify a sensor and processing technique that is capable of mapping the environmental parameters needed to make the identifications of the classes of the classification system. In the next section recommendations are made based on a review of the literature and ERIM experience regarding which sensor to use for mapping the features of wetlands. On the basis of these recommendations, it should be possible for a user to identify which sensor is most appropriate for a given inventory job.

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Classification of a typical northern white cedar (Thuja occidentalis) swamp
using the Interim Classification of Wetlands and of the United States developed
by the U. S. Wildlife Service for the Natural Wetlands Inventory.

ORDINAL LEVEL   AVAILABLE DESCRIPTORS

1. Ecological System: Marine, Estuarine, Riverine, Lacustrine, Palustrine

2. Ecological Subsystem: None

3. Class: Vegetation Dominant, Non-Vegetated Substrate
                             Forested, Shrub, Emergent, Moss/Lichen, Floating-
                                  leaved, submergent

4. Subclass: Deciduous Forested, Evergreen Forested

5. Order: Mineral soil, organic soil

FIGURE 11.   EXAMPLE OF WETLAND DESCRIPTION USING A HIERARCHICAL CLASSIFICATION SYSTEM

Most General

Most Specific

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4.3   SENSOR SELECTION

Selection of a sensor should depend not only on being able to detect required environmental parameters, but also on such factors as cost and organizational capabilities. Thus, even if 100% of the inventory data required to use a certain wetland classification system can be obtained using sensor A, if sensor B can provide as much as 85% of the required data at only one-half to one-third the cost, then sensor B may be rated the better choice.

The organization of the material in this section on sensor selection is organized on the basis of the three broad classes of wetland physical resources that most users want to know something about: vegetation, water, and soils.

Vegetation.   Most resource inventory work involving vegetation is concerned with the identification of (1) general groupings of plants with the same life form (i.e., physiognomy; e.g., trees vs shrubs vs emergent vegetation) or (2) individual plant species,or (3)groups of commonly associated species.   Photographic and MSS remote sensing systems are both capable of accomplishing these tasks to varying degrees.   Photographic systems have the advantage of finer resolution, which permits an image interpreter to make considerable use of factors like shape, texture, and association to make identifications.   MSS systems, by virtue of their ability to examine finer samples of spectral reflectance over a broader spectral range, differentiate plant communities of different life forms well on the basis of the aggregate spectral signature of their components and can quantitatively describe other interesting parameters like biomass, as well.

Vegetation is not uniformly identifiable throughout

the year, however, even on the ground. Factors that influence the seasonal detectability of plant species or communities include stand density, and contrast with the background. The annual development of plants is called phenology and successful remote sensing is largely based on a critical analysis of phenology. Phenology enables us to detect individual plants or groups of plants, due to plants becoming structurally distinct from others, or becoming spectrally distinct, or both, as the growing season progresses.

Thus, the key to successful remote sensing is partially a function of matching the diagnostic phenological reflectance of plants of interest to the spectral sensitivity of the remote sensing system to be used. Since most multispectral scanners potentially can collect data across the entire visible and infrared spectrum, use of this system generally insures the collection of useful data, once the right time of year to collect the data is identified. Photographic systems require more fine tuning, however, because films of different spectral sensitivities exist, and it is essential to pick one capable of recording radiation in the spectral region where the phenology results in maximum contrast.

The choices available for varying the spectral responsivity of camera systems occur on two planes; those associated with black and white films and those associated with color films. Within these two groups, the basic options are whether to record only visible light, only infrared radiation, or a combination of the two.

In our wetlands mapping projects at ERIM we have the opportunity to make assessments regarding which film types and what time of the year represent the optimum combinations for effectively imaging different types of wetland vegetation.

Our recommendations for the season and the spectral regions in which to acquire remote sensing data to take maximum advantage of the phenological differences among common wetland vegetation types are presented in Table 5. On the

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TABLE 5.   RECOMMENDATIONS FOR MAXIMIZING SPECTRAL DISCRIMINATION
OF IMPORTANT WETLAND VEGETATION TYPES BASED ON PLANT PHENOLOGY

Vegetation Type	Season of Maximum Contrast with Background	Spectral Region of Maximum Contrast
Aquatic		
Submergent		
at shallow depth	Summer	Near infrared
at greater depth	Fall	Visible
Floating	Summer	Near infrared
Marsh emergent and meadow	Fall	Visible
Shrubs	Summer or Fall	Visible or near infrared
Trees	Fall	Visible

basis of this table, natural color photography or visible
MSS data collected in the fall appear to be the logical
choices for most wetland inventories. In practice, however,
there are several constraints that may make summer CIR film
and MSS data more usable. Only a very short time period or
"window" is available in the fall when the important phen-
ological contrasts occur and this window can be further
restricted by the likely occurrence of bad weather. Also,
color film is more affected by haze so that data collection
is restricted to lower altitudes. As a result, large area
coverage is made more expensive to obtain.

ERIM and other investigators have found that the discrimination
capabilities of photographic systems for detecting certain
species can be improved by using special film/filter
combinations. Filters are thin transparent windows placed
over camera lenses that selectively absorb incoming radi-
ation at some wavelengths and transmit it at others. For
more information about film/filters that have proven succes-
sful and what they were used to detect, see Appendix C.

Determining the minimum resolution that will permit
fulfilling wetland inventory informational requirements
necessitates answering two important questions. First,
what is the smallest wetland complex that must be detected?
Many states have considered this to be 1 hectare (2.5 acres)
because that is the smallest area whose equivalent can
legibly be drawn on a 1:24,000 USGS topographic map. Many
biologists, however, particularly those concerned with water-
fowl management, feel .1 hectare (1/4 acre) is a more
desirable minimum size class.

Since it is normally desirable to be able to distinguish
between different types of wetlands, another set of resolution

requirements must also be considered. In this case resolution
must be fine enough to permit identification of wetlands
based on, for example, dominant vegetation lifeform. Typically,
the kinds of distinctions that are made at this level are those
of distinguishing between woody, shrub, and herbaceous
vegetation types.

The most demanding situation in terms of resolution is
where it is important to identify the presence of specific
herbaceous plant species which do not grow in homogeneous
stands. Where important species do form dense enough assemb-
lages, the additional information provided by the tonal con-
trasts of the entire stand and its background often make it
possible to identify them with less resolution than the
isolated herbaceous species. Table 6 summarizes ERIM's
findings regarding the range of scales for which different types
of vegetation information can be interpreted from photography.

Photographic systems provide the finest spatial reso-
lution from a given flying height of the three sensors under
consideration, as shown in Table 2. It is obvious from this
table that scales larger than 1:20,000 are needed to detect
individual plants, with the possible exception of large
trees. Furthermore, at any scale much smaller than 1:80,000
it is really only the tone of the canopy of a plant com-
munity of considerable extent that is observed. Thus, the
usefulness of the smaller scales of photography is largely
limited to making identifications of plant communities with
distinct spectral characteristics.

MSS resolution is defined in terms of the scanner's
instantaneous field of view (IFOV), the solid angle from
within which radiation reflected or emitted from the scene
is instantaneously integrated. The ground patch resolution

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TABLE 6. RANGE OF PHOTOGRAPHIC SCALES AT WHICH
DIFFERENT LEVELS OF VEGETATION DESCRIPTION
INFORMATION CAN BE OBTAINED

SCALE	INFORMATION
1:500 - 1:5,000	Plant species
1:5,000 - 1:20,000	Plant assemblages
1:20,000 - 1:40,000	Physiognomic groups
1:40,000 - 1:120,000	Broad hydrologic groupings

of an MSS can be calculated by multiplying the IFOV by the
flying height of the data collection platform. For example,
if an aircraft scanner has an IFOV with a typical value of 3
milliradians (0.003 rad), and flies at 300 m (10,000 ft.)
altitude, the size of the ground patch will be 0.003 x 300 m
(10,000 ft.), or 9 m (30 ft.) on a side at nadir. As the
altitude at which the aircraft flies is increased, the size
of the ground patch also increases, decreasing resolution.

As mentioned earlier, the use of a spacecraft as a data
collection platform offers a tradeoff of resolution in favor of
increased areal observation capability. Thus, while Landsat has
a maximum resolution capability of only .4 hectare (1 acre),
each frame covers an area 185 km (115 mi) on a side, or a total
of 32,000 sq km (12,000 sq mi). In practice, however, the smallest
size objects that can be consistently recognized are 1.6 hectare
(4 acres) in size. The difference here is due to the fact that
the grid sampling pattern of the instantaneous field of view (IFOV)
of Landsat's MSS falls on a wetland in random fashion. For each
picture cell, the sensor integrates the radiation it receives from
the whole IFOV, so that unless a very small wetland is entirely
located within the IFOV, it will not dominate the signal for
the cell and the cell will not be classified as a wetland.

Water. Physical information about water that is useful
includes transparency, chlorophyll concentration, suspended
solids and temperature. The significance of being able to
make these measurements using remote sensing is that a nearly
instantaneous picture of these dynamic phenomena can be
obtained over very large areas.

The maximum penetration of light (radiation) in pure
water is in the green spectral region (about 0.53 μm).
As water becomes increasingly turbid, the wavelength of

maximum penetration shifts toward the longer wavelength portion of the spectrum. Because water is penetrated best by blue and blue-green light more of this type of light is desirable to be reflected back to the camera from an underwater scene. Color film which is very sensitive in this part of the spectrum thus is one of the best film types for mapping underwater detail. At the same time, however, this makes it less useful for precise definition of the land-water interface. This sensitivity to short wavelength light also causes another problem in that it also makes color film sensitive to the effects of haze. In general, performance is improved with this film type as the flying height is decreased.

Suspended sediments, however, are more reflective in the red spectral region, so either color or color infrared film can be used. When haze is a problem, color infrared film may be the better choice due to superior haze penetration capabilities.

The calibration potential of scanner data, the ability to use machine processing, narrow bandwidths and the ability to collect thermal data make the MSS the most useful sensor when comprehensive quantitative water parameter data are to be collected.

MSS data processing techniques developed by ERIM (Wezernak, 1974) make it possible to extract information regarding water transparency and chlorophyll content because of the following facts: 1) the addition of suspended solids to water decreases its transparency, and also causes an increase in reflectance which is more pronounced in the red than in the green region of the spectrum; and 2) the addition of chlorophyll "a" to water causes a relative decrease in reflectance in the blue region, as compared to the green and

red regions. Thus, ratios of observed reflectance in the appropriate narrow spectral bands can be used as indicators of water transparency and chlorophyll.

The collection of thermal data over water is also possible using an MSS and has been used routinely for several purposes. It can be done to an accuracy of 1°C.

Soils. Soils information of interest in wetlands inventory is mostly concerned with drainage condition. Drainage condition information is useful ancillary data for identifying the upper boundaries of wetlands and for determining soil capability classes. Near infrared data collected in the early spring using photographic or MSS systems can reveal much about the extent of spring flooding and where excess water exists which can have an effect on the appearance of a soil type. Color infrared film has little advantage over black and white infrared film for this use because most vegetation is dormant at this time of year and is uniform in appearance on either film type. During the spring season, color film is generally preferred for soil type identification, while CIR film is recommended for drainage analysis.

4.4 SURVEY STRATEGIES

4.4.1 Total Enumeration

The use of a hierarchial resource classification system for inventory work, coupled with the use of sets of survey data of different resolutions, is an economical approach to meeting the minimum inventory requirements of different levels of government. This approach has the additional advantage that it can be expanded or contracted as other needs, and fiscal and manpower limitations dictate. ERIM has found using a classification system of coarser resolution as area

involved increases, is practical because decisions by higher
levels of government tend to be based on summary data rather
than on specific resource location and distribution informa-
tion (refer to Table 4). As a result, as long as at each
level a critical threshold (in terms of classification detail)
is not passed whereby the information available cannot be
effectively used to make resource allocation or management
decisions, a hierarchial classification system can provide
the necessary information for less work.

Programs at the federal and state level are logical
candidates for the use of this approach. They include:

1. Management program effectiveness studies
2. Assessment studies aimed at identifying new
   wetland protection and preservation requirements
3. Trend identification studies of fish and wildlife
   habitat conditions.

At the regional/county level, data are most often
required to provide a basis for general land use planning
and regulation. At the township and other local levels,
delineation of wetland regulation boundaries for individual
property ownership becomes the main issue. For individual
management units, such as a refuge area, data equivalent to
that used at the local level is often used to establish a
data base in support of research and management activities
on the area.

As the information needs of more local levels of
government are addressed, a trend towards the use of inven-
tory data to evaluate site quality and use potential and
to delineate boundaries is apparent. For these latter
purposes, only the use of a sensor with very fine resolution

will do. The work done at these levels can still benefit
from the analysis of coarse resolution data collected at
higher levels, however, because priorities can be set for
which areas to complete first.

Thus, as part of a federal inventory or an independent
program of an individual state, an inventory might be designed
which had four levels of detail: level 1, the entire state;
level 2, regions or counties; level 3, counties or townships;
level 4, individual wetland complexes. Because the information
that would be gathered at each stage would be of increasingly
finer detail, sensor systems with corresponding increases in
resolution could be comployed. As an example, for level 1,
Landsat could be used; level 2 might be done using high-altitude
color infrared aerial photography; level 3, low altitude
natural color aerial photography; and level 4, hand-held
oblique photos from a light aircraft or helicopter, combined
with ground transects or plot sampling.

The advantage of this approach is that a general state-
wide picture of the resource is available immediately at a
level of detail consistent with the use of the information
and cost. If the classification system is hierarchial it
then becomes possible to add in the data at the successive
levels when funds become available to inventory the dif-
ferent areas. It is also possible to skip an intermediate
inventory level. In some cases where many individual wet-
lands are being studied, it would even be possible to work
from the most detailed level back up to the general level
by aggregating categories.

4.4.2 Multistage Sampling

Sometimes, however, resource managers do need very
detailed resource description data over very large areas.
This combination of user requirements is normally the most

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demanding in terms of cost and time required to do the inven-
tory. Yet, the organizational burden these requirements impose
can be reduced substantially in cases where the information can
be nonpoint specific (ie, in the form of summary statistics for
the whole area), by using a multistage sampling approach.

Multistage sampling is an efficient technique when applied
to natural resource inventories because it combines the best
advantages of remote sensing and field work. The basis of
this approach lies in successive sampling of the study area
using remote sensing systems of increasing information sup-
plying capabilities (primarily related to resolution) to
increase the efficiency of sample selection at each subsequent
sampling stage. According to Langley (19?) the precision of
the overall survey results depends solely on the relationship
between predictions derived from the processing of remote
sensing and the ground measured characteristics of the sample
units used to estimate the population. Thus, the efficiency
of this approach is dependent on having good correlation
between population parameters measured by remote sensing and
ground measurements. This makes classification system sel-
ection and sensor selection an extremely important issue.

Another advantage of multistage sampling is that it
concentrates the successive sampling work close to the primary
sampling units (Husch, et al, 1972). This is an important
advantage because it means successive remote sensing data
collection missions can be clustered, reducing mission plan-
ning costs. Furthermore, increasing familiarity with the
area should yield better interpretations from the remote
sensing data if the same inventory staff is involved at
each stage.

The multistage sampling approach is most applicable to
wetland inventories of very large areas, especially if
they have to be updated frequently. A very promising way

of employing it appears to be the use of Landsat data for the first stage and then high altitude and/or low altitude photography and field measurements at the successive stages. This mix of data sources is a good one for the following reasons: Landsat data is very cheap to acquire and process in comparison with other forms of remote sensing. Thus even though the level of detail that can be obtained is not great, generally the most valuable types of wetlands (those covered by open standing water or characteristic wetland vegetation) can be detected. Its only other real drawback is that very small wetlands are missed because of resolution limits. ERIM has devised such an approach for the inventory of duck ponds in North Dakota (see Figure 12).

If aerial photography is used as the second stage, however, most of the limitations of the Landsat data are compensated for, and the need for photo data collection and interpretation and field work is greatly reduced.

Many states are also interested in setting up a series of permanent sample measurement plots for monitoring wetland resources. Since field work is so difficult and expensive it is important to place such plots properly and to establish only as many plots as are absolutely necessary. The last stage in a multistage sample which consists of the plots on which the field measurements are made is a logical framework for such a statewide monitoring system and one that has already been efficiently arrived at.

4.5 SUPPORTING FIELD MEASUREMENTS

Pettinger (1971) states that field data are collected in support of remote sensing projects for one of the following three purposes:

1. calibration of remote sensing systems
2. evaluation of experimental applications of remote

1st STAGE SAMPLING GRID

Strata:
1. Drift
   Prairie
2. Coteau du
   Missouri
3. Coteau Slope

LANDSAT Coverage
of North Dakota

100 mi

100 mi

Frame of LANDSAT Data

2nd STAGE SAMPLING GRID

10 mi

10 mi

Aircraft Photographic
Flightlines

3rd STAGE SAMPLING GRID

10 mi

1 mi

Field Survey Plots
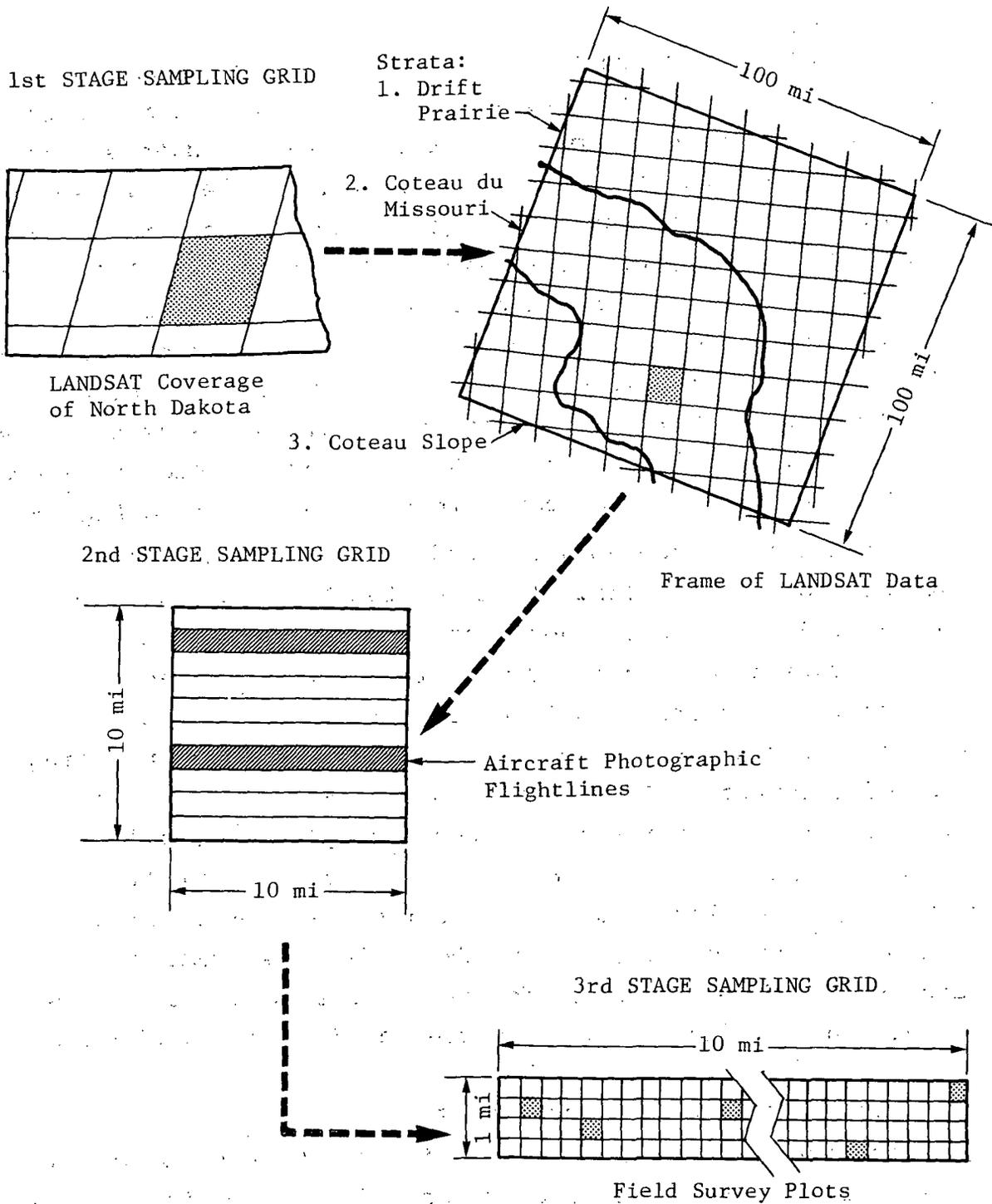
FIGURE 12. A STRATIFIED MULTISTAGE SAMPLING DESIGN AS IT MIGHT BE
APPLIED TO A STATEWIDE WETLAND INVENTORY.

sensing data

3. carrying out large scale resource studies and inventories.

