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SEMINAR ON REMOTE SENSING APPLICATIONS AND TECHNOLOGY TRANSFER FOR INTERNATIONAL DEVELOPMENT

APRIL 18 - 21, 1979
ANN ARBOR, MICHIGAN, U.S.A.

SPONSORED BY:

Office of Science & Technology
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SEMINAR ON REMOTE SENSING APPLICATIONS AND TECHNOLOGY TRANSFER FOR INTERNATIONAL DEVELOPMENT

ANN ARBOR, MICHIGAN

18-21 APRIL 1979

PREFACE

This seminar, sponsored by the Office of Science and Technology/Development Support Bureau of the U.S. Agency for International Development, was organized and conducted by the Environmental Research Institute of Michigan in conjunction with the Thirteenth International Symposium on Remote Sensing of Environment.

Held on the campus of The University of Michigan from 18 to 21 April 1979, the seminar was primarily intended to provide a broad overview of the utilization of remote sensing technology in various development programs of interest to administrators and decision-making officials from developing countries throughout the world. The seminar also sought to provide a more detailed treatment of certain techniques, methodology and results of importance to representatives of the scientific and technical community.

The program emphasized the use of modern remote sensing techniques in selected areas of importance to international development, including:

- Desertification
- Ground water hydrology
- Agriculture, Forestry and Environmental Monitoring
- Statistical sampling and forecasting
- Non-renewable resource delineation

as well as the effective transfer of remote sensing technology throughout the developing world.

A total of 53 speakers, delegates and observers representing 17 nations and 4 international organizations participated in the seminar, including:

Chile	France	Nigeria
Costa Rica	India	Singapore
Ecuador	Italy	South Africa
Egypt	Iran	Switzerland
England	Jamaica	United States
Finland	Japan	United Nations

Commission of the European Communities
Interamerican Development Bank
Instituto Interamericano de Ciencias Agricolas

This volume documents the seminar program through publication of summaries or, as available, the complete text of 21 presentations made by leading experts in the aforementioned topic areas.

Finally, the significant contribution to effective communication, international cooperation, and technology transfer being made by the Agency for International Development, through the sponsorship of seminars such as this, is greatfully acknowledged. Only through continued direct and personal contact, effective communication and interdisciplinary interaction, as provided by programs such as herein represented, can modern technology be brought to bear effectively upon pressing problems of international development.

SEMINAR ON REMOTE SENSING APPLICATIONS
AND TECHNOLOGY TRANSFER FOR INTERNATIONAL DEVELOPMENT

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SEMINAR ON REMOTE SENSING APPLICATIONS AND TECHNOLOGY TRANSFER FOR INTERNATIONAL DEVELOPMENT

SPONSORED BY: Office of Science & Technology, Development Support Bureau, U.S. Agency for International Development, Washington, D.C.

ORGANIZED AND CONDUCTED BY: Environmental Research Institute of Michigan
Ann Arbor, Michigan

Jerald J. Cook, Program Chairman

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Ann Arbor, Michigan

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Toulouse, France

SEMINAR ON

REMOTE SENSING APPLICATIONS AND TECHNOLOGY TRANSFER FOR INTERNATIONAL DEVELOPMENT

APRIL 18 - 21, 1979

Assembly Hall
Michigan Union
530 S. State Street, Ann Arbor, Michigan

The following program, sponsored by the U.S. Agency for International Development, and organized and conducted by the Environmental Research Institute of Michigan, is designed to provide a broad overview of the utilization of remote sensing technology in various areas of importance to international development, as well as address various means for the effective transfer of remote sensing technology throughout the developing world.

Jerald J. Cook
Chairman

WEDNESDAY — APRIL 18

10:30 WELCOME AND INTRODUCTION

Charles F. Withington
Office of Science and Technology,
Agency for International Development
Washington, D.C. U.S.A.

DESERTIFICATION

Chairman: Victor I. Myers
South Dakota State University
Brookings, South Dakota U.S.A.

10:45 DESERTIFICATION: CAUSES, EFFECTS AND ASSESSMENT

Harold E. Dregne
International Center for Arid and Semiarid Land Studies, Texas Tech University
Lubbock, Texas U.S.A.