The purpose of this section is to describe several specific measurements that ERIM has found should be made at the time of remote sensing data collection to increase its usability for all the purposes listed above.

A. Study Area Description

Several types of ancillary data are usually available for most areas. The use of these types of data with remote sensing data in a joint interpretation mode can often be very revealing. Examples of these types of data include topographic maps, soils maps, land use maps, property ownership maps, and reports on previous management practices.

B. Resource Description at Time of Data Collection

For most applications current information on vegetation types and condition is essential to the successful extrapolation of remote sensing observations. For vegetation the information most often collected includes descriptions of the plant community for areas for use as training sets or in the development of photointerpretation keys, species phenology, plant vigor and percent cover.

One method often used to collect this data is to run transects to sample the vegetation. To make the ground-to-air translation of the results most effective, the position of the transect must be accurately locatable in the remote sensing data. Seher and Tueller (1973) devised a ground transect marker that also aided in making scale determinations on large-scale (low altitude) photography.

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sun angle   flight path

8' "T" post

4'X 2'plywood (white)

ground level
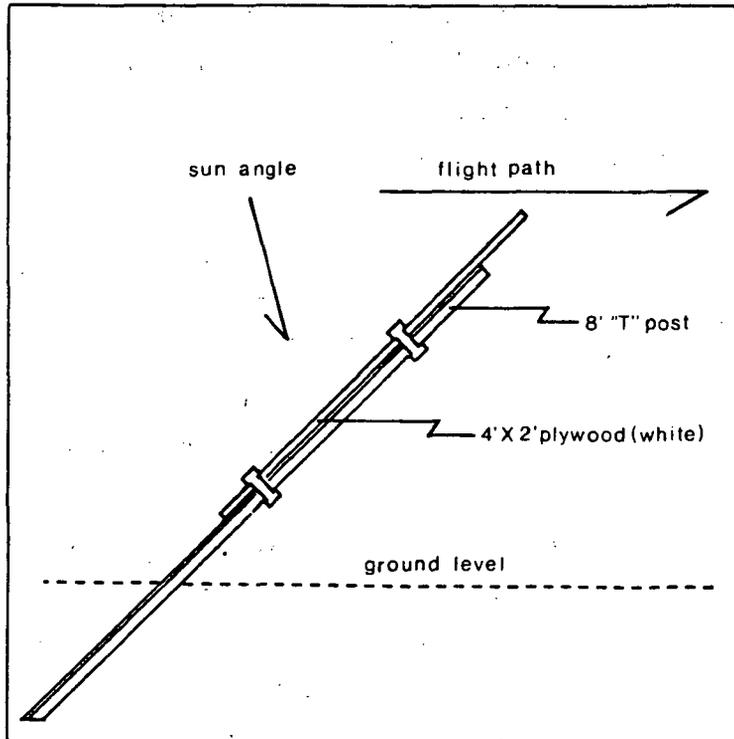
FIGURE 13.   GROUND TRANSECT MARKER
(After Seher and Tueller, 1973).

The use of a set of special markers like the one pictured
above is extremely useful in wetlands mapping for several
reasons. For one thing, they can be used to help pilots
line up flightlines. Another important use is providing
a feature of known size for making scale determinations. A
network of such markers also makes it easier to accurately
translate the location of important features between the
remote sensing data and the ground by furnishing a common
local reference point.

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The marker design is shown in Figure 13. Each marker was built by attaching a 0.6m x 1.2m (2ft x 4ft) plywood sheet painted white to a 2.4m (8ft) T-Type fence post. The post was then implanted in the ground leaning 45° down the planned flight lines. Transect location is indicated by placing a panel at each end. To aid in scale determination three markers with smaller shields (0.6m x .15m/2ft x 0.5ft) were spaced in a row 3m (10ft) apart.

C. Environmental Conditions at the Time of Data Collection

Environmental factors of importance that should be noted fall into three categories: illumination, atmospheric and meteorological.

Under illumination conditions it is valuable to record such things as solar azimuth and elevation and sun time. Atmospheric conditions of importance include humidity, visual range and concentration of suspended particulate matter.

Meteorological conditions especially important are wind speed and direction, air temperature near the ground and cloud conditions.

D. Reflectance Calibration

Several uses for reflectance data are found in processing and interpreting remote sensing data, particularly multispectral data. One of the most important of these uses is determining atmospheric transmittance. This is difficult to measure directly, but its effects can be determined if calibration references are included in the data collected. One way to do this is to place black and white and color panels of known reflectance within the study area. Tone contrasts and color differences recorded in the data can then be compared with the known characteristics of the panels to determine the influence of the atmosphere on the remote sensing data.

E. <u>Timing</u>

Field checking should be accomplished as soon after remote sensing data collection as possible, or at least during the same season of the year. Otherwise ground conditions can vary substantially from those at the time of overflight and the development of photointerpretation keys or MSS training set selection can become very difficult.

4.6 CARTOGRAPHY

4.6.1 Level of Detail

The need for sufficient sensor resolution in order to distinguish certain scene objects was discussed in relation to the informational needs of wetland managers and land use planners in section 4.3. At that time certain generalizations were made regarding the minimum resolution limits for certain inventory applications. Another consideration related to resolution, and hence to scale, has to do with the accuracy of positional location of type lines and area measurements made from remote sensing data.

In manually classifying wetland types from remote sensing imagery the normal procedure is to use a finepoint drafting pen with black ink and to draw the natural boundaries observed on the imagery on a base map. It is important to realize that the width of the line drawn in ink, even though it may appear very fine, corresponds to a considerable distance on the ground. This ambiguity can be important, particularly if questions of legal boundary location are involved. Table 7 shows the ground width covered by ink lines of several widths.

The ability to accurately measure the area of types manually drawn on imagery is similarly affected. For

TABLE 7. EQUIVALENT GROUND WIDTH OF
AN INK DRAFTED MAP TYPE LINE

Remote Sensing Imagery or Map Base Scale	Line Widths (in ft)		
	0.006"	.012"	0.018"
1:3,960	2	4	6
1:7,920	4	8	12
1:15,840	8	16	24
1:20,000	10	20	30
1:24,200	12	24	36
1:40,000	20	40	60
1:60,000	30	60	90
1:80,000	40	80	120
1:120,000	60	120	180
1:250,000	125	250	375

most purposes, a 2.5mm(1/10sq in) or a circle of 2.5mm (1/10)
in diameter is the minimum practical map unit size; it is
still possible to get a 4-digit type identification code
number inside a unit of this size. The minimum equivalent
ground areas that this corresponds to on maps or imagery of
different scales are shown in Table 8.

These two tables make it clear that where the accurate
location of legal boundaries or very precise vegetation
inventories are required, only very large-scale imagery
will provide an acceptable basemap. If the maps are being
prepared primarily for reconnaissance purposes, however,
the medium-scales can provide an acceptable data base at
considerably less cost. The very small scale imagery such
as Landsat data has limited usefulness for making accurate
manual measurements of ground areas because of its small
scale. LANDSAT digital data processed using a computer can
provide significantly more precise area measurements.

4.6.2 Basemaps

In cartography, aerial photography is often en-
larged to produce maps at scales larger than the original image.
In practice we have found acceptable base maps can be made at
scales up to 5x enlargements of the photo scale. The basemap
that could be produced from 5x enlargements of commonly col-
lected scales of aerial photography are shown in Table 9.

The ability to produce basemaps from photography is an
important feature that should not be overlooked in designing
a wetlands inventory. The only complete USGS topographic
map coverage for the entire U.S. is at the scale of 1:250,000,
and although many states have their more populated areas

TABLE 8. GROUND AREA EQUIVALENT SIZE
OF 2.5 mm (1/10 in) sq. MAP UNIT

Scale of Imagery or Map	Ground Area Equivalent Size	
	(acres)	(hectares)
1:3,960	0.31	0.13
1:7,930	1.25	0.51
1:15,840	5.00	2.02
1:20,000	7.97	3.23
1:24,000	11.48	4.64
1:40,000	31.89	12.90
1:60,000	71.74	29.03
1:80,000	127.53	51.61
1:120,000	510.12	206.44
1:250,000	1245.497	503.99

TABLE 9.   PRACTICAL BASE MAP SCALES DERIVABLE FROM
           THE ENLARGEMENT OF AERIAL PHOTOGRAPHY

Photo Scale	Base Map Scale (5X enlargement)	Area represented on a map sheet the size of a 7 1/2' quad. (sq. mi.)
1:20,000	1:3,960	1.5
1:30,000	1:7,920	6
1:60,000	1:15,840	24
1:120,000	1:24,000	56

adequately covered in the 1:24,000 7-1/2 minute USGS quad map series, few have complete up-to-date coverage. The potential to fill in these gaps quickly and to up-date existing maps at minimal cost by using the analysis photography for a secondary purpose (i.e., making basemaps on which to display the data), thus may be an important consideration in selecting a photo scale when using a photographic system

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APPLICATIONS

This chapter contains summary descriptions of four wet-
land inventory demonstration projects performed at ERIM in
which remote sensing was used to obtain information typical
of that useful in wetlands research, management, and land-use
planning. The projects described were selected for inclusion
on the basis of both the application of the information
obtained and the remote sensing technique used to generate
the information. Thus, each project summary has two key
aspects of which the reader should be aware.

The reason for including these project summaries is to
provide the reader with a concrete example of the perform-
ance that can be expected from the various types of remote
sensing systems under a given set of operational conditions.
Using these performance results as a starting place, the
reader should then be able to judge, based on the material
discussed in Chapters 3 and 4, how, under another set of
operational conditions, the results obtained would be dif-
ferent. In this way a basis has been established for the
reader to begin evaluating which type of remote sensing is
best for his own situation and needs.

Normally, when presenting the results of demonstrations
like those which follow, it is desirable to state the costs
incurred in carrying them out. In this case, however,
since the projects described were in the nature of feasibil-
ity and research studies, the costs involved do not truly
reflect what a user should expect to encounter in an operational
situation. In every case operational costs would be lower than
those incurred and the reader will get a better estimate of the

true cost of such work by extrapolating figures from the cost data presented in Appendix A.

The author was in charge of projects 6.2 and 6.3; Mr. A. "Buzz" Sellman conducted project 6.1; and Messrs. Robert Shuchman and Ben Drake carried out project 6.4

5.1 WETLAND CHANGE DETECTION:AERIAL PHOTOGRAPHY

The State of Michigan would like to acquire a 1260 hectare area known as St. John's Marsh located on Lake St. Clair at the mouth of the St. Clair River for the purpose of preserving it as a state wildlife refuge (Figure 14). The area is unique in that it is the last large block of privately owned marsh remaining along the southeastern Michigan shoreline. Biologists consider it important for its role in waterfowl and fish propagation. The marsh is also located along a major waterfowl flyaway that is used by canvasbacks (Aythya valisineria) and other diving ducks. This also makes it important from a conservation and recreation standpoint.

Public acquisition of St. John's Marsh would eliminate the threat of a continuing loss of marshland to residential development and its accompanying pollution that has been observed in recent years. However, the achievement of this goal will require the estimated expenditure of over $3 million of public funds. To obtain these funds the Michigan Department of Natural Resources (DNR) has had to prepare an environmental impact assessment of the proposed purchase,including an estimate of what the consequences will be if the marsh is not acquired.

To determine the consequences of continued private ownership of the marsh, remote sensing data were used to identify the trends in wetland losses that have occurred

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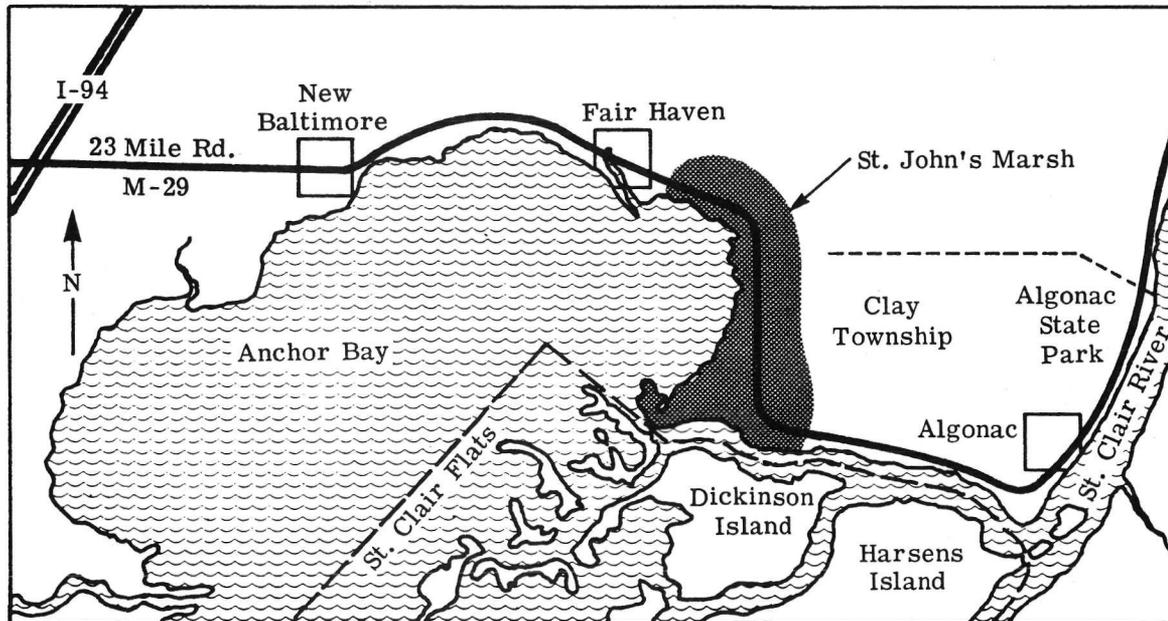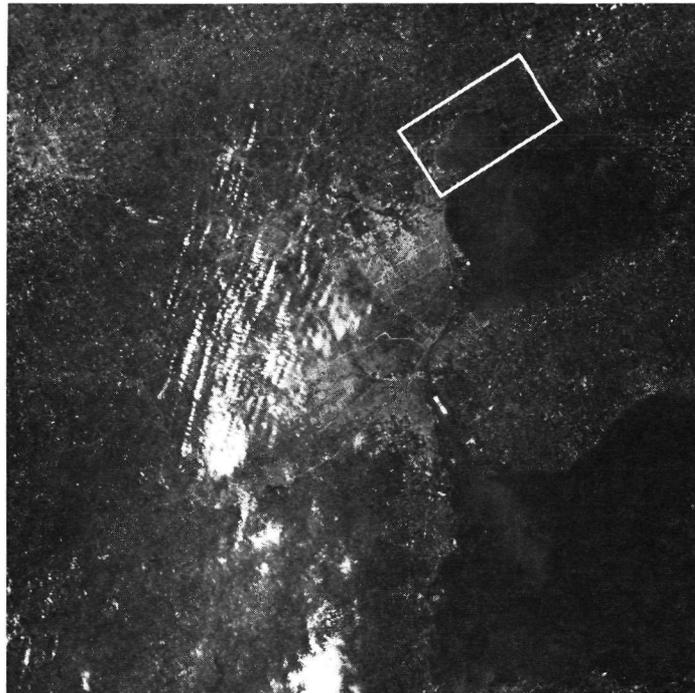
FIGURE 14. ST. JOHN'S MARSH. The location of the marsh next to the highly populated metropolitan area of southeastern Michigan is evident in this S190A SKYLAB photo.

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over the last 36 years. Under NASA sponsorship, ERIM furnished
the Michigan DNR with data which showed that 8% of the marsh
was lost to encroaching residential construction and 4% to
canalization between 1938 and 1974 (Roller, 1976). Recent
applications for permits to dredge and fill sites for addition-
al residential dwellings show that this trend threatens to
continue.

The technical work from which this information was
derived was based on the interpretation of historical and
current aerial photography of the marsh. Using the Michigan
Land Cover/Use Classification System, type maps were prepared
from photo mosaics of the marsh of two different dates
(Figure 15). The past condition of the marsh was obtained by
analyzing a mosaic of black and white ASCS (original scale
1:20,000) airphotos collected in 1938. The current condition
of the marsh was derived from a mosaic of 1974 Michigan
Shoreline natural color photography collected by ERIM (origi-
nal scale 1:10,000).

The change detection between dates was accomplished by
registering a grid with a ground equivalent resolution of
0.4 hectare (1 acre) on both maps and comparing the cover
types present in a given cell. Notation of changes observed
were then stored in a matrix from which the summary statistics
were finally generated. Table 10 presents these results.

The map that portrayed the marsh in 1974 also showed
another interesting fact: in spite of the destruction of
some wetlands by urban development, more wetlands currently
exist in the area than did in 1938. The reason for this is that
the Great Lakes are now at the peak of a high water cycle.
The effect of this cycle is to create a zone of transient
wetlands that encroach upon and retreat from the shoreline

75
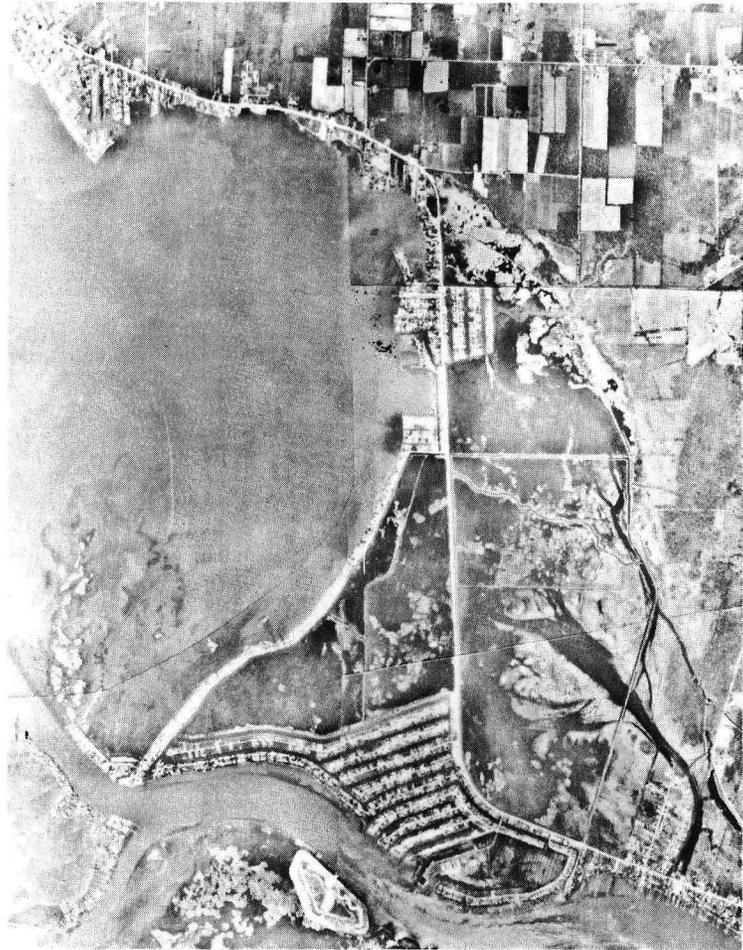
1938   1974

FIGURE 15.   LOSS OF WETLANDS IN SOUTHEASTERN MICHIGAN CAUSED BY RESIDENTIAL CONSTRUCTION AND
CANALIZATION OVER 36 YEARS.

TABLE 10. SUMMARY OF CHANGE DETECTION
FOR ST. JOHN'S MARSH

Area: 5579 acres; 8.72 sq. mi.

Land Use Cover Type	1939	1974	Change
Urban Build Up	313 / 6[a]	793 / 14	+480 / +8
Recreation	147 / 3	15 / 1	-132 / -3
Agricultural	2035 / 36	1066 / 19	-969 / -17
Rangeland	1467 / 26	584 / 10	-883 / -16
Forest	606 / 11	903 / 16	+297 / +5
Waterways	52 / 1	269 / 5	-217 / +4
Wetlands	959 / 17	1949 / 35	+990 / +18

[a] (acres/%)
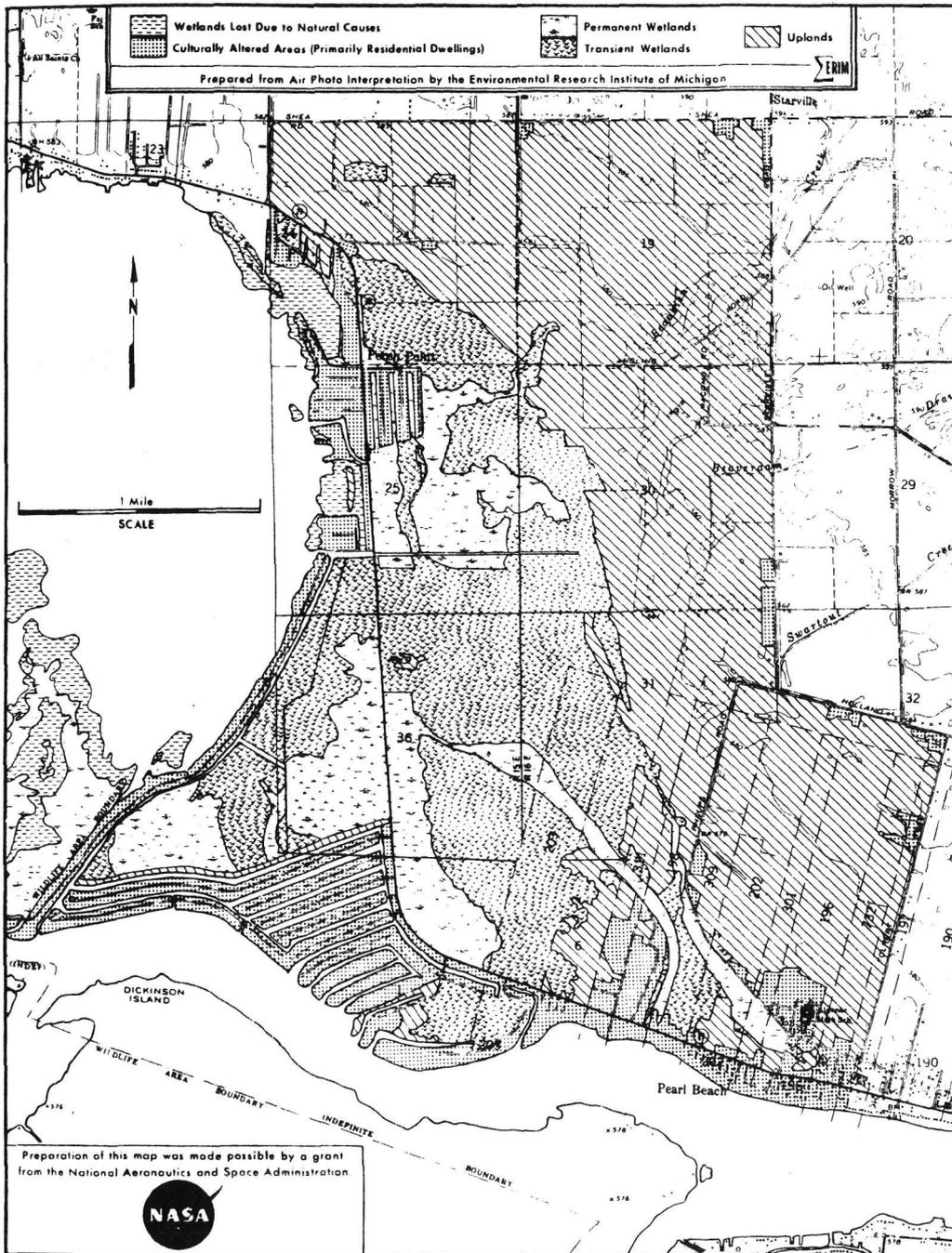
FIGURE 16

DISTRIBUTION OF PERMANENT AND TRANSIENT WETLANDS IN
ST. JOHN'S MARSH

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in concert with the lake level. Naturally, such an area is unsuitable for development but it has considerable ecological value if left in its natural state.

ERIM was able to identify this zone for the Michigan DNR by comparing the location of the upper wetland boundary between the two maps, because 1938 was a low water year for the lakes (Figure 16).

Based on these findings and other data the DNR has already denied a permit to begin construction of additional residential housing in an effort to protect the marsh until the funds to purchase it can be allocated.

5.2 WATER LEVEL MANIPULATION EVALUATION: AIRBORNE MULTISPECTRAL SCANNER

This project summary illustrates the potential of remote sensing to provide quantitative data suitable for evaluating the effectiveness of a particular management treatment in a timely fashion. It also illustrates the type of information that can be derived from automated MSS data recognition processing.

The Pointe Mouillee mapping project was undertaken in 1973 for 3 related reasons: 1) to document the area's vegetation communities, 2) to correlate current vegetation condition with water level manipulation practices, and 3) based on 1 and 2, to assess the area's current and potential capability for use by waterfowl.

Pointe Mouillee State Game Area is located at the mouth of the Huron River, on the shoreline of Lake Erie, just south of Detroit (Figure 17). For generations this area has been an important waterfowl nesting and stopover point, situated as it is on the confluence of two important migration corridors for ducks and geese.

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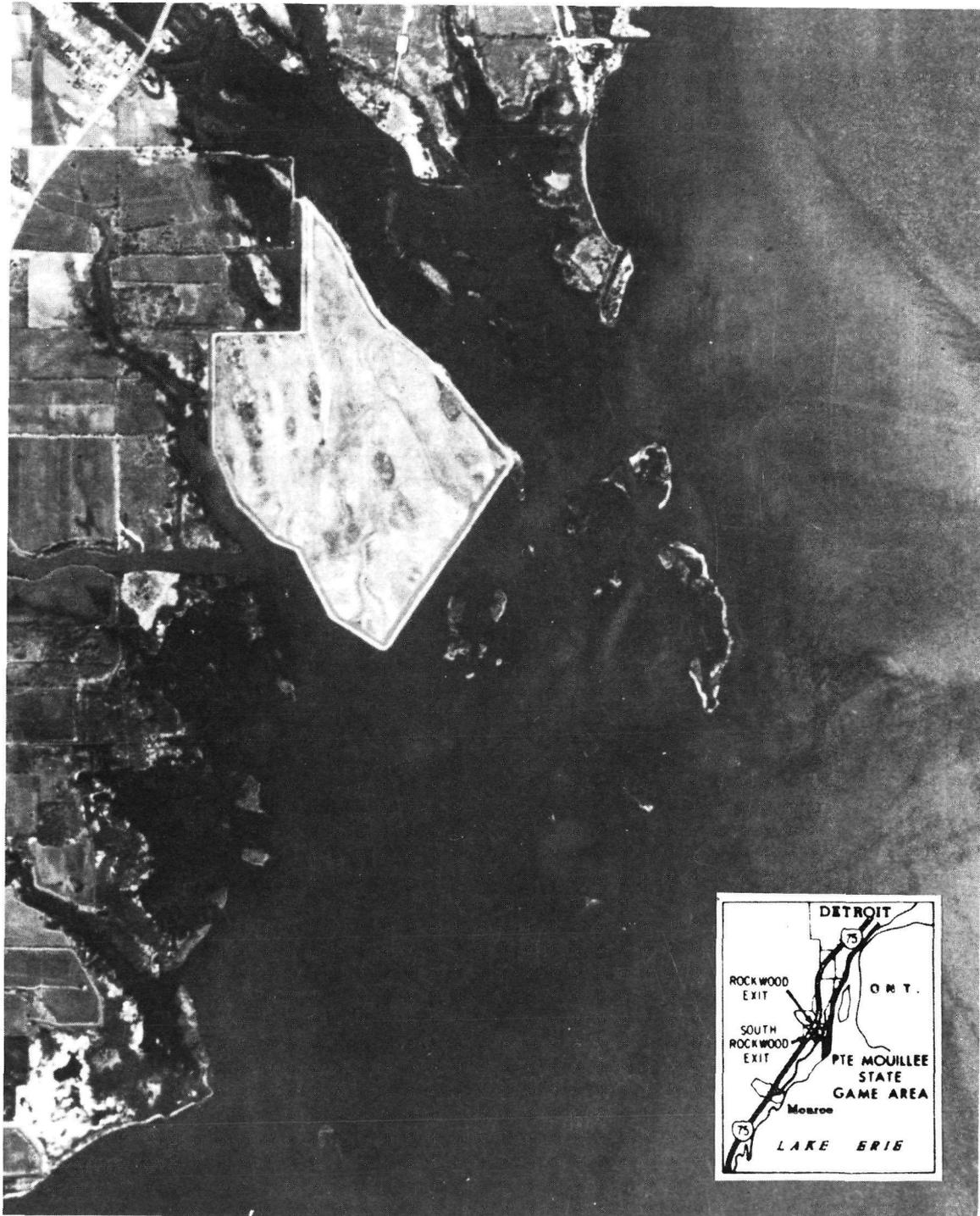
FIGURE 17.   POINTE MOUILLEE STATE GAME AREA.   Portion of a NASA CIR high altitude photo showing the diked portion of the refuge area and the surrounding estuary of the Huron River.
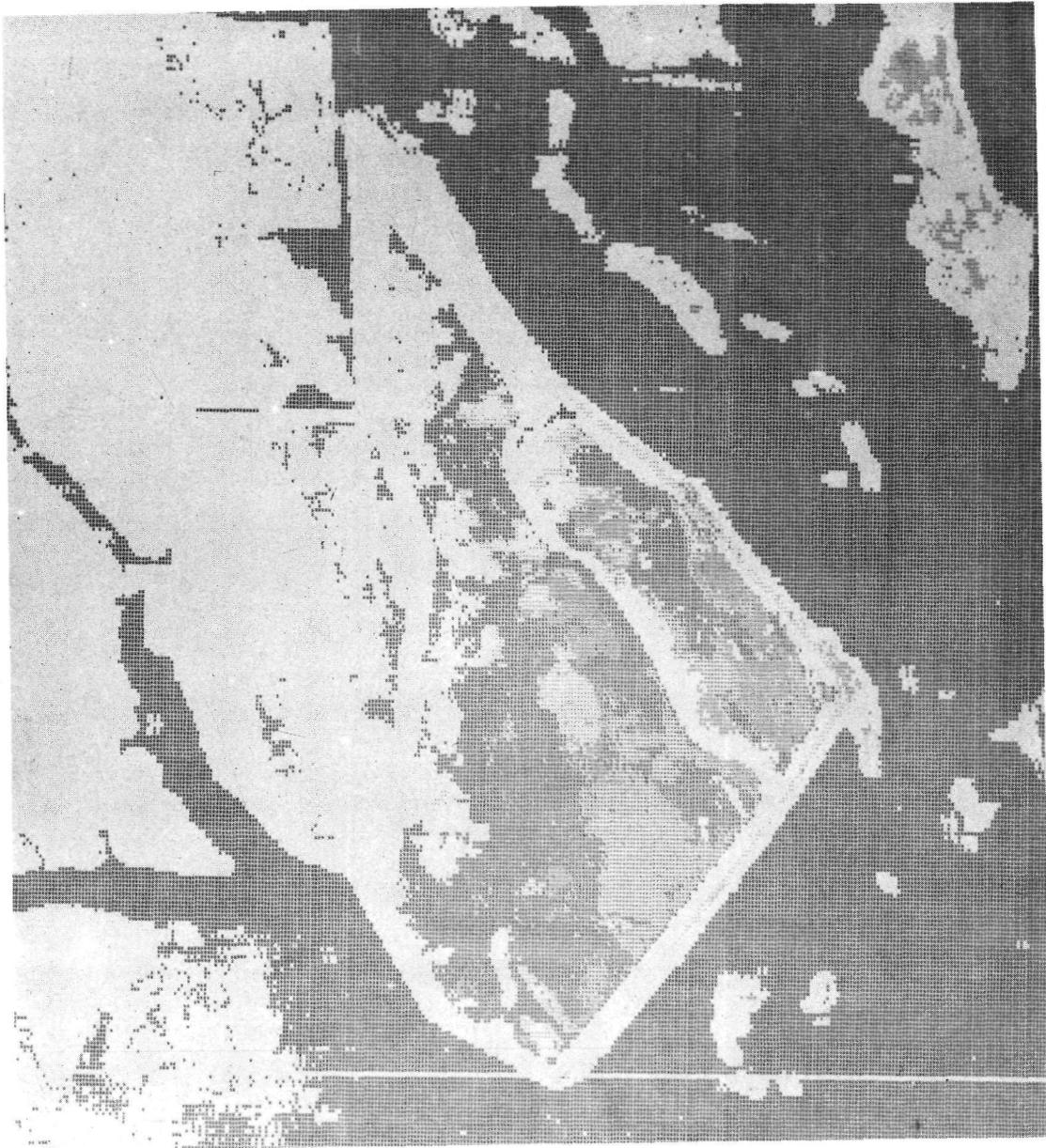
LEGEND

Desirable Vegetation	Less Suitable Vegetation	Other
₦ Green – Smartweed	* Green – Mixed Grasses	. Red – Dead Vegetation
θ Red – Pigweed	₦ Red – Other Undesir-	₦ Blue – Open Water
* Blue – Mixed Smart- weed & Pigweed	able Species	

FIGURE 18.   VEGETATION COVER TYPE MAP OF IMPORTANT FOOD AND COVER IN DIKED
PORTION OF POINTE MOUILLEE STATE GAME AREA. Data collected 29 August 1972.

The management problem at Point Mouillee is really two-fold: first, to largely exclude cattails (Typha spp.) which are the dominant cover type in the surrounding marsh, from the refuge area, and second, to favor the establishment of emergent plant species more valuable as waterfowl food, such as smartweed, pigweed and burweed. This is accomplished basically through manipulation of the water level within the diked refuge area. Pumps are used to drain the area in late spring so that the food species can grow and mature; the area is flooded in the fall. The use of benchmark vegetation inventory data in this context, then, is to measure the effects of varying the drawdown date in the spring, flooding depth in the fall, artificial planting of certain food species, etc.

To demonstrate the potential of remote sensing for providing the quantitative information needed to meet this objective in a timely fashion, automated data processing techniques were applied to airborne MSS data acquired under NASA sponsorship (Sellman et al, 1974). The data were processed using supervised classification based on the maximum likelihood recognition rule. The results are shown in the map presented in Figure 18.

The accuracy of the MSS results was checked by comparing to results obtained from interpretation of large scale (1:4,000) CIR photography supplemented with field checks. The results are shown in the table below.

Cover Type	Area (hectares) from Computer Map	Area (hectares) from Large-scale Photography and Field Checking
Open Water	50.3	43.2
Smartweed	91.9	90.0
Other Desirable Emergent Vegetation Species	124.1	109.2
Less Suitable Vegetation	115.2	126.6
TOTAL	381.5	368.9

Analysis of these statistics show that there were two
types of non-productive areas: areas of dead vegetation
and areas of non-desirable vegetation such as upland
grasses or brush. Field investigations of the dead
vegetation revealed it to be last year's smartweed. On
the basis of this evidence DNR biologists hypothesized that
the water level in the dike had not been lowered sufficiently
during the spring of the current year to permit the smart-
weed to germinate. The identification of the areas of less
suitable non-marsh vegetation provided a method of locating
the areas within the dike where it is necessary to increase
winter flooding.

Before the initiation of this project, all the manage-
ment decisions mentioned above were made on the basis of
the refuge manager's intuition. While such decisions are
typically sound, having their basis in many years experience,
the lack of quantitative data to support them does little
to establish general management guidelines. This makes it
difficult to transfer the lessons learned to other areas, and
when the present manager leaves his replacement must start
over from scratch because of a lack of records. With the use
of remote sensing the quantitative data needed for effective
local management and general policy formulation can now
be made available in a useful time frame.

5.3 QUANTITATIVE EVALUATION OF WATERFOWL HABITAT: LANDSAT

Landsat promises to aid those concerned with wetland condition
analysis by providing them with a current, synoptic data base.
To demonstrate the usefulness of such a data base for regional
wetland condition evaluation a project was carried out to illus-
trate how this data could be used to evaluate waterfowl habitat
quality.

The project was conducted in two steps: terrain mapping
and habitat quality rating (Sattinger et al, 1974).

Step 1. Terrain Mapping

Land cover maps were prepared of an area in southeastern
Michigan by unsupervised classification of multidate Landsat
data. By using two dates, one in early spring (27 March)
and one in early summer (7 June), it was possible to take
advantage of significant phenological variations in the
reflectance of several cover types during the classification
process which improved the accuracy of the map.