A COMPARATIVE LOOK AT SOME OF THE PROBLEMS OF DESERTIFICATION AND REMOTE SENSING DATA SOURCES

Priscilla Reining
Office of International Science, American Association for the Advancement of Science
Washington, D.C. U.S.A.

DISCUSSION

12:00 Lunch

1:30 TECHNOLOGY TRANSFER - A NEW APPROACH TO SOLVING PROBLEMS OF DESERTIFICATION

Charles F. Withington
Office of Science and Technology,
Agency for International Development
Washington, D.C. U.S.A.

REMOTE SENSING FOR MONITORING RESOURCES FOR DEVELOPMENT AND CONSERVATION OF DESERT AND SEMIDESERT AREAS

Victor I. Myers
Remote Sensing Institute,
South Dakota State University
Brookings, South Dakota U.S.A.

DISCUSSION

3:00 Break

3:30 THE APPLICATION OF REMOTE SENSING TO UNDERSTANDING THE DESERT LANDSCAPE

Farouk El-Baz
Center for Earth and Planetary Studies,
Smithsonian Institution
Washington, D.C. U.S.A.

MONITORING OF DESERTIFICATION ELEMENTS IN EGYPT BY REMOTE SENSING TECHNIQUES

Mohamed Abdel Hady
Remote Sensing Center
Cairo, Egypt

DISCUSSION

THURSDAY — APRIL 19

AGRICULTURE, FORESTRY AND THE ENVIRONMENT

Chairman: A. B. Park
General Electric Company
Beltsville, Maryland U.S.A.

8:30 INTRODUCTION TO MULTIPURPOSE AGRICULTURAL SURVEYS

William H. Wigton
Statistical Research Division,
U.S. Department of Agriculture
Washington, D.C. U.S.A.

UTILIZATION OF AN AREA SAMPLING FRAME TO ESTIMATE AGRICULTURAL PRODUCTION

Roy Russell
Data Bank and Evaluation Division,
Jamaican Ministry of Agriculture
Kingston, Jamaica

INTEGRATING SATELLITE DATA INTO AN AGRICULTURAL INFORMATION SYSTEM

William H. Wigton
Statistical Research Division,
U.S. Department of Agriculture
Washington, D.C. U.S.A.

DISCUSSION

10:00 Break

10:30 THE USE OF LANDSAT IN AGRICULTURAL EVENT DETECTION AND ASSESSMENT

A. B. Park
Space Division,
General Electric Company
Beltsville, Maryland U.S.A.

INTERRELATIONSHIPS BETWEEN AGRICULTURE, FORESTRY AND MAN'S USE OF LAND

C. E. Olson, Jr.
School of Natural Resources,
The University of Michigan
Ann Arbor, Michigan U.S.A.

DISCUSSION

12:00 Lunch

1:30 THE USE OF REMOTE SENSING IN FOREST INVENTORY

Philip G. Langley
Earthsat Corporation
Berkeley, California U.S.A.

AN INTEGRATED REMOTE SENSING SYSTEM FOR RANGELAND INVENTORY

Charles E. Poulton
Moffett Field, California U.S.A.

DISCUSSION

3:00 Break

GROUND WATER HYDOLOGY

Chairman: Morris Deutsch
U.S. Geological Survey
Reston, Virginia U.S.A.

3:30 SIGNIFICANCE OF GROUND WATER AS A PART OF THE HYDROLOGIC CYCLE and

APPLICABILITY OF REMOTELY SENSED DATA FOR HYDROGEOLOGIC INVESTIGATIONS

Morris Deutsch
U.S. Geological Survey,
U.S. Department of the Interior
Reston, Virginia U.S.A.

PRINCIPLES OF EXTRACTING GROUND WATER INFORMATION FROM LANDSAT DATA

Gerald K. Moore
Applications Branch, EROS Data Center,
U.S. Geological Survey
Sioux Falls, South Dakota U.S.A.