The topography of the study site is typical of that of
glacial origin. The hilly uplands which run diagonally
across the area from northeast to southwest are morainic in
nature and covered by oak-hickory forest, interspersed with
small kettlehole marshes.   To the northeast is a level
outwash plain dominated by agriculture.

Twenty-seven spectral signatures were used to classify
the scene initially, after which similar individual recog-
nition classes were then lumped into six more general categor-
ies of specific interest for waterfowl habitat analysis. An
accuracy analysis of the map based on interpretation of high
altitude CIR photography showed that 90% of the scene was
correctly classified, with an average of class accuracies of
89% (See Figure 19a and 19b).

Step 2. Habitat Quality Rating

The carrying capacity of a given unit of habitat depends
on having the right proportion and arrangement of essential
food and cover requirements within the daily activity radius
of the wildlife under study. In general, techniques for
assessing habitat quality have taken this into account by
considering three basic characteristics of the environment.

These are: 1) the vegetation types of the area which supply food and cover, 2) the interspersion of these cover types, and 3) the pattern of the juxtaposition of the cover types.

A quantitative model was developed for integrating these factors into a single expression based on measurements derived from the area coverage statistics of the cover types mapped and a computer-derived measurement of their "edge."

Application of the model to the recognition results resulted in the ratings shown in Figure 19d for each section.

A quick look at the ratings and the recognition map reveals several things: most apparent is that the sections dominated by agriculture and forest and without a lake present score very low, as expected. Conversely, sections with a lake present usually rate fairly well (in the 50's). However, the absence of any sections rated in the 70's, 80's and 90's shows that the study area does lack in really prime habitat.

The section that is rated best is Section 29, an area known as Winnewanna Impoundment, created by the Michigan DNR as a waterfowl management area. Winnewanna was created with the intention of providing a good abundance of cover types for waterfowl. Not surprisingly, because it is good water-fowl habitat, it rated superior to all the other sections.

Several advantages of using remote sensing for regional resource condition inventories are illustrated by this project. One very obvious advantage is observed by comparing the digital cover type map with the USGS topographic map of the area (Figure 19c) for Section 29. The topographic map for this area was prepared in 1919 and is quite out of date. This explains why Winnewanna Impoundment which was created in 1957, does not appear.

Lakes - Blue
Deep Marsh - Purple
Shallow Marsh - Yellow
Shrub Marsh - Magenta
Forest/Brush - Green
Agriculture/
    Cleared Land - Orange

(a) 1973 Landsat digital
    cover type map
    (Section lines
    and numbers shown)

(c) Current USGS
    topographic
    map (1919)

FIGURE 19. AUTOMATED WATERFOWL HABITAT EVALUATION USING LANDSAT.
A synoptic look at the waterfowl habitat of Lyndon Township, Washtenaw
County, Michigan was obtained by developing and exercising a computer
model which integrates measurements of vegetation cover types into a
single numerical index reflecting an area's relative habitat quality.
(Continued)

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Outwash Plain →

← Interlobate Moraine Zone

(b) 1969 NASA high-
   altitude color-
   infrared aerial
   photograph

(d) Habitat quality
   ratings by section

Poor Habitat = 0
Excellent Habitat = 100

FIGURE 19. AUTOMATED WATERFOWL HABITAT EVALUATION USING LANDSAT.
(Concluded)

Thus, when recent map coverage is not available, Landsat can provide a current picture of available resources.

Another important benefit is that the manager gets a detailed look at the entire resource available to wildlife, both publicly and privately owned. This is an important benefit because it allows better long term planning. It may turn out, for example, that all prime habitat occurs on private land, and that upgrading habitat on public land would cost more then buying the private land.

At the same time, when habitat improvement on public land is contemplated, an analysis working back through the habitat quality rating for a given area permits identifying its deficiencies and at the same time provides a prescription for its treatment.

5.4 DETECTION OF MOSQUITO BREEDING AREAS: AIRBORNE RADAR

Mosquitoes are a serious pest in many parts of the U.S. and the tropics. Malaria and encephalitis are only two of the many potentially serious diseases they carry and transfer to humans. Mosquito larvae breed in shallow stagnant water and a major form of mosquito control is to treat these areas with larvacides. Before these areas can be treated, however, they must be located.

In many parts of the country, small isolated pockets of standing water occur in large marsh areas, often partly covered by vegetation. Detecting such areas by visual observation or from aerial photography is difficult. Because radar possesses the potential to penetrate certain types of herbaceous vegetation it was thought that it might prove useful in locating these hidden mosquito breeding areas.

To evaluate this potential ERIM conducted a project sponsored by NASA in Brevard County, Florida in 1973.

Figure 20A shows the Lake Poinsett region of the St. John's River in Brevard County, Florida as imaged by the four simultaneously obtained radar channels of the ERIM radar system. The X-band wavelength is 3.2 cm, while the L-band wavelength is 23.0 cm. Both like and cross polarization data were collected. The resolution of this image is approximately 9.1 x 9.1 meters.

For comparison, Figure 20B is a B & W panchromatic aerial photograph and Figure 20C is a broad band (8-12.5 micron) thermal infrared (IR) image obtained over the same area shown in Figure 20D. The thermal data was obtained within 2 hours after sunrise. The radar, photography, and IR imagery as well as the ground evaluation were all obtained within a period of 25 days.

5.4.1 Vegetation Analysis

The location of several marshes are indicated on the different images by the letter A. Note the ease with which they can be distinguished on the L band parallel polarization radar data. On the thermal data it is difficult to locate the land-water boundaries of these areas, however, because the open water is nearly the same temperature as the air in the marsh. In the photography it is easy to identify the marshes with low vegetation density, but where the vegetation density is high these areas look very similar to the uplands. Thus, in this case, radar data is the more accurate means of delineating the boundaries of marshes characterized by heavy vegetation cover, although color photography may have been effective, too.

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Far Range   Near Range
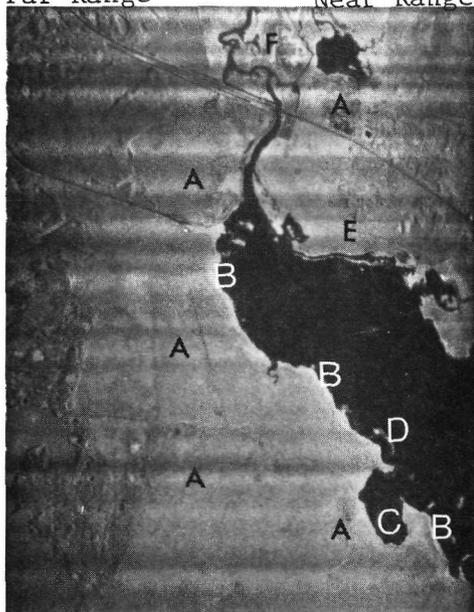
X-Band Parallel Polarization
30 x 30 Ft.

X-Band Cross Polarization
30 x 30 Ft.
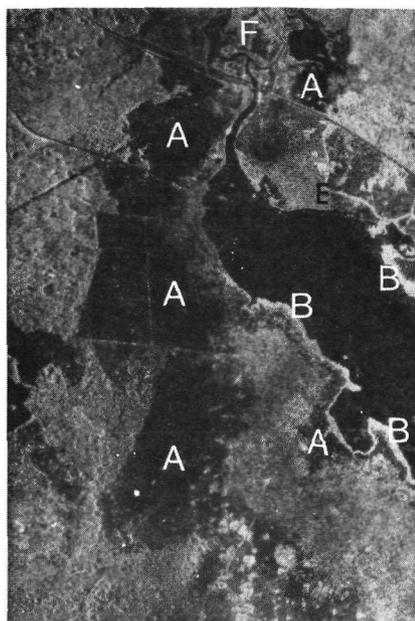
L-Band Parallel Polarization
30 x 30 Ft.

L-Band Cross Polarization
30 x 30 Ft.

(a) Simultaneously obtained dual wavelength SAR radar imagery (7 Oct. 1973)

FIGURE 20.   MULTI-SENSOR IMAGERY OF LAKE POINSETT REGION, ST. JOHNS RIVER, BREVARD COUNTY, FLORIDA (Continued)

90
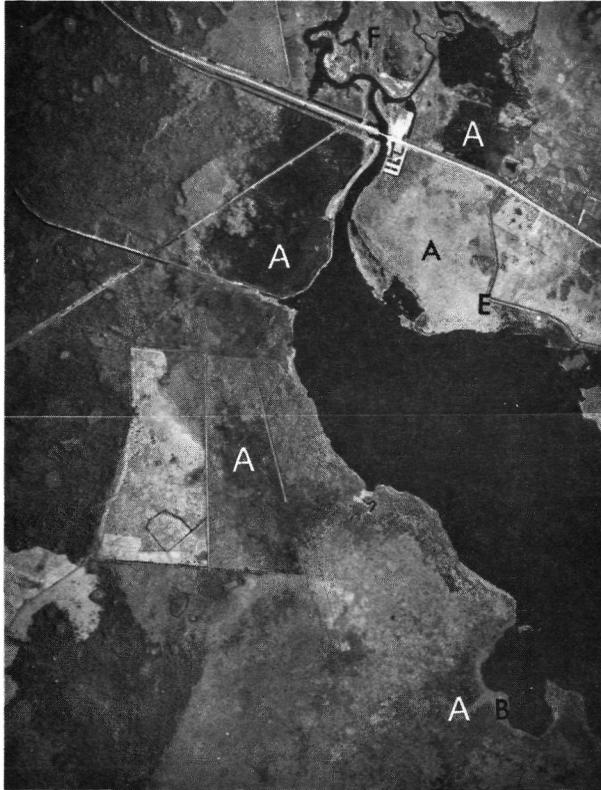
(b) Panchromatic aerial
photograph (31 Oct. 1973)

(c) Thermal MSS data
(27 Oct. 1973)
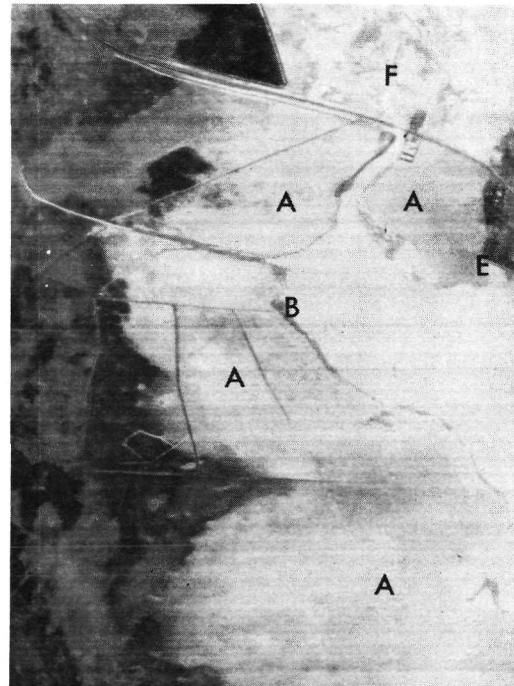
FIGURE 20.   MULTI-SENSOR IMAGERY OF LAKE POINSETT REGION, ST. JOHNS RIVER,
BREVARD COUNTY, FLORIDA (Concluded)

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The ability to distinguish between vegetation types on radar data is illustrated by the different appearance of the marshes at B and C. Area B is dominated by water hyacinth, while area C is covered with water lilies. The hyacinths are also detectable on both the photograph and thermal data, whereas the lilies are only faintly visible on the photography and not detectable at all in the thermal data.

Radar data can also detect very sparse stands of wetland vegetation. At point D there is a very sparse stand of reeds The individual reeds are not touching yet the stand is detectable in the radar data. It is not observable in the thermal image, and only barely so in the photo where detection was helped by the presence of a floating mat of water hyacinth that had blown in after the radar data was collected.

5.4.2 Land-Water Interface

Radar, particularly at X-band and shorter wavelengths, generally is an excellent indicator of the land-water boundary. Even though the boundary between water and low vegetation that is even in height cannot be located on the L-band imagery, it can be seen on X-band imagery. Therefore, the location of the land-water boundary should be checked on both the X- and L-band imagery. On the aerial photographs, the land-water boundary generally can be determined, but locally there are ambiguities as to its location, especially when there is shallow water directly offshore. Because these ambiguities do not exist on the radar imagery, radar is generally a better sensor for determining the land-water boundary, particularly in shallow water situations.

Radar imagery is also consequently well suited for deter-
mining how much of low-lying islands and shorelines are
above water at different flood stages.

The water-land boundary cannot be accurately placed on
the thermal infrared imagery regardless of the height of the
vegetation at the water's edge, except where there is a large
thermal contrast between the water and land. Such contrasts
only occur where dense growths of trees and some types of
pasture directly border the water body.

5.4.3 Drainage Analysis

The drainage patterns in the Brevard test area
can be delineated equally well on the SAR imagery and on the
aerial photography. The stream patterns can be seen on the
thermal IR imagery also, but locally cannot be delineated
and traced as well. X-band imagery is better than L-band
imagery for tracing the stream patterns.

Braided streams can be seen as well on the radar imagery
as on the aerial photography, but on the thermal IR imagery
the narrow streams are not clearly distinguished unless there
is a strong thermal contrast between the stream channel and
the bordering land.

The channels that are choked with aquatic vegetation
can be identified quite readily on the aerial photography,
thermal IR imagery, and the X-band imagery. Locally, on
the L-band imagery, however, it is difficult to distinguish
the vegetation-choked channels from other vegetation features.
Area F on the Lake Poinsett imagery is such an area where
the stream channels are choked with water hyacinths.

6

SUMMARY AND CONCLUSIONS

6.1 SUMMARY

To protect and properly manage wetlands several types of information are needed; among these are (1) resource description (wetland location, abundance, distribution, and condition), (2) change and trend information, and (3) data on surrounding land use. To obtain these types of information inventories must be carried out.

Remote sensing is a cost-effective way to obtain this information because it permits gathering and analyzing the large volume of raw data required to generate this information in a short enough period of time so that when the information is available it is still relevant to decision making. The basis of the cost-effectiveness of remote sensing lies in the fact that it substantially reduces the amount of field work associated with an inventory of natural resources. This is particularly valuable with regard to the inventorying of wetlands because many types of wetlands are so difficult to move about in, due to poor trafficability and dense vegetation.

The special advantages of remote sensing that combine to make it such an attractive alternative to traditional resource survey methods are 1) economy, 2) timeliness, 3) a favorable viewing perspective, 4) a synoptic observation capability and 5) the creation of permanent graphic records.

The few limitations of remote sensing center around two basic issues: first, it may not be physically possible to obtain certain types of information by remote sensing and second, the information that can be collected may not correspond precisely with traditional types of decision making

information, making it difficult to use efficiently in existing decision models. Nevertheless, remote sensing is a valuable tool whose few drawbacks can be overcome by intelligent use and its many benefits thereby realized.

6.1.1 THE SENSORS

The three sensors which have demonstrated a feasibility for collecting useful wetlands inventory data are (1) photographic systems (cameras, filters and film), (2) multispectral scanners, and (3) radar. The advantages of photographic systems can be summarized as (1) best resolution from a given flying height (2) excellent spatial fidelity (3) low cost and wide availability and (4) relatively sophisticated interpretation can be done by users familiar with the biology of what they are looking at, even though they are not remote sensing experts. Its usefulness is limited somewhat by the fact that cloud free weather is necessary for data collection.

Multispectral scanners (MSS) have a wider range of spectral sensitivity than photographic systems and they can detect both reflected and emitted radiation. Unlike photographic data, MSS data is stored in electronic form which permits directly processing it by computer. It is also quantitative in nature and, therefore, can be calibrated if reference standards are available. The chief disadvantages of MSS systems are the difficulty of accurate cartographic presentation and the high costs of machine processing. The use of airborne MSS systems is further hampered by the very

limited number of operational systems available. For most
users Landsat data is the most practical form of MSS data
to consider because it is routinely collected, cheap and
can be manually interpreted.

Radar is useful primarily because it can collect data
under cloudy conditions, and longer wave length radar systems
have the ability to penetrate herbaceous vegetation canopies
and tell something about the surface underneath the canopy.
The disadvantages of radar are high cost, complexity and
limited data availability.

With regard to data collection platforms, spacecraft
can obtain large area coverage quickly, provide repetitive
coverage on a regular schedule, take advantage of sensors
with a narrow view angle, and provide data in nearly
orthographic form. Aircraft, on the other hand, have a
quick reaction potential, can collect data with different
levels of resolution simply by varying flight height, and
(with the same sensors) obtain better resolution than
spacecraft.

6.1.2 INFORMATION SUPPLYING CAPABILITIES

In order to evaluate the potential usefulness
of remote sensing for fulfilling the information require-
ments of wetland managers and land use planners, it is
essential for these individuals to know what types of
information are obtainable and its accuracy. The general
information classes of most interest to these users can be
divided into 5 broad categories: (1) vegetation, (2) water,
(3) soils and flooding, (4) wetland boundaries, and (5)
land-use surrounding wetlands.

Vegetation. Space photography has been found to be capable of yielding accuracies of greater than 80% for large, homogeneous stands of vegetation found in coastal zones.

Aerial photography provides an opportunity for more detailed interpretation and, in addition to plant communities, finer classifications can be made including common generic associations of plants, distinctive physiognomic (life form) groups, and under special conditions even individual species. Very distinct vegetation life forms such as forests can be identified to nearly 90% on very small scale space photography. Forest stand characterization, on the other hand, generally requires scales of under 1:50,000 for similar accuracies. For most tree species groups, acceptable identification is only possible at scales between 1:20,000 and 1:10,000. Identification of individual trees can be done for some species at scales as large as 1:10,000, but obtaining 90% accuracies for all the tree species in a scene generally requires scales of under 1:1,500. The larger scales are needed for accuracy because detailed tree species identification relies as much, if not more, on the shape of a tree's crown as on its tonal appearance. As a general rule, smaller scales can be used with equivalent accuracy if color films are used instead of black and white.

Herbaceous vegetation generally requires scales of 1:20,000 or larger for effective mapping, except where very large homogenous stands occur. A greater increase in accuracy of identification of herbaceous vegetation occurs with an increase in scale from 1:20,000 to 1:15,000, than from 1:10,000 to 1:1,000. At scales of under 1:1,000, 90% accuracies are achievable. Color and color infrared film are superior to black and white film types, but little advantage is generally observed between the two types of

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color film if flying height is under 4600m (15,000 ft.).
Over 4600m, the haze penetration capabilities of color infra-
red film make it a better choice. If inexperienced inter-
preters are used, the normal rendition of vegetation pro-
vided by color film can be an advantage.

Landsat MSS data has proved useful for mapping large
homogenous stands of vegetation such as occur in coastal
environments with accuracies of from 85-95% when
spectral contrasts due to vegetation phenology are at their
maximum. In some cases, better accuracies have been obtained
using Landsat MSS data than airborne MSS data, because of
the satellites narrow view angle, which minimizes the
effects of varying canopy illumination.

In addition to important species of coastal zone veg-
etation, Landsat data has also proved effective for mapping
certain classes of inland wetland including those described
in U.S. Fish and Wildlife Served Circular 39 (e.g., shallow
marsh, deep marsh, shrub swamp).

Aircraft multispectral scanners have not been tested
extensively for wetlands mapping, so few quantitative
estimates of classification accuracy are available. In
general, the accuracy results that have been obtained are
not encouraging if one is seeking detailed vegetation identi-
fication.

Radar appears to be a useful means of identifying broad
wetland classes over large areas, particularly if they are
perpetually cloudy.

Water. Mapping of open surface water is best accomplished
using a sensor sensitive to near infrared radiation. Near-
infrared photography is very useful for drainage network
analysis. Both aircraft and spacecraft multispectral

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scanners have been used effectively to map ponds using a digital thresholding technique.

Multispectral data is also useful for mapping water quality parameters. Turbidity and transparency are both measurable using aircraft and Landsat data combined with ground truth. Aircraft scanners also make it possible to make nearly instantaneous surface temperature maps of water bodies.

Soils and Flooding. The relative soil moisture content of bare soil fields can be estimated from near-infrared photography and multispectral scanner data. This capability can be used to determine the flooding extent, and, to a lesser degree, its severity.

Wetland Boundaries. Good success has been achieved in locating wetland/upland boundaries by mapping the edge which occurs between vegetation communities, when one community is characteristic of a wetland, and the other occurs on higher drier sites. The positional errors associated with locating wetland/upland boundaries in this fashion vary with the scale of photography used. Larger scales produce more accurate results.

Land-Use. For general land use information high altitude aerial photography is the best remote sensing system, because in its analysis both land cover and activity are considered by the interpreter. In comparison, MSS data has only one dimension of information, color. Color films are better for land cover analysis than black and white.

6.1.3 INVENTORY DESIGN

For a given set of inventory design components to yield a desired user information output product, these same components must, when taken together, form a sufficient basis for successful information extraction and output product generation. Each of the components in the inventory design must, therefore, be consistent with, and appropriately suited to, the other components with which it is combined in order to insure a successful outcome.

The key inventory components that must be jointly developed are: (1) a wetland classification system, (2) the selection of a sensor and data processing technique, (3) a survey strategy, (4) supporting field work, and (5) cartography.

6.1.3.1 Wetland Classification System

The transition between wetland and upland often takes the form of a gradual continuum. Where this happens, there frequently is no clearcut boundary between the two environments. This has led to the proliferation of a great many definitions of wetlands based on widely varying criteria and has made it difficult in the past to communicate effectively about wetlands.

In the event it is decided not to use the National Wet-
land Classification System, the choice of an alternative
system should be made with care. It is essential that
agreement among all the potential users of an inventory
be reached as to what information is required before selectina
a classification system, because the system chosen will determine
what data will be collected and hence what information the
project will furnish. Since the costs of remote sensing data anal-
ysis are often one of the major financial outlays of an
inventory, it is also important to pick a classification
system that will not generate a lot of extraneous data or
be unwieldy to use.

Hierarchial classification systems are particularly
well suited to resource inventory work by remote sensing
because they permit combining different levels of information
detail and survey intensity without any loss of data. In a
well designed hierarchial classification system, all the
classes at a given level are interpretable to about the
same degree of accuracy. Thus, a map of uniform accuracy
can be produced. Another important advantage is that suc-
cessive surveys can build effectively upon the results of
previous work.

6.1.3.2 Sensor Selection

The choice of the sensor to use to
collect wetlands inventory data should be made on the basis
not only of its ability to detect the environmental para-
meters used as class identification criteria in the classi-
fication system, but also on the basis of cost, and the

degree to which the user agency can or wants to get involved
in the collection and processing of the data. The following
recommendations regarding sensor selection are grouped
according to the broad classes of wetland resources most
users wish to inventory: vegetation, water, and soils.

Vegetation. Photographic systems typically provide
more data for the user to make vegetation identifications
from because, in addition to spectral information, detailed
spatial information is also available for use in the analysis
process. Multispectral scanners can also be effective, how-
ever, if data collection is timed to take advantage of spectral
contrasts between scene classes as a function of vegetation
phenology.

In general, summer or fall are the best times of year
to collect remote sensing data for wetland vegetation identi-
fication. In the fall, contrasts between upland and wetland
vegetation are maximized, but bad weather often limits data
collection opportunities. For this reason, late summer is
often a more practical time to collect data. Early summer
is less desirable because many plant communities will not
have reached their maximum development.

The discrimination capabilities of photographic systems
can often be enhanced by using special film/filter combina-
tions.

Another important factor that influences sensor selection
for vegetation mapping is resolution. Resolution must be
considered from two standpoints: What is the smallest map
unit that one wants to be able to recognize, and how much
smaller are the parameters that must be recognized in order
to characterize that unit? Here again, for very detailed
survey work, aerial photography is the sensor that typically

provides the image resolution required at a reasonable cost.
Where large areas are to be inventoried, however, the synoptic
observation capabilities of Landsat combined with the low
cost of obtaining and processing this data (per unit area)
may result in it being the most cost/effective sensor system.

Water. The calibration potential and machine processing
caompatibility of multispectral scanner data make it an
excellent choice for obtaining information about water quality
parameters. In addition, multispectral scanners are the only
sensors that can produce surface temperature maps.

Although it cannot be calibrated as easily as MSS data,
photography can also be effective for studying water related
parameters. For examining underwater detail color film is
most useful; for analyzing the relative concentration of
suspended sediment either color or color infrared film is good.

Soils. For drainage analysis a photographic system
using a film sensitive to near infrared radiation is best
(either black-and-white or color-infrared). Data should
be collected when the soil's surface is bare, for example, in
the spring. For soil type identification, natural color
film is generally better.

6.1.3.3 Survey Strategies

Survey strategies can be broken down into two
basic groups: total enumeration and sampling. From a remote
sensing standpoint, total enumeration surveys can be optimized
on the basis of the user involved because generally, the
higher the level of government, the less detailed the
information requirements are but the larger the survey
area. As a result, for very large areas - such as an entire
state or several states - a sensor like Landsat can be used

effectively because it provides the broad area coverage
required at a reasonable cost. Even though the information
of the data is low compared to what is obtainable using other
sensors it is sufficient for the user application (policy
formulation) that takes place at the federal or state level of
government involved. For smaller sized areas the increased
information content of aerial photography is usually required
to make an inventory cost-effective. The trade-off between
area coverage and information content provided by high altitude
color infrared photography makes it a good choice for regions
several counties in size. Low altitude natural-color photography
is often considered the best choice for single county sized
areas. For individual wetland complexes very low altitude
oblique natural color photos and field work provide the
ultimate in information (but not geometric fidelity). The
principal advantage of following the above strategy for
collecting resource inventory data is that a complete picture
of the resource is obtainable at a reasonable cost and level
of detail consistent with the application of the information
for each category of user (local, county, region, and state
and federal).

Multistage sampling is an effective way to gather non-
point specific wetland description data over very large
areas. Its basis lies in successive sampling of the study
area using remote sensing systems of increasing information
supplying capabilities to increase the efficiency of sample
selection at each subsequent sample stage. The final stage
plots of a multistage inventory may also be useful for
serving as the basis for a continuous wetland monitoring
system for a state or region.

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6.1.3.4 Supporting Field Measurements

Several types of measurements and obser-
vations should be recorded during remote sensing data col-
lection to maximize its information supplying capabilities.
These include: (1) study area description, (2) resource
description at the time of data collection, (3) environmental
conditions at the time of data collection, and (4) reflect-
ance calibratio.1 data (specific type depends on sensor).
The timing of field data collection is often critical and
it should be accomplished as soon after the remote sensing
data is collected as possible.

6.1.3.5 Cartographic Considerations

Evaluating the level of detail required
in a wetlands survey is an important step because it deter-
mines sensor resolution requirements and output product
specifications. If maps are to be an output product then
a map scale must be used which permits showing and labelling
the minimum survey unit size and accurately delineating
its boundaries. Thus, depending on the user's objectives,
map scale can be a very important specification which sig-
nificantly influences the choice of other inventory design
components.

6.2 Conclusions

- A variety of remote sensing techniques exist which, under certain circumstances, can fulfill wetland information needs more cost-effectively than field work alone.

- For a remote sensing inventory of wetlands to be successful, the individual components which make up the inventory design must be consistent with, and appropriately suited to each other.

- If very detailed wetland classification and mapping with high accuracy is required, aerial photography is the best sensory system to use.

- Landsat is a useful means of producing regional inventories of extensive wetland types.

- Airborne multispectral scanners and radar are, in general, too expensive to use, unless there is a need for the unique types of data they can obtain.

- Multistage sampling employing a different sensor or data collection platform at each stage can be a cost-effective way to quickly gather non-point inventory data over large areas.

- The information supplying capability of any given sensor can be optimized by proper data collection mission planning and scheduling.

APPENDIX A

SENSOR DESIGN, OPERATION,
DATA PROCESSING, AND COSTS

In this Appendix an overview is provided of the tech-
nology behind the three basic remote sensor systems for
inventorying wetlands. Photographic systems are discussed
first, followed by multispectral scanners (including Landsat),
and then radar.

A.1 PHOTOGRAPHIC SENSORS

A.1.1 SENSOR DESIGN AND OPERATION

A.1.1.1 Cameras

A wide variety of aerial cameras are presently available
in several film size formats for which several lens sizes
are also available. A conventional aerial camera has four
basic components: 1) a film magazine, 2) a drive mechanism,
3) a cone, and 4) a lens (Figure 21).

The most common film format sizes are 35 mm, 70 mm, and
9 in. square. Clegg and Scherz (1975) performed several
tests to determine the differences between these formats.
Their conclusions were that at lower flying heights (<300 m/
1,000 ft) comparable resolution is possible with any one of
these formats, while at higher altitudes, the resolution of
the 9 in. camera is much better. The metric accuracy of the
smaller formats is also somewhat less; at 1,500 m (5,000 ft)
flying height, positional errors of about 3 m (10 ft) ground distance are
normal. The 9 in. format is also preferable for stereo viewing.
On the other hand, the small format cameras cost only one-tenth
as much as the 9 in. systems, so if purchase of a camera once
limited budget is contemplated, small formats should be consid-
ered. The ability to collect data using more than one type of
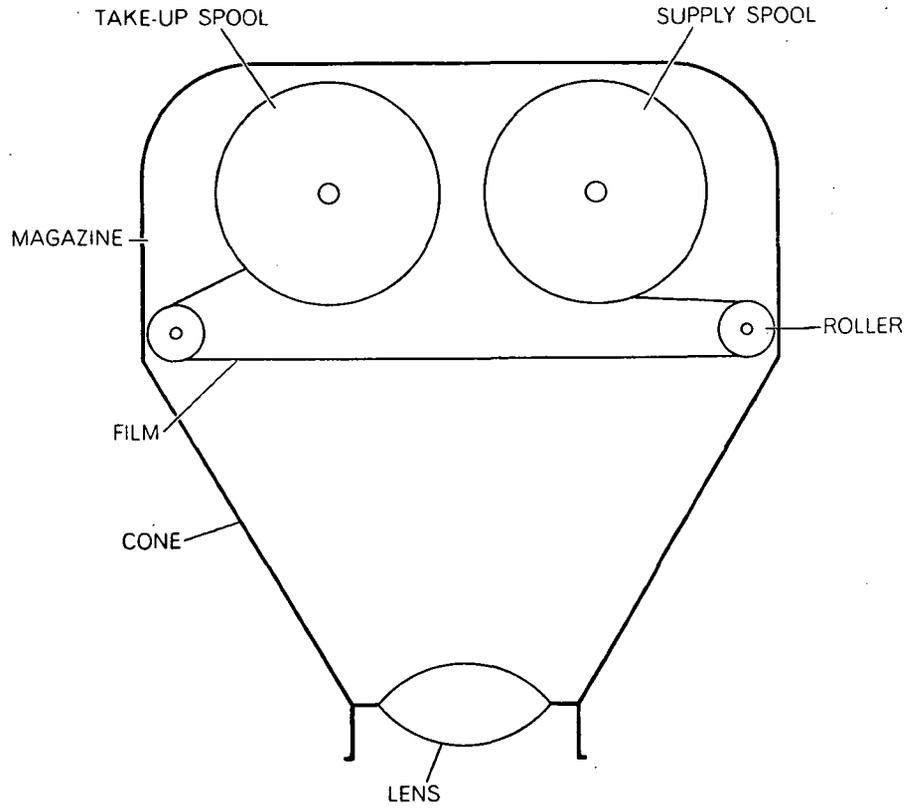
FIGURE 21.   CONVENTIONAL AERIAL CAMERA
(After R. Colwell, 1968).

film simultaneously is also an important asset, and the low
cost and weight of the small format cameras means that two
or more small format cameras could be used to expose
several film types in place of a single 9 in format camera.

The selection of the proper focal length lens is
important because it determines the scale relationship of
an object's true physical size to its image size in the
film. Thus, depending on what you want to do, a lens can
be selected to produce either the scale or area coverage
desired. For example, nearly the same area coverage per
frame can be obtained with different format size cameras
flown at the same altitude simply by varying the focal length
of the lens (Figure 22). The general rule is: For a given
format size, a shorter focal length lens always provides
larger area coverage. On the other hand, the radial dis-
placement of objects also increases greatly when a short
focal length lens is used which may make interpretation
harder. This explains why longer focal length lenses (corres-
ponding to smaller angular fields of view) are recommended
for use in mountainous areas where the substantial relief of
the scene would be overexaggerated with a short focal length
lens, and much of the scene would be obscured by near-
profile views of tall objects.

Up to this point the discussion has dealt with air
photos taken with the camera aimed straight down, and with
the film plane parallel to the ground, but non-vertical or
oblique photography is also useful for studying wetlands.
Oblique photos provide a means to examine terrain in closer to
normal viewing perspectives and have much value for qualita-
tive analysis (e.g., comparing the shapes of tree crowns).
Measurements of area or height, however, are difficult.

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9 IN x 9 IN FORMAT   70 MM. FORMAT   35 MM. FORMAT

Photo Scale =   1:10,000   1:38,100   1:63,500

Len's Focal Length =   6 in. (152 mm)   40 mm.   24 mm.

— Flightline

1524m (5,000 ft) AGL

— Nadir

Area
Covered: 2222m (7290 ft) x
          2286m (7500ft) square   2184 m (7166 ft) square   1524 ft (5000 ft)
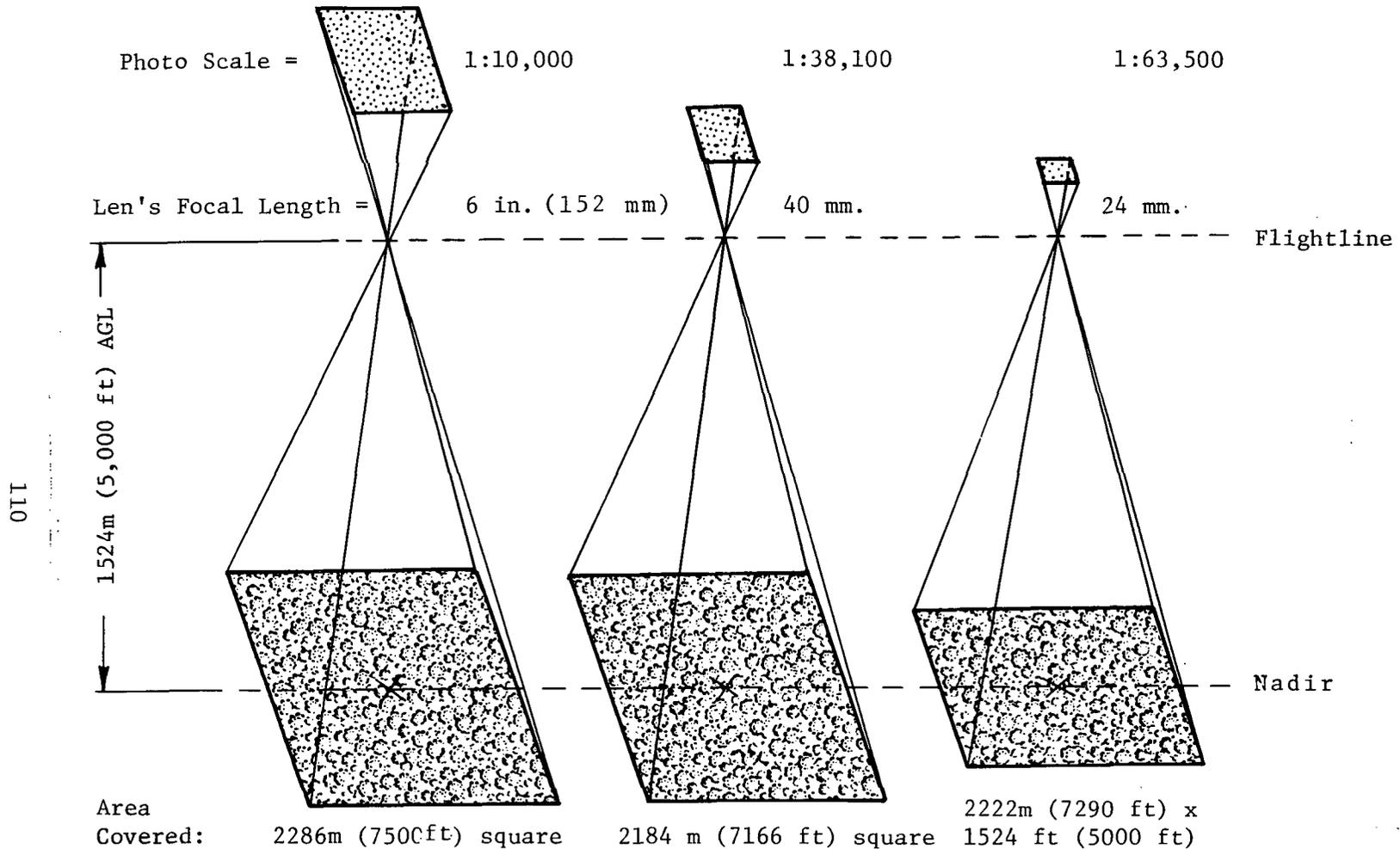
FIGURE 22.   COMPARISON OF PHOTO SCALE AND RELATIVE AREA COVERAGE FOR 9-INCH, 70 MM., AND 35 MM.
AERIAL PHOTOGRAPHY.   The relationship between lens focal length, photo scale, and
ground area coverage is illustrated in the diagram.   For a given flying height approx-
imately the same ground area coverage per photo can be obtained by choosing the proper
focal length lens.   Note, however, that the scale of resulting images differ greatly
(after Clegg and Scherz, 1975).

Photos that include the horizon in the background are termed high obliques; low obliques do not include the horizon.

A.1.1.2 Films

Several films that vary in spectral sensitivity are available for aerial photography. They vary both in the wavelength region of maximum sensitivity and in the total range of sensitivity. Thus, films are available that are sensitive only to visible light while others can also detect infrared radiation (See Figure 23).

Black and White. Black and white films produce images in which scene features appear in varying shades of gray comparable to the density of an object's color as seen by the human eye. Two types of black and white film are available: Panchromatic (PAN) and infrared (B&W IR).