CASE STUDIES ON GROUND WATER INTERPRETATION BASED UPON REMOTELY SENSED DATA

DARYACHEH YE NAMAK, IRAN: EMPLOYING REPETITIVE OPTICALLY AND DIGITALLY PROCESSED LANDSAT DATA

Manouchehr Abtavi
Tehran, Iran

DISCUSSION

FRIDAY **APRIL 20**

8:30 CASE STUDIES ON GROUND WATER INTERPRETATION BASED UPON REMOTELY SENSED DATA (continued)

REMOTE SENSING APPLICATIONS FOR DETERMINING POTENTIALS OF GROUND WATER RESOURCES IN EGYPT

M. M. El Shazly
Remote Sensing Center
Cairo, Egypt

USE OF RADAR IN GROUND WATER EXPLORATION: NIGERIA

Ron Gelnett
Motorola Aerial Remote Sensing, Inc.
Phoenix, Arizona U.S.A.

GROUND WATER CONDITIONS IN TENNESSEE, U.S.A. BASED UPON SKYLAB DATA

Gerald K. Moore
Applications Branch, EROS Data Center,
U.S. Geological Survey
Sioux Falls, South Dakota U.S.A.

DISCUSSION

10:00 Break

10:30 GROUND WATER CONDITIONS IN THE MT. KENYA VOLCANIC AREA BASED UPON INTERPRETATION OF LANDSAT IMAGERY

Morris Deutsch
U.S. Geological Survey,
U.S. Department of the Interior
Reston, Virginia U.S.A.

PHOTO-OPTICAL AND DIGITAL ENHANCEMENT OF LANDSAT DATA FOR APPLICATIONS IN HYDROGEOLOGY AND CIVIL ENGINEERING

Morris Deutsch and Gerald K. Moore
U.S. Geological Survey
Reston, Virginia & Sioux Falls, South Dakota

DISCUSSION

12:00 Lunch

NON-RENEWABLE RESOURCE DELINEATION

Chairman: *W. D. Carter*
U.S. Geological Survey
Reston, Virginia U.S.A.

1:30 GLOBAL NEEDS AND OUTLOOK FOR NON-RENEWABLE MINERAL AND ENERGY RESOURCES

Ulrich Petersen
Hoffman Laboratory, Harvard University
Cambridge, Massachusetts U.S.A.

REMOTE SENSING TECHNIQUES IN THE SEARCH FOR NON-RENEWABLE RESOURCES

James V. Taranik
NASA Headquarters
Washington, D.C. U.S.A.

DISCUSSION

3:00 Break

3:30 MINERAL AND ENERGY EXPLORATION - A WORLDWIDE APPROACH

W. D. Carter and L. C. Rowan
U.S. Geological Survey,
U.S. Department of the Interior
Reston, Virginia U.S.A.

THE APPLICATION OF REMOTE SENSING IN THE SEARCH FOR NON-RENEWABLE RESOURCES IN DEVELOPING COUNTRIES-BOLIVIAN CASE HISTORY

Carlos E. Brockmann
GEOBOL
La Paz, Bolivia

DISCUSSION

SATURDAY **APRIL 21**

TECHNOLOGY TRANSFER

Chairman: *Jerald J. Cook*
Environmental Research Institute of Michigan
Ann Arbor, Michigan U.S.A.

8:30 RESOURCE DEVELOPMENT IN DEVELOPING COUNTRIES THROUGH THE TRANSFER OF REMOTE SENSING TECHNOLOGY

Suvit Vibulsresth
National Remote Sensing Agency
Bangkok, Thailand

A REVIEW OF THE CURRENT STATUS AND FUTURE NEEDS FOR REMOTE SENSING TRAINING AND TECHNOLOGY TRANSFER IN LATIN AMERICA

Rafo Bazan
Instituto Interamericano de Ciencias Agricolas
San Jose, Costa Rica

THE ROLE OF THE INTERAMERICAN DEVELOPMENT BANK IN TRANSFERRING REMOTE SENSING TECHNOLOGY TO LATIN AMERICA

Pierre-Marie Adrien
Interamerican Development Bank
Washington, D.C. U.S.A.

DISCUSSION

10:00 Break

10:30 THE UNITED NATIONS ROLE IN SATELLITE REMOTE SENSING

H. G. S. Murthy
Outer Space Affairs Division,
United Nations
New York, New York U.S.A.

WHAT'S APPROPRIATE ABOUT REMOTE SENSING TECHNOLOGY? THE LESSONS OF AN AID GRANT PROGRAM

Thomas W. Wagner
Environmental Research Institute of Michigan
Ann Arbor, Michigan U.S.A.

DISCUSSION

12:00 Lunch

1:30 TOUR OF LOCAL REMOTE SENSING FACILITIES
(Details to be announced)

DESERTIFICATION: CAUSES, EFFECTS AND ASSESSMENT

Harold E. Dregne
International Center for Arid and Semiarid
Land Studies
Texas Tech University
Lubbock, Texas

DESERTIFICATION INDICATORS

Studies on indicators of desertification have been confined almost exclusively to rangelands. These studies were not directed toward finding indicators of incipient or extreme desertification, per se (desertification was not a widely used term until recently). Instead, they were intended to provide data on range vegetation conditions that would permit decisions to be made about the need for changes in management practices. Knowing the potential productivity, the present condition, and the condition trend (whether it is getting better or worse or staying about the same) of range sites over time means that the degree and rate of desertification can be determined since range deterioration is one form of desertification. Similar determinations can be made for other land uses, but that has not been done to anywhere near the degree that it has for rangelands.

Indicators of desertification of rangelands, rainfed cultivated lands, and irrigated lands should, desirably, be quantitative, sensitive to small changes, easy to measure, and small in number. Direct or indirect measurements may be used. Those physical, biological, or sociological factors that integrate a number of other factors are especially useful. An example is the measurement of the amount of meat produced in a grazing area. Meat production can be a useful indicator of changes in the quantity and quality of plant biomass if factors such as disease do not complicate the interpretation. While the measurement of desertification indicators should be simple enough for a nonspecialist to carry out, the interpretation of the significance of the condition measured must be done by an experienced individual.

Desertification indicators can serve two purposes: they can be used to estimate how much land degradation has occurred in the past and what effect current management practices are having on the ecosystem.

Purpose of Indicators

The kind of desertification indicators that will provide guidance to managers, planners, and policy makers is the kind that can be used to determine directly or indirectly whether a particular piece of land is deteriorating, staying the same, or improving under current management practices. The indicators should enable an observer to determine the equivalent of range condition and range condition trend for all land uses, on any property. Where such indicators can be of special utility is in assisting in the evaluation of the effectiveness of management changes by individuals as well as by the managers of development projects. At present, assessments of the impact of changed practices imposed in a development project are seldom, if ever, made a part of the project structure. Accountability cannot be required if there is no way to determine, first, whether changes are occurring and, second, whether the changes are or are not due to the introduced practices. Desertification indicators, then, are crucial to the evaluation of management practices.

Interpretation of Indicators

It obviously is difficult - if not impossible - to identify unambiguous direct indicators of desertification in non-irrigated land. Drought complicates the interpretation of all indicators except those of salinization and waterlogging. The complexity of separating land management effects from drought effects can be illustrated by an example from rangelands. The onslaught of a drought can cause plants to die, seedlings to fail to become established, and plant growth to stop even on the best managed ranges. After two or more consecutive years of a moderately severe or severe drought, ground cover is lessened and the soils become more susceptible to wind erosion. Since winds tend to be stronger during drought periods, dust storms normally are more frequent, more intense, and of longer duration at that time. An increase in dust storms does indicate a deterioration in vegetative cover but not necessarily an increase in man-made desertification. On the other hand, a well-managed range in excellent condition may show little or no increase in dust storms even after two or three consecutive drought years. Isolating drought influences from management influences is not easy.

Crop and animal yield is an ambiguous indicator of desertification, not only due to the effect of weather variables but to those of disease and insect plagues and private or public plant and animal protection schemes. Tsetse fly infestations are responsible for keeping large parts of African savannahs in good or excellent condition by excluding livestock. In that case, a low livestock yield means little desertification and the tsetse areas represent, in a sense, plant reserves waiting to be tapped. Locust swarms can devastate crop and pasture lands irrespective of their ecological condition, reducing yields to zero even in the absence of any mismanagement of the land.