The sensitivity of black and white PAN film ranges from $0.36-0.72$ μm. Thus, although truly different colors are readily distinguishable on PAN film, most vegetation -- because it is all basically some variation of green -- tends to appear tonally similar. As a result, the shape, size, texture, and shadow of plants are often the key elements in vegetation identification on black and white photos.

B&W IR film is sensitive to reflected near-infrared radiation as well as part of the visible spectrum ($0.36 - 0.9$ μm). When filtered to exclude the visible radiation, the gray tones of objects on B&W IR film are due primarily to the degree of infrared reflectivity of an object rather than color we see. Another noticeable characteristic of

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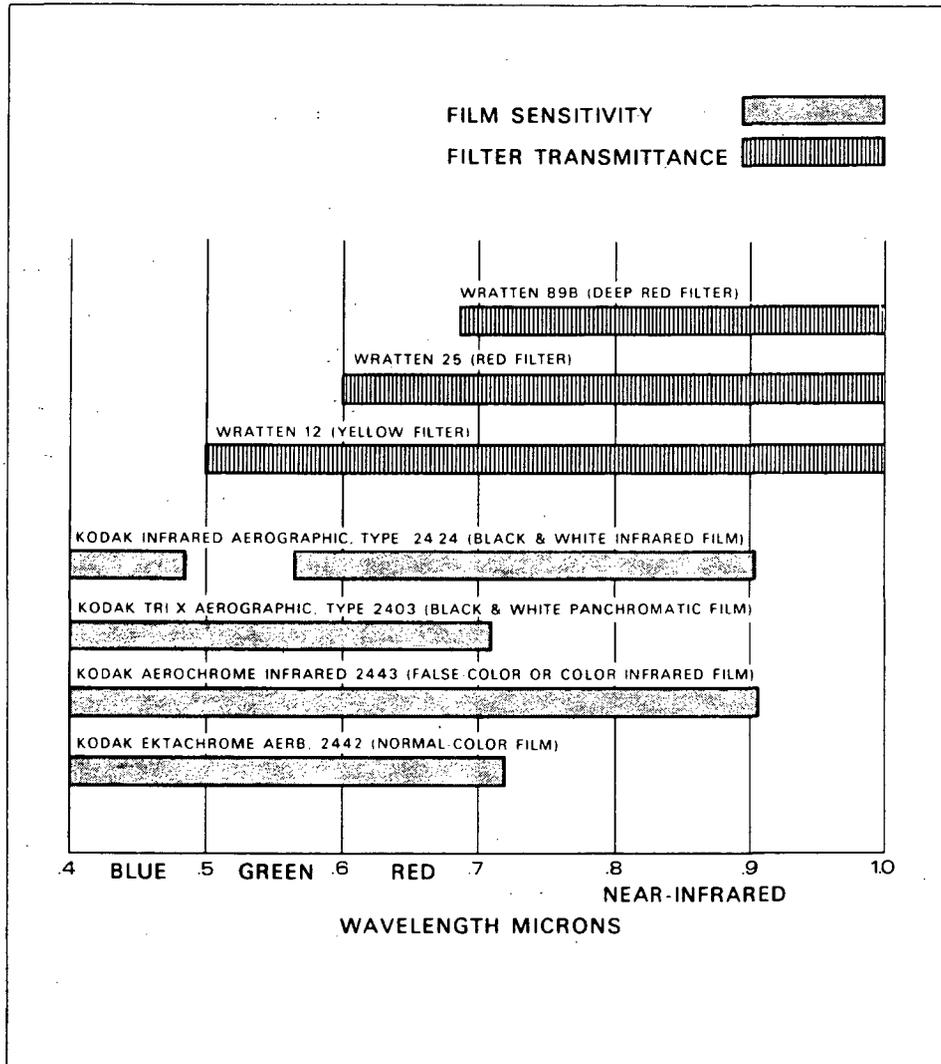
FIGURE 23. APPROXIMATE SPECTRAL SENSITIVITIES OF
FOUR COMMON FILMS AND WAVELENGTH TRANSMISSION OF
THREE COMMONLY USED FILTERS (After Murtha, 1972).

B&W IR film is the lack of detail in shadows which are
usually very dark. The detail normally seen in shadows
on films sensitive to visible light comes from the reflec-
tion of scattered blue light, but properly filtered B&W IR
film is not sensitive to this type of radiation and hence
no energy is received to produce an image.

Color. Both color and color-infrared films work on
the subtractive principle and consist of three inseparable
emulsion layers deposited on a single polyester (estar)
base. Each emulsion layer is primarily sensitive to light
in a different wavelength region than the others. In
the subtractive color process three absorption filters are
used to control the transmission of red, green, and blue
radiation. The filters used are cyan (also called "minus
red" because it attenuates primarily red radiation);
magenta (minus green); and yellow (minus blue). By
varying the densities of the three filters any hue can be
reproduced, the saturation of the hue depending on the
densities of the filters.

Natural color (NC) film has a sensitivity range of
from 0.38-0.70 μm. It is generally considered superior
to PAN film for vegetation mapping because it offers a
much greater basis for object discrimination, vis a vis
the subtle gradations of the color green it can record.
The reversal process of color formation for NC film is ex-
plained in Figure 24.

In color infrared (CIR) film, the blue sensitivity of
NC film is dropped and that layer is made sensitive to near-
infrared radiation, thus the total sensitivity range of CIR
film is now from 0.5-0.9 μm. The dyes are also shifted, so
that now the cyan dye layer is sensitive primarily to infra-
red radiation (from 0.7-0.9 μm), the yellow dye is sensitive
to green and the magenta dye layer is sensitive to red.

Unexposed and undeveloped emulsion

Developed silver

Incoming Light

White is the combination of light of all colors and black · the absence of all color

Exposure

The blue sensitive layer containing the yellow color component.

The green sensitive layer containing the magenta color component.

The red sensitive layer containing the cyan color component.

Exposure records the blue light in the first layer, the green in the second layer and the red in the bottom layer. During the first development black and white images are formed.

Processing

Step 1

The blue sensitive layer contains metallic silver and yellow image.

The green sensitive layer contains metallic silver and magenta image.

The red sensitive layer contains metallic silver and cyan image.

After washing, the film is exposed to white light and redeveloped. This second development forms both metallic silver and colored images in those portions of the emulsion layers unaffected by the first development.

Step 2

The blue sensitive layer contains the yellow dye image.

The green sensitive layer contains the magenta dye image.

The red sensitive layer contains the cyan dye image.

All metallic silver formed during both the first and second development is removed by the bleaching bath, leaving only the dye images in the three emulsion layers.

Processed Image

The three primary colored dye images (yellow, magenta and cyan) when combined in proper proportions, form neutral grays or black.

The cyan, magenta and yellow dye images combined reproduce the original colors of the subject.

FIGURE 24. REVERSAL PROCESS OF COLOR IMAGE FORMATION IN NATURAL COLOR FILM (AFTER MOEN, 1947).

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To understand why healthy vegetation generally appears reddish on CIR film it is helpful to remember that the dye responses of these layers are inversely proportional to their level of exposure. Since healthy vegetation is highly reflective of infrared light, little or no dye is formed in the cyan layer of the film. Instead the yellow and magenta dyes make up most of the image that is viewed on a transparency over white light. This combination produces a reddish color to the eye.

When vegetation senesces, however, it loses infrared reflectance while increasing in reflectance in the visible portion of the spectrum. This causes more cyan dye to be formed and less magenta and yellow. Depending on the situation, the vegetation may then appear dark red or black, cyan, or straw-colored.

In spring and summer, healthy deciduous trees appear magenta or red on CIR film, and healthy conifers photograph bluish-purple. Deciduous leaves or evergreen needles that are dead or dying usually appear cyan. Healthy deciduous trees whose leaves have simply turned red or yellow in the fall retain a considerable amount of infrared reflectivity, so that red leaves appear yellow and yellow leaves appear white.

One of the greatest assets of CIR film is its ability to produce high-quality imagery even on hazy days or from high altitudes. The explanation for this effectiveness lies in its lack of sensitivity to light where the greatest amount of random light scattering occurs.

Finally an important distinction that should be made here is that there are two types of infrared radiation, reflected and emitted. Near infrared radiation is

reflected radiation and heat is emitted radiation. Photo-
graphs can only detect a small portion of the near infrared
radiation that objects reflect. Thus it is not possible
to detect heat with infrared film.

A.1.1.3 Filters

Filters are sometimes used. They consist of thin, trans-
parent windows that are placed over the lens where they selec-
tively absorb certain wavelengths of incoming light and trans-
mit others. The selection of filters depends on the type of
film used, the scene, and environmental conditions. Recommen-
dations on appropriate filters to use for certain combinations
of these conditions are given in Appendix C.

A.1.2. DATA PROCESSING (PHOTO INTERPRETATION)

In extracting information from photographs
interpreters use the same principles we normally use to
identify things in our everyday life. Another way of saying
it is that deductive reasoning is used, based on a conver-
gence of evidence. In practice many visual clues are used
to identify objects and judge their significance. C. Olson
(1966) calls these the elements of photo interpretation.
These are:

1. shape
2. size (including length, width, height, and area
   or volume).
3. tone (or hue)
4. shadow (may reveal hidden silhouettes)
5. pattern (repetition is particularly useful for
   cultural features)
6. texture (roughness)
7. site (location with respect to terrain)

8. <u>association</u> (consistent grouping with respect
      to other natural or cultural features)

9. <u>resolution</u>

    A great aid to the identification of features is the use of stereoscopic vision, in which the interpreter can view the scene in 3-D. Photos must be collected in a special way, however, before stereo vision is possible; so if its use is anticipated, this must be specified in the data collection mission planning.

    In general, transparencies are better for interpretation and prints are better for field work (Welch, 1968).

    To remove some of the drudgery from measuring areas on photos, electronic planimeters have been developed that greatly speed up the job and result in more precise measurements as well.

A.1.3 COSTS

    The cost of collecting aerial photography varies on the basis of several factors. Among the most significant of these are the specification of the characteristics of the photography to be collected, how far the area to be covered is from the plane's base, and the weather. Costs representative of having commercial firm collect black and white aerial photography are shown in Table 11. Interpretation costs can add another $3-6/sq km ($8-15/sq mi) to this figure with an additional $0.75-2.00/sq km ($2-5/sq mi) necessary to produce finished map products in quantity.

    These cost figures point out an interesting situation. Data collection costs for aerial photography are quite low in comparison to the other sensors, yet data analysis and output product costs are quite high. Just the opposite is

TABLE 11.   APPROXIMATE COST PER SQUARE MILE FOR CONTRACT AERIAL
            PHOTOGRAPHY, BY SIZE OF AREA AND PHOTO SCALE (AFTER
            ULLIMAN, 1970)

Area in Square Miles	Aerial Photo Size				
	1:20,000 or 1,667 ft.in.	1:15,840 or 1,320 ft.in	1:12,000 or 1,000 ft.in.	1:9600 or 800 ft.in.	1:7,920 or 660 ft.in.
25	$ 35.00	$ 40.00	$ 42.00	$ 45.00	$ 50.00
50	20.00	22.00	26.00	30.00	45.00
100	12.50	15.00	20.00	25.00	35.00
200	8.60	13.80	18.00	20.00	27.00
400	7.50	12.00	15.00	17.00	23.00
800	6.20	9.90	12.00	14.00	18.00
1,500	5.10	8.20	10.00	12.00	17.00
2,500	4.80	7.70	9.00	11.00	16.00
5,000	4.20	6.70	8.00	10.00	15.00

Prices listed represent averages from several sources and thus do not apply
to any specific area in all instances, stereoscopic coverage on black and
white (panchromatic) film is assumed. Cost of ground control work and
preparation of maps from the photographs are NOT included.

often true with the other sensors. MSS and radar data
are very expensive to collect, yet the ability to process
the data using a computer and to make maps using computer
technology can result in data processing costs less than
that of manual photointerpretation and cartography.

One possible way to take advantage of the best part
of both worlds is to code photo interpretation results into
computer compatible form and then use computers to produce
maps.

A.2 MULTISPECTRAL SCANNERS

A.2.1. DESIGN AND OPERATION

In understanding how a multispectral scanner
works it is helpful to consider how the human eye makes it
possible to distinguish between various materials on the
basis of their distinctive color; e.g., snow is white,
vegetation is green and soil is brown. An MSS is designed
to exploit this capability for spectral discrimination by
measuring the amount of radiation reflected or emitted
from objects in several wavelength intervals in different
parts of the electromagnetic spectrum. These intervals are
called spectral bands, and the individual pattern of
reflectance that various objects exhibit over these
spectral bands is called a spectral signature. More will
be said shortly about how spectral signatures are used
in the processing of MSS data.

A.2.1.1   Airborne MSS

In operation a typical airborne MSS works
as follows (refer to Figure 25); radiation (either reflected
or emitted) from the scene enters the instrument's aperture
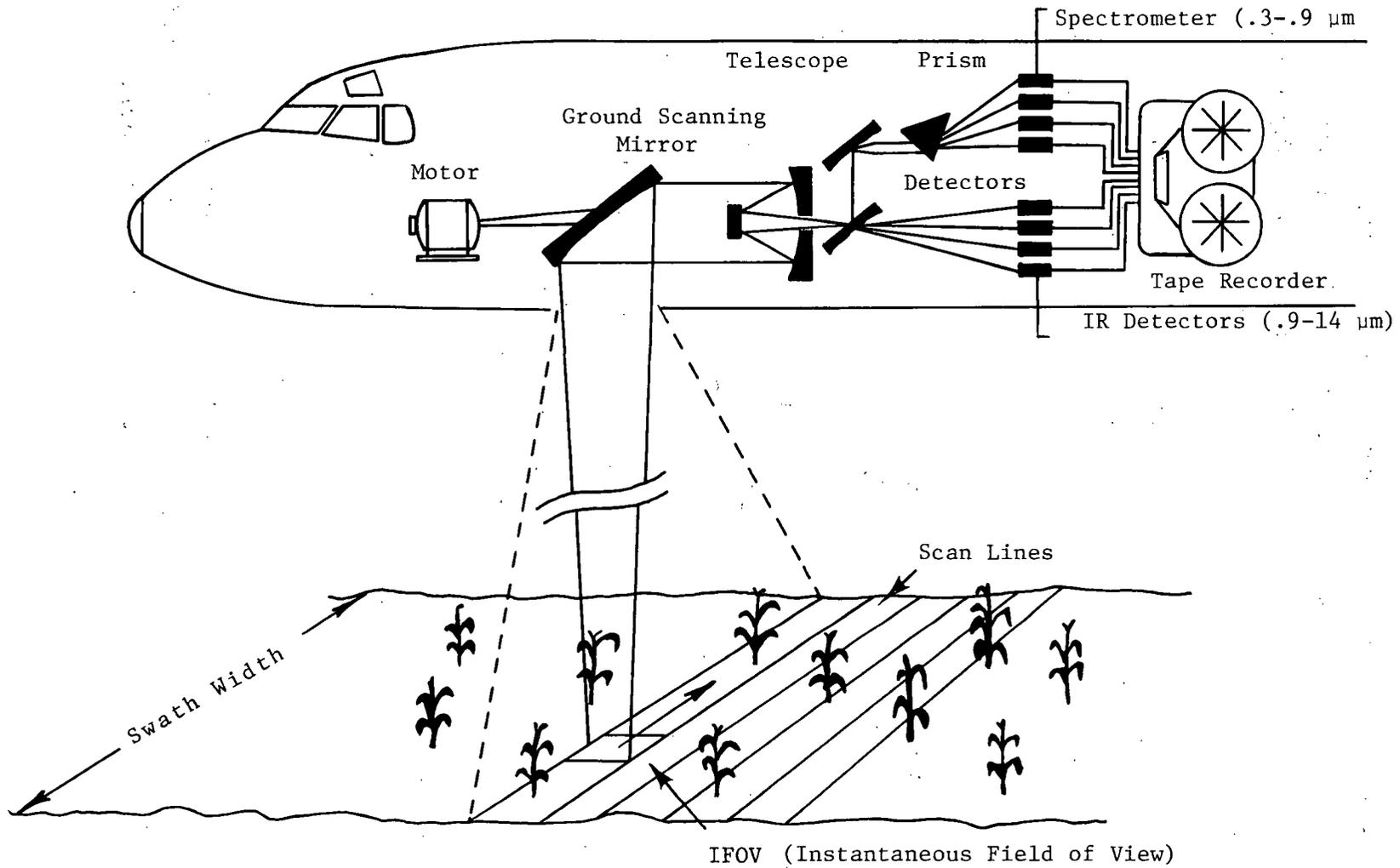
FIGURE 25. SCHEMATIC DIAGRAM OF AN AIRBORNE MULTISPECTRAL SCANNER

and is directed into a telescope by a ground scanning
mirror. The telescope optics then focus the radiation on
an array of detector elements sensitive to different
wavelengths. Each detector responds to this incident
radiation by producing an electronic signal which is
proportional to the power received in a narrow spectral
band. As the instantaneous field of view (IFOV) slides
across the scene at right angles to the direction of
flight, the signal varies. Because the mirror is spinning
rapidly during operation, actually a continuous strip of
overlapping IFOV's is recorded along a scan raster line
for a distance corresponding to the swath width. By the
time one scan is finished and the next one begins, the
data collection platform has moved forward, so that
each subsequent scan line covers an adjacent strip of
terrain to produce continuous coverage of the terrain beneath
it. Data collection is completed by amplifying and recording
the output signal of each detector on magnetic tape along
with calibration data.

Several airborne scanners are in operation today.
Typically they have around ten spectral bands available
ranging in sensitivity from the ultraviolet to the
thermal portion of the spectrum. Normal band width is
often 0.02 or 0.03 micron in the visible and near infrared
portions of the spectrum. For thermal channels, 2-4 micron
band widths are common. Most of these systems have a
resolution of about 3 milliradians (mr). Thus, when flying
at an altitude of 300 m (1000 ft), the IFOV is about 1m x 1m
(3 ft x 3 ft) on a side, or 1 sq m (9 sq ft).

A.2.1.2 Landsat

The primary sensor on board the Landsat satellites
(1 and 2) is also an MSS. It has only 4 spectral bands,
however: two in the visible part of the spectrum (0.5-0.6 μm
and 0.6-0.7 μm) and two in the near-infrared (0.7-0.8 μm and
0.8-1.1 μm). The IFOV of Landsat is 59 x 79 m (193 x 259 ft)
or about 0.4 hectares (1 acre).

Each Landsat is in a circumpolar orbit 570 m (920 km)
above the earth and completes 14 orbits a day. From this
vantage point, the satellite passes over the same spot at
the same sun time every 17 days. The orbits of Landsat 1
and Landsat 2 are staggered such that for a given geographi-
cal area, Landsat 1 follows Landsat 2 by six days and pre-
cedes the next Landsat 2 pass by twelve days.

A.2.2 DATA PROCESSING

Multispectral data processing is characterized by two
basic approaches: (1) image analysis, and (2) numerically
oriented analysis (Landgrebe, 1971). The two types of sys-
tems are compared in Figure 26. The distinction between the
two systems is most evident when considering the location
of the "form image" box in both systems. In the image-
oriented type, it is an essential, in-line function that
precedes any analysis. Numerically oriented systems, on
the other hand, do not need to generate an image before
analysis can proceed.

A.2.2.1 Image Analysis

The technology for image-oriented processing is well
developed. Several "image enhancing" systems are currently
available commercially and analysis techniques based on
photo interpretation procedures are well defined. This
type of processing has the advantage of being easily

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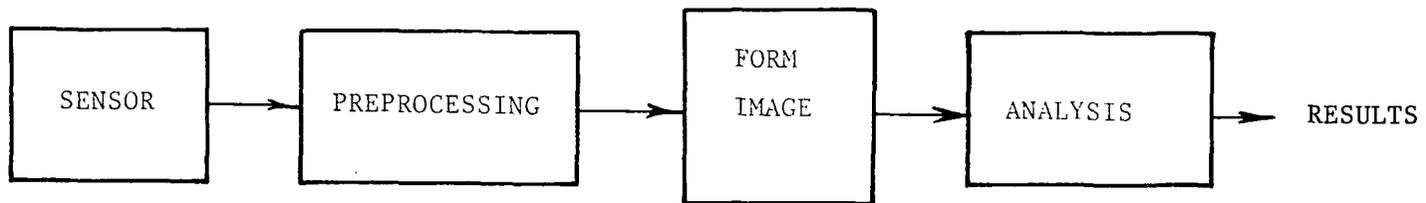
IMAGE ORIENTATION
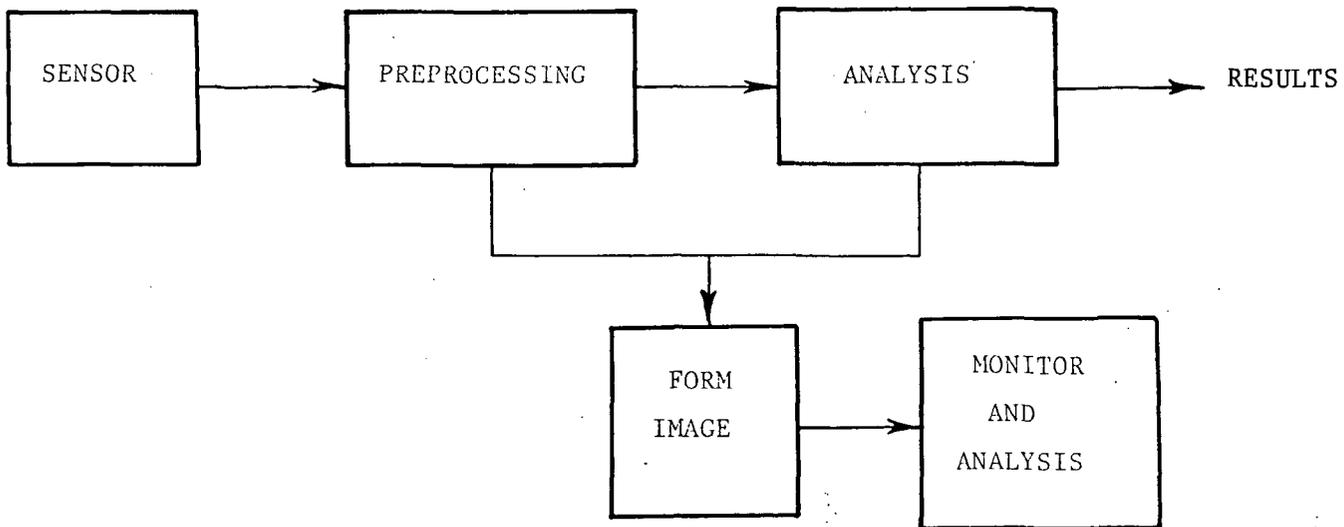
NUMERICAL ORIENTATION

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FIGURE 26. ORGANIZATION OF IMAGE-ORIENTED AND NUMERICALLY
ORIENTED MULTISPECTRAL SCANNER DATAPROCESSING SYSTEM (After Landgrebe, 1971)

accomplished by the neophyte user. This is an advantage
because the user can do his own processing and avoid the
expense and possible delay involved in having an outside
source to do it. This type of system produces subjective
data often of a very high degree of sophistication, depending
on the experience and knowledge of the interpreter.

"Image enhancement" is a term which describes a variety
of techniques for producing a map-like product from multi-
spectral data that goes beyond the generation of a simple
photo-like image to the point where the interpretability
of the image is greatly increased. The three most common
image enhancement techniques are discussed next.

Thresholding and Level-Slicing

These are techniques applied to a single channel of
multispectral data. In essence, the computer acts as a
filter to reduce the noise presented to the viewer. In
thresholding, signal intensity level is used to segregate
the data into two categories, one above a certain level and
one below. This level is typically set so that the data in
one of the two categories is correlated with the occurrence
of a scene feature of interest. Open surface water, for
example, can be mapped effectively this way. Open water
is a very weak reflector of near-infrared radiation under
most conditions and its signal is therefore usually much
lower than any other scene class. By placing a threshold
level on a near-IR channel of MSS data between the signal
of water and the signals of the other terrain features, it
becomes very easy to segregate and subsequently locate
all the water bodies in a set of data (Work, 1974).

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Level slicing is a slightly more involved form of thres-
holding in that the dynamic range of the signal in a channel
is split up into a number of intervals. Actually this tech-
nique amounts to electronic equidensitometry that results
in images with several gray tones. A temperature map of
the outfall of a water treatment plant could be made this
way. This application also illustrates how level slicing
can be used to calibrate an image, i.e., the levels selected
have some absolute, as well as relative meaning to the viewer.

Color Composite Images

The data in up to three spectral bands can be color
coded the same way the layers of color and color infrared
film are colded. In this way, it is possible to simulate
these film types as in the case of the color composite images
made from the three Landsat spectral channels which approxi-
mate the spectral sensitivity of CIR film and are color coded
the same way.

On the other hand, by using spectral channels outside
0.4-0.9 m, data not detectable photographically can also
be included in an image using this technique. It is also
possible to "stretch" the contrast of an individual channel
before color coding to bring out subtle scene features.
Thus, this method of producing color images offers the
potential for tailor-making a very sophisticated image with
a great deal of pertinent information for the interpreter
to use.

Ratioing

In this technique, the signal in one spectral band is
divided by that of another to produce a third channel which
represents the ratio of the two. The result is to emphasize

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the appearance of scene features whose reflectances are
negatively correlated in the two bands used. Subsequently,
level slicing may be used to further refine the image.
This technique has several good uses; under certain conditions,
for instance, ratioing a red and near-infrared spectral band
is a quick and effective way to separate live from dead vege-
tation (J. Colwell, 1974).

Ratioing can also be an effective means of reducing
the effects of uneven illumination or atmospheric conditions
because these phenomena exhibit highly correlated effects
in adjacent spectral channels. As a result ratioing is
often used to prepare data for pattern recognition
processing.

A.2.2.2 Numerically Oriented Analysis

Numerically oriented MSS data processing
techniques are newer, less intuitively easy to grasp, and not
nearly so routine to apply. The rationale for developing
these computer implemented techniques has been summarized
by Erickson (1972) as follows: first, automated data
processing potentially can be done in near real-time, which
is an advantage where it is important to get information
quickly. Second, automated processing is more cost effective
than manual data processing when the information content
of the data is low but the volume of data that must be
processed is high. Third, automated data processing has
the potential for greater consistency because objective
classification standards are used. Finally, the information
derived from automated processing can be directly integrated
into the data bases of other information systems.

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Multispectral Pattern Recognition

Multispectral pattern recognition is a computer-implemented data processing technique for identifying various surface features in multispectral data. Its use is based on the assumption that the "spectral signatures" (i.e., the spectral radiances observed by the multispectral scanner in discrete wavelength bands) of various terrain features are sufficiently different to permit recognition of these features by the variation of their spectral pattern of spectral reflectance/emittance.

Typical computer algorithms for pattern recognition processing require training of the recognition processor. To implement this step, spectral signatures (which define spectrally separable scene classes) are derived from either "training sets" (representing samples of known terrain features) or from "clustering" and fed to the recognition processor. After training (on typically a small fraction of the total data set), the processor uses an algorithm to classify each element of the unknown data according to the similarity of its spectral signature to the set of training signatures.

The assumption that the spectral signature of a terrain class is distinctive enough to permit good recognition is crucial to the success of pattern recognition techniques. Also, the conditions of data collection, including illumination, scanner system stability, and atmospheric state must remain fairly uniform to allow good performance. Since in practice, these data collection conditions are only approximately uniform, various preprocessing techniques have been developed to reduce the sensitivity of pattern recognition performance to variations in collection conditions over wide areas.

The uniqueness of spectral signatures of terrain classes (under uniform collection conditions) is the fundamental limiting factor in determining the ability of pattern recognition techniques to separate the classes in multispectral data. If two signatures closely resemble each other, the separation of the classes those signatures represent will be difficult. This realization has motivated the search for spectral bands where various terrain classes have signatures sufficiently different to permit their accurate separation.

In addition to picking the spectral bands that optimize the discrimination of important scene features in data collected on a given date, the temporal variation in the reflectance patterns of these features can also be employed to improve the potential for discrimination by merging two or more data sets collected on different times. The fact that this can be done quickly and fairly simply for large areas by computer for Landsat data has made it possible to improve overall scene recognition as much as 12% (from 84 to 96) (Sattinger, et al., 1974).

A.2.3 COSTS

Costs vary considerably for both the collection and processing of aircraft MSS data. The author estimates the average cost of a flight time mile of 12 channel MSS data to be in the neighborhood of $3-5/sq km ($7-13/sq mi). The costs of aircraft MSS data processing depends on the type of processing required and how much data is involved. In general, the image processing techniques cost less than the numerically oriented ones. Costs for the image oriented techniques (level slicing, ratioing) are generally only a

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few dollars per sq km. Prices for the more sophisticated
mineral techniques are likely to reach $8-10/sq km ($20-25/
sq mi).

Landsat data, on the other hand, can be purchased at a cost
of one cent per sq kilometer and processed using pattern recogni-
tion for as little as an addition $.20/sq kilometer ($.50/ sq mi)
for areas larger than three or four thousand sq kilometers. This makes
Landsat data the most economical form of MSS data available
to most users.

A.3 RADAR

A.3.1 DESIGN AND OPERATION

A simple radar system (Figure 27) consists of a
transmitter, a receiver, and a cathode ray tube display,
with the transmitter and receive alternately connected to
an antenna. When a switch connects the transmitter to the
antenna, the radar system emits a short burst of radio
frequency energy along a narrow beam in space. By the time
the signal has radiated out at the speed of light, been
reflected from a target and returned to the antenna, the
switch has coupled the antenna to the receiver. The
received signal is amplified to produce a spot in a position
on a cathode ray tube corresponding to the direction and
range of the observed target. This positioning is
accomplished by initiating the sweep of the
electron beam across the cathode ray tube at the same
instant each radar pulse is emitted by the antenna. Since
the constant speed of the spot across the face of the tube
corresponds to the radiation of the radar pulse at the
speed of light from the antenna, the radar system is
determining the range to the target by measuring the round
trip time from the radar antenna to the target. Thus, the
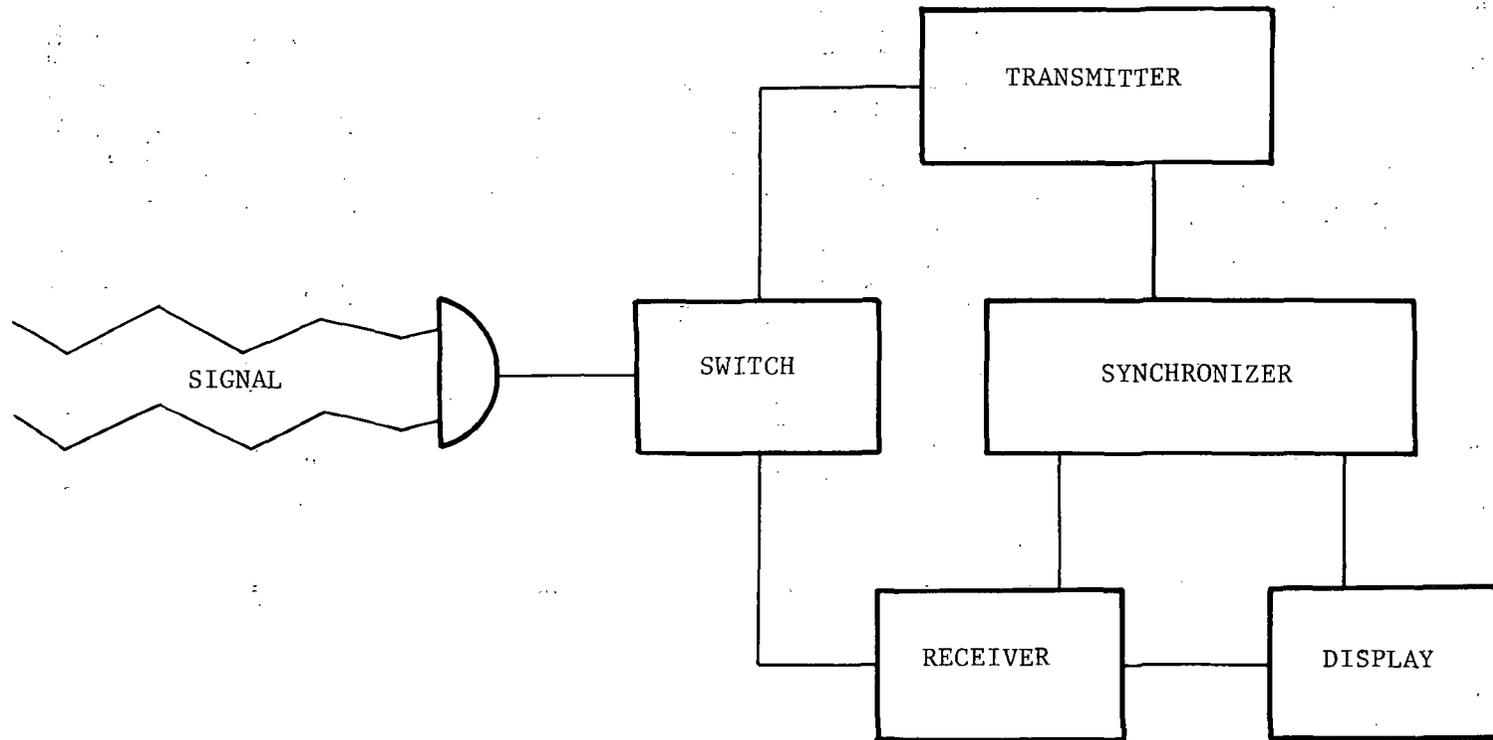
FIGURE 27. RADAR SYSTEM BLOCK DIAGRAM (AFTER MOORE, 1971)

returning pulse intensifies the beam at a spot on the tube
corresponding to the location of the target. The synthetic
aperture radar is a more sophisticated type of radar giving
much higher resolution, but its final display of scene
objects is similar to that described here.

A radar scene may be thought of as a complex array of
point targets. Thus, an image of a large area is formed on
a cathode ray tube by controlling electron beam position
and intensity to correspond to the stream of signals
returning from such complex targets consisting of vegeta-
tion, landforms, man-made structures, etc.

A radar image shows how the signal sent out by the
transmitter was scattered as it hit the ground. The
factors controlling ground scatter fall into two categories,
properties of the radar signal and properties of the terrain
surface. The most important property of the surface is its
smoothness (See Figure 28). Thus, a rough surface such as
a forest will appear bright on the radar screen, while
calm water will reflect very little of the signal back to
the antenna and will, therefore, appear dark. Apparent
roughness of a surface also depends on the radar wavelength.
A surface which appears rough to a radar pulse of a
wavelength shorter than the surface irregularities will
appear smooth to a longer wavelength. In addition, the
reflected signal strength depends on the electrical
characteristics of the target material. A good electrical
conductor, such as a metal, is a strong reflector of radar
signals, while poor conductors may be nearly transparent.
The material's dielectric constant thus also affects signal
strength. The radar image, therefore, is an indicator
of both target structure and composition.

Surface Condition	X – Band $\lambda = 3.2$ cm	L – Band $\lambda = 24$ cm
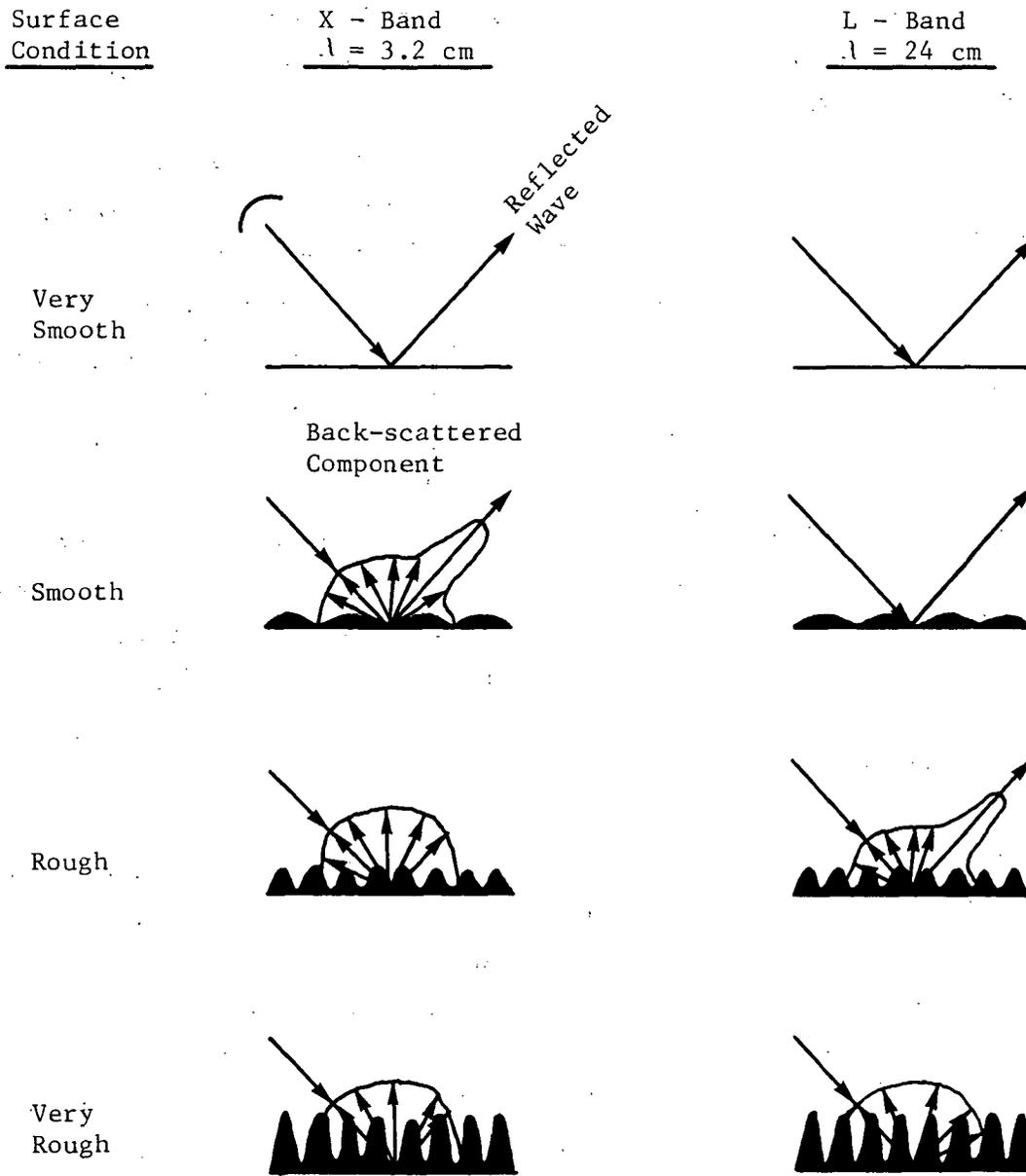
FIGURE 28. DIFFERENTIAL EFFECTS OF SURFACE ROUGHNESS SHOWING INTENSITY OF SCATTER FOR OBLIQUE INCIDENT RADIATION OF TWO DIFFERENT WAVELENGTHS.