It probably is safe to say that the only unambiguous indicators of desertification are the salinity level of the soil and the depth to the ground water table. Those two are indicators of salinization and waterlogging under any kind of land use, most commonly that of irrigated agriculture.

Socio-economic Indicators

Drought is the most common complicating factor in determining whether environmental deterioration and a reduction in human well-being is due to man-made desertification or to other forces. Great care must be taken in arriving at decisions with respect to socio-economic indicators. This is particularly true when using satellite imagery to estimate changes in land use (National Academy of Sciences, 1970).

Monitoring Schedule

Monitoring must be done repetitively if change is to be measured. The frequency with which this is done depends upon the sensitivity of the indicators to change and the influence season of the year has on the indicator. Monitoring should be done on an annual schedule, at least for each indicator. Some of the indicators can be monitored periodically (e.g., plant biomass) where others should be monitored episodically (e.g., dust storms).

Soil erosion is the number one desertification problem in the rainfed cultivated lands.

Inappropriate water management is the main cause of desertification on irrigated lands.

A COMPARATIVE LOOK AT SOME OF THE PROBLEMS OF DESERTIFICATION AND REMOTE SENSING DATA SOURCES

Priscilla Reining

Office of International Science,
American Association for the Advancement of Science
Washington, D.C. U.S.A.

In this brief paper, the objective is to take an additional step in the preparation and implementation of a strategy for research design and monitoring design for desertification. I distinguish between research and monitoring because an operational monitoring system differs from some aspects of research and vice versa.

Two key questions are repeatedly being asked: what is happening in the processes of desertification and why is it happening. The aim of this workshop on remote sensing and desertification is to aid the further discussion and provides summaries of what can be monitored with the aid of remote sensing data sources. The sources of data cannot provide an explanation of why certain phenomena are occurring, but if care is taken to make observations, adapt methodology and use existing data sources in both the managed and unmanaged biosphere then the basis for comparative analysis is created. I use the term managed to refer to inhabited, culitivated, or other land directly affected by human activity (off road vehicles, mining, and so forth); in this context the phrase less managed or unmanaged biosphere refers to ungrazed grasslands, savanna, and swampy areas. The other types of unmanaged biosphere (polar regions, tundra) do not commonly come under the rubric of areas subject to desertification. In the long run, scientific comparison of the effect of human activity can only come from detailed, long term analysis of matched areas, managed and unmanaged. Stratified sampling, in my opinion, must have this principle as a basis. In this paper, I am summarizing what is considered necessary to monitor and what can be monitored.

Before going further, it is important to quote the definition of desertification decided upon by the United Nations (1). I also note the elements taken from the definition which were picked up by the Science Associations' Nairobi Seminar on Desertification (2).

Biological - - - - - - - - - - - -

Biological - - - - - - - - - - - -

Social- - - - - - - - - - - - - - - -

Social (biological parameters)- -

Biological (yield)- - - - - - - -

Physical and Biological- - - - -

Biological (vegetation)
Physical (soil, water) - - - - -

Biological (animal)- - - - - - -

Social (social processes) - - - -

Desertification is the diminution or destruction of the biological potential of the land, and can lead ultimately to desert-like conditions. It is an aspect of the widespread deterioration of ecosystems, and has diminished or destroyed the biological potential, i.e., plant and animal production, for multiple use purposes at a time when increased productivity is needed to support growing populations in quest of development. Important factors in contemporary society -- the struggle for development and the effort to increase food production, and to adapt and apply modern technologies, set against a background of population growth and demographic change -- interlock in a network of cause and effect. Progress in development, planned population growth and improvements in all types of biological production and relevant technologies must therefore be integrated. The deterioration of productive ecosystems is an obvious and serious threat to human progress. In general, the quest for ever greater productivity has intensified exploitation and has carried disturbance by man into less productive and more fragile lands. Overexploitation gives rise to degradation of vegetation, soil and water, the three elements which serve as the natural foundation for human existence. In exceptionally fragile ecosystems, such as those on the desert margins, the loss of biological productivity through the degradation of plant, animal, soil and water resources can easily become irreversible, and permanently reduce their capacity to support human life. Desertification is a self-accelerating process, feeding on itself, and as it advances, rehabilitation costs rise exponentially. Action to combat desertification is required urgently before the costs of rehabilitation rise beyond practical possibility or before the opportunity to act is lost forever.