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A.3.2. DATA PROCESSING

Most radar data is interpreted in image form by trained radar image analysts using the conventional photo interpretation approach. Recently, however, some experimental work has been done in an attempt to see if the pattern recognition techniques developed for processing multispectral data can also be used to process multi-channel radar data.

A.3.3 COSTS

Radar data is also expensive to collect. Typical data collection costs run as high as $10/sq km ($25/sq mi). Processing to produce images and interpret them could cost an additional $11-14/sq km ($30-35/sq mi) (ERIM Radar Lab, personal communication). Thus, to use radar data, the user should be prepared to spend at least $17-23/sq km ($50-60/sq mi).

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APPENDIX B

GUIDELINES FOR OPTIMIZING
REMOTE SENSING DATA COLLECTION

In this appendix recommendations are made regarding how to
collect good remote sensing data over wetlands. In the
first section the sources of variation in remote sensing data
are briefly reviewed. This review is then followed by a dis-
cussion of the two major factors that should determine the
scheduling of data collection: time of year and time of day.
Some of the routine flight planning that should be done by
anyone contemplating remote sensing are then discussed in
the following section on Mission Planning. Finally, some
of the considerations involved in contracting data to an
outside agency are considered, for those who prefer or need
to have their data collected this way.

B.1   SOURCES OF VARIATION IN REMOTE SENSING DATA

In Chapter 2 and Appendix A it was stated that the
basic premise of remote sensing is that a unique and con-
sistent pattern of spectral reflectance is associated with
most natural materials. Yet, we also know that the radiation
a remote sensor receives consists of radiation both re-
flected from an object and that which was scattered into
the field of view from several other sources. In practice
this means that many different objects can have the same
apparent reflectance while different examples of the same
material located a distance apart may appear dissimilar.

The most important causes of these variations in
object reflection can be broken down into the three basic
categories shown in Table 12. Many of these causes of
variation are controllable, and their adverse effects can

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TABLE 12.   SOURCES OF VARIATION IN REMOTE SENSING DATA

A. Environment
       Changes in irradiance (illumination)
       Changes in atmospheric transmittance
       Changes in path radiance

B. Scene
       Changes in viewing geometry
       Changes in object reflectance
       Changes in object geometry

C. Instrumentation
       PHOTOGRAPHIC SYSTEMS
           Processing
           Emulsion

       MSS
           Scanner electronics and tape recorder
             instabilities
           Gain changes
           Non-uniform view angle responsivity
             of detectors

       RADAR
           Gain changes
           Variations in antenna response as a
             function of depression angle
           Unaccounted for aircraft motion

be avoided by proper planning and execution of data collec-
tion.

B.2   DATA COLLECTION SCHEDULING

Two data collection specifications that must be
properly handled to insure good data collection, because
they control several of the sources of signal variation
are the time of day and the time of year that data is
collected.

B.2.1   TIME OF DAY

Water is a specular reflector; i.e., it reflects light
in a manner similar to a mirror. The angle at which in-
cident light is reflected from its surface is equal to the
angle at which it arrives, but in the opposite direction.
Around solar noon, sun angle is very close to being normal
to the earth's surface. Therefore, remote sensing data
collected by a sensor also oriented normal to the earth's
surface, are likely to pick up this specular reflection.
Since specular reflection or glitter obscures detail in
the area from which it originates, it destroys the use-
fulness of that part of the image it dominates and it is
therefore desirable to avoid it.

Glitter can be avoided by collecting data when sun
angle is less than 35° above the horizon. On the other
hand, at very low sun angles, the long shadows of tall
objects become prominent which also may obscure detail.
To avoid this latter problem, collecting data at a sun
angle of greater than 25° is also recommended. For a
given local time, sun angle varies by season and latitude.
To find out when sun angle is between 25° and 35° for local
time on a given day solar ephemeris tables should be con-

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sulted (e.g., Smithsonian Meteorological Tables).

As a general rule, however, in the northern U.S. acceptable remote sensing data normally may be collected from April to September by beginning data collection two hours after sunrise and ending it 1-1/2 hours later in the morning; in the afternoon data collection should begin 3-1/2 hours before sunset and end 1-1/2 hours later. After September, begin and end 1 hour earlier in the morning and 1 hour later in the afternoon (Lukens, 1968).

B.2.2 TIME OF YEAR

Seasonal variations in the spectral properties of scene objects must also be considered in designing data collection missions. If aquatic and submergent vegetation or bottom type are of interest, missions should be scheduled for that time of year when water turbidity is lowest. Turbidity is generally higher in the spring due to meltwater runoff and one or two days after major storms. Thus, late summer or early fall is often the best time of survey these objects. Additionally, aquatic and semi-aquatic plant communities will also be at the height of their vegetative development at this time of year, improving detectability and allowing their maximum extent to be determined. If data collection is delayed until emergent vegetation senesces and turns brown, the spectral contrast between these communities and still-green submergent types will add another dimension to their separatability. Haze is also generally less during the fall. The only potentially serious drawback in waiting until September is that bad weather often becomes more frequent making missions difficult to schedule efficiently.

Another important phenological consideration is when leaf-out of deciduous vegetation occurs. It is often

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difficult to identify the presence of small wetlands be-
cause during the growing season they are covered by a
dense vegetation canopy. This is particularly true of
forested wetlands covered by deciduous trees. This type
of wetland can be identified much more easily by the
presence of standing water in the spring just before the
buds break on the trees (but see Figure 29). Spring flooding
can also be useful in locating the upper limits of other
types of wetlands as well (refer to Figure 3). The ability
to determine wetland plant condition (in terms of the per-
centage of live and dead vegetation) and species composition
is severely restricted at this time of year, however, be-
cause most of the vegetation is a uniform brown and only
these plants with persistent over-wintering parts will be
observable.

Another reason for collecting photography during the
leafless season is that it aids in revealing surface topo-
graphy. In heavily forested mountain parts of the country,
often the only time the actual surface of terrain can be
viewed is a short period between snow melt and bud break.

On the other hand, when the objective is to determine
the species composition of deciduous plant communities,
remote sensing data collected during the growing season is
usually preferred.

B.3 MISSION PLANNING

In planning a data collection mission several important
factors must be considered and the following information
specified:

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FIGURE 29. FORESTED WETLAND INDICATED BY EARLY FALL COLOR CHANGE
OF TREE CANOPY.

Area to be covered:	Including location, size, and area boundaries.
Sensor:	Selection based on project objectives.
Spectral sensitivity:	Specify the appropriate spectral intervals the sensor is to operate in.
Flying height:	Determined by a consideration of sensor resolution characteristics, detail required for data interpretation and area coverage.
Position of flight lines:	Typically parallel and oriented in a cardinal compass direction, unless navigation is made simpler using some other orientation, like along a drainage pattern or road network. If mosaicing of photos is intended, all flight-lines must be flown in the same direction.
Time of photography:	Both time of day and time of year should be specified, based on the interim discussed in the preceding sections.
Data processing:	Thought should be given to this to make sure raw data output products are compatible with the equpment and techniques available for later processing.
Output products:	Exactly what is desired should be stated and when it is to be available as well.
Supporting field data collection:	What is needed, and the time period in which it must be collected should be determined.

More information specifically on photographic mission
planning is available in the Manual of Remote Sensing (1975)
and Eastman Kodak Company's publication M-5 (1971) "Photo-
graphing from Light Planes and Helicopters".

B.4 CONTRACT DATA COLLECTION

Costs of remote sensing data collection vary with time
of year, locality, weather, type of sensor and general
business conditions. Thus, when requesting a quotation from
a company that conducts aerial surveys or from another
branch of one's own agency, it is desirable to be able to
specify the optimum data collection requirements as closely
as possible. Most textbooks on aerial photograph inter-
pretation contain a chapter on this subject that is worth
reading if such a move is contemplated (e.g., Avery, 1968,
chapter 7). For planning the interpretation task associated
with photographic data, it is also useful to be able to
compute before hand how many photos will be on hand.
Lund (1969) has developed formulas and tables to facilitate
these computations.

Finally, after the data has been collected, it is
necessary to evaluate whether it is acceptable or needs to
be redone. Inspecting the data can be simplified by using
a checklist similar to the one proposed by Avery (1968).

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APPENDIX C

FILM/FILTER COMBINATIONS FOR PHOTOGRAPHIC
REMOTE SENSING OF WETLANDS

The use of the proper filter with a given film type
can greatly improve the contrast of certain scene objects
in relation to their background which greatly enhances
their interpretability. Filters must be used with caution,
however, if valuable information is not to be inadvertently
thrown away.

An obvious example of how this might occur in the course
of mapping aquatic (i.e., submerged) vegetation and bottom
features are as follows. The maximum transmission of light
in clear water occurs in the blue end of the visible
spectrum, distributed around .53 µm. Since haze filters,
e.g., WR 12 (.500 µm cut on) and WR 15 (.510 µm cut on),
eliminate a large amount of the blue light which penetrates
water, their use would severely restrict the amount of
underwater detail that can be obtained by greatly attenuating
the reflection from submerged objects. A better solution would
be to wait for a very clear day, or fly early in the morning
before haze builds up, and use only a UV filter – one that
cuts on around .42 µm.

Film/filter combinations that have proven effective
in past projects are listed by application in
Table 13.

Over typically hazy areas like wetlands, or at high
altitudes, a major factor that works against getting a
good photographic IR record is that water vapor can
severely attenuate infrared radiation. The hazy humid
conditions over a wetland can act as a water baffle cut-
ting down on the amount of IR light reaching the camera.

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TABLE 13. FILM/FILTER COMBINATIONS FOR PHOTOGRAPHIC
REMOTE SENSING OF WETLANDS

APPLICATION/PARAMETER STUDIED		FILM/FILTER		REFERENCE
1. Water				
	Turbidity	Color	UV	1
	Bottom Features, in clear water	PAN B&W	yellow	6
	moderately water	PAN B&W	orange	6
	very turbid water	PAN B&W	red	6
2. Vegetation				
	Aquatic & Submergent			
	A. Chara, Nitella, Niaid, Water Milfoil	Color	UV	1
	B. Aquatic plants in general	CIR	25A	2
	Emergent			
	A. Juncus sp. (black rush)	PAN B&W	Wr 58	2
	B. Wild rice, water lily, rush, reed, pickerel weed, salt marsh reed, cord grass, salt meadow grass	Color	UV	3
	C. Reed, cattail, yellow pond lily, wild rice, stand density classes	CIR	Wr 12 or Wr 15	2
	D. Marsh elder	CIR	Wr 61	3
	E. Sparse bulrushes, reed-grass and wild rice	Over-exposed B&W IR	Sr 89B	8
	Trees and Shrubs			
	Willow, black ash, elm, black spruce, tamarack	CIR	G 15/30M	9
3. Drainage Analysis				
	Shoreline Delineation	CIR	Wr 61	3
	2nd and 3rd order channels	B&W IR	Wr 89B	6
	Land-Water interface	B&W IR	Wr 89B, 87 or 87C	8
	Soil Moisture	B&W IR	Wr 89B, 87 or 87C	8
4. Land Use				
	Drainage and vegetation	CIR	Wr 12 or Wr 15	5
	Soils and cultural features	Color	UV	5

REFERENCES:

1. Lukens, 1968	4. Eitel, 1972	7. Colwell, 1961
2. Anderson, 1971	5. Anson, 1966	8. Cowardin & Meyer, 1972
3. Anderson, 1968	6. Parry and Turner, 1971	9. Deshong, 1971

Additional "minus visual" filtration can be used to rebalance the exposure of CIR film and overcome this problem in some cases. For moderate haze conditions a CC30B filter can be used with a Wratten 12 or 15 filter. For drastic haze conditions, an 80B filter can be used.

CIR film does not have an AGA film speed as does natural color film. Experimentation, however, has determined that for 35 mm, through-the-lens metering cameras, good results are obtained using the following settings on clear sunny days.

TABLE 14

CIR Filter Systems for Use with 35 mm Cameras
(after Pease & Bowden, 1969)

Filter	Haze	AGA
WR 15	normal	160
WR 15 + CC30B	moderate	100
WR 15 + 80B	heavy	60

APPENDIX D

ORGANIZATIONS THAT COLLECT AND
PROCESS REMOTE SENSING DATA

D.1   SOURCES OF AERIAL PHOTOGRAPHY

The addresses of most major aerial survey firms can
be obtained from a current copy of Photogrammetric Engineer-
ing, the Journal of the American Society of Photogrammetry.
Quotations on mission costs and photo indices of available
coverage can be obtained by direct inquiry.

Photography is also available from the federal govern-
ment. To find out if an area of interest has been photo-
graphed the following publication should be ordered:

> "Status of Aerial Photography in the U.S.",
> Map Information Office
> U. S. Department of the Interior
> U. S. Geological Survey
> Washington, D. C.   20240

This report, which is updated periodically, shows all
areas of the U. S. that have been photographed by or for
the following agencies:

> ASCS - Agricultural Stabilization & Conservation
>   Service
>
> SCS - Soil Conservation Service
>
> USFS - Forest Service
>
> USGS - Geological Survey
>
> USCE - Corps of Engineers
>
> USAF - Air Force
>
>   Coast and Geodetic Survey

The names and addresses of the agencies holding nega-
tives for given missions are listed and inquiries should be
sent directly to them. The bulk of photo collection has been
done by the top three agencies listed above. Coverage

typically consists of 1:20,000 panchromatic black and white
photography for ASCS and SCS and 1:15,840 black and white
panchromatic or infrared photos for the U.S. Forest Service.
Recently, ASCS has changed to a smaller scale 1:40,000 while
the Forest Service is using color and color infrared film
types.

To obtain information on Canadian photographic coverage,
one should write to:

>   National Air Photo Library
>   Room 180, Surveys & Mapping Building
>   615 Booth Street
>   Ottawa, Ontario K1A OE9, Canada

EROS Program

The Earth Resources Observation Systems (EROS) Program
of the U.S. Department of the Interior administered by the
Geological Survey was created in 1966 to apply remote
sensing. As part of this program the EROS Data Center
located in Sioux Falls, South Dakota, is operated to provide
access to NASA's Landsat imagery, aerial photography acquired
by the Department of the Interior and imagery collected by
NASA's research aircraft and SKYLAB, APOLLO, and GEMINI
spacecraft.

To inquire about the availability of data for a certain
area, contact:

>   Users Services Unit
>   EROS Data Center
>   Sioux Falls, South Dakota   57198

Guidance in the use of remotely sensed data is also
available at the EROS Data Center in the form of scheduled
training courses and workshops.

D.2 SOURCES OF MULTISPECTRAL SCANNER DATA

There are currently several domestic sources of air-
borne MSS data and data processing services. Airborne MSS
data collection is served by three basic sensor system
designs. The firms which built and operate these systems
(and, in the case of Dendix and Daedalus, sell them) are
located in Ann Arbor, Michigan. Inquiries about existing
data sensor capabilities and performance specifications can
be directed to the following addresses by those interested.

1. Bendix Corporation
    Aerospace Systems Division
    3621 South State Road
    Ann Arbor, Michigan 48107

    M^2S scanner system 11 bands; (10 located
       .35-1.20 µm spectral region + 1 thermal
       band)

    Thermal mapper

2. Daedalus Enterprises, Inc.
    P. O. Box 1869
    Ann Arbor, Michigan 48106

    Daedalus Multispectral Scanner 11 bands;
       (10 located .38-1.10 µm + 1 thermal band)

3. Environmental Research Institute of Michigan
    P. O. Box 618
    Ann Arbor, Michigan 48107

    M-7 Multispectral Scanner 12 bands;
       (typically 10 channels from .33-2.6 µm +
       1 or 2 thermal bands)

Each of these firms also supplies data processing.
Quotations for services can be obtained through the same
addresses.

Two other firms supplying multispectral data processing
are:

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Earth Satellite Corporation (EARTHSAT)
7222 47th Street
Bethesda, Maryland   20015

General Electric Company
Box 8555
Philadelphia, Pennsylvania   19101

In addition, several universities have developed capa-
bilities for processing MSS data.   Two of the most prominent
are:

Purdue University
Laboratory for the Application of Remote Sensing
(LARS)
1220 Potter Drive
West Lafayette, Indiana   47906

Colorado State University
College of Forestry and Natural Resources
Fort Collins, Colorado   80521

Several MSS systems have been carried aboard NASA
spacecraft.   These include the MSS systems aboard the
Landsat satellites, and the S-192 sensor aboard Skylab.
Inquiries about this data should be addressed to the EROS
Data Center.

D.3   SOURCES OF RADAR DATA

In 1966 NASA initiated a program through which the
APQ-97 could be used to generate radar imagery for earth
resource survey purposes.   Flight data were collected over
specified test sites as well as at miscellaneous locations
in North and Central America, and these data were turned
over to investigators at a variety of institutions, in-
cluding University of Kansas, CRREL, U. S. Army Topographic
Command, and Raytheon-Autometric.   Many of the results
obtained during these early attempts to assess SLAR as a

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remote sensor have been published via the International Symposia on Remote Sensing of Environment, and in reports and journal publications of staff members of these institutions. The APQ-97 has been donated to the Miami NOAA-NESS Lab and will be flying again shortly.

SAR X-band (3 cm) radar imagery over most of the continental U.S. is available courtesy of Strategic Air Command through C. A. Anderson, Goodyear Aerospace Corporation, P. O. Box 85, Litchfield Park, Arizona 85340. Simultaneously obtained X- and L-Band (3 and 24 cm, respectively) dual polarization data of limited areas in the U.S. is available from the Environmental Research Institute of Michigan, P. O. Box 618, Ann Arbor, Michigan 48107.

Currently an L-band SAR is being designed to image from a satellite. The SAR system will be part of the NASA satellite SEASAT A, which is to be launched in the second quarter of 1978. Although primarily designed to image the oceans, the SEASAT A L-band SAR will be operated over selected land targets. The imagery produced will be parallel polarization and have an IFOV size of 25 x 25 m. Imagery from this satellite will eventually be available to the public through the EROS distribution centers at Sioux Falls, South Dakota.

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