Indicators are from the Handbook on Desertification Indicators (2)

From: United Nations Conference on Desertification, New York: United Nations, 1978, 7. (1)

To focus attention on the most feasible areas for using remote sensing data sources to assess desertification, I have constructed a matrix composed of the indicators selected in Nairobi. A comparison between physical and biological phenomena, and types of land and residential use in the "managed biosphere" is shown in Figure 1. The land and residential use categories were identified as social indicators by SANSOD and the numbers correspond to the ones used in the Handbook (2). The applicability of remote sensing data sources of varying scales and types follows this code:

a^1 -Detailed, 1:10,000; Aircraft photography and sensors.

a^2 -Detailed, 1:10,000; Systematic reconnaissance flight (SRF)

b -Reconnaissance, 1:20,000 to 1:100,000; aircraft reconnaissance as available

c -Synoptic, 1:250,000 to 1:1,000,000; Landsat 1 - 3 (CCTs)

d -Synoptic, 1:250,000 to 1:1,000,000; Landsat D (launch in 1981).

e -Synoptic, greater than 1:1,000,000; Meterological satellites.

Judgment of the possibility of using remote sensing data sources comes from several sources: (3), (4), (5), (6), (7), (8), (9), (10), (11), and (12). The use of these sources does not, however, constitute an extensive literature search and depends, in part, on working papers. The main purpose is to eliminate the least suitable possibilities and begin to narrow the search to the most suitable as they are understood at present. The emphasis on managed biosphere is consistent with the definition of desertification as caused largely by human activity.

In all cases, as is stressed in the cited research reports, results from field work or ground truth are necessary if the remote sensing data are to be properly verified.

Figure 1. Suitability of remotely sensed data sources to assess the status of physical and bio-agricultural phenomena indicative of desertification. The phenomena are organized by land use and residential categories.

	3.1 Type of land use and water source							3.2 Residential			
	.1 Irrigation	.2 Dryland Agriculture	.3 Pastoral/range	.4 Mining	.5 Firewood Collection area	.6 Off-road vehicles	.7 Water holes	.1 New	.2 Expand	.3 Diversify	.4 Abandoned
1.1 Soil											
.1 Changes in soil depth-seen in mosaic coloring		a^1,b (5)					a1	a^1,b			
.2 Surface seals			b (5)								
.3 Salt crusts	a^1 (3) (5)	b (5)									
.4 Sand Drifting		a^1 (5)	a^1 (5)								
.4 Major dust storms (also unmanaged biosphere)		c,d (5),(3)	c,e (5).(3)								
.4 Remobilized dunes		b,c (5)									b,c
.5 Alkalinization	b (5)										
1.2 Water											
.1 Falling water tables	a^1 (5)										
.1 Water logging, moist ground surface	a^1 a^2b (5)										
.1 Abandoned land due to ground water	a,b,c, (5)										
.1 Abandoned land	a^1(5)										a^1
.2 Change in extent of standing water		(5) c	c (5)								

Figure 1. (continued)

	.1	.2	.3	.4	.5	.6	.7	.1	.2	.3	.4
.3 Status of drainage system, influenced by land use in catchment area. .3 Silting as evidence of acclerated erosion in catchment area	a^1 (5)										
.3 Turbidity	c(5)						a^1 (5)				
.3 Extension of gully systems		a^1, c	a^1, c								
.4 Regional changes in climate and water balance, long term comparison	Unmanaged plus managed biosphere, c plus e with sufficient repetition to capture rainfall events										
2.1 Vegetation (data appropriate for .2, .3, .5 & .7 may be combined to show multiple use) .1 Changes in cover of perennial vegetation (see*)		a,b (5), (9)	a, b (5), (9)		a,b (5), (9)						
.2 Changes in distribution of perennial vegetation		a^1, a^2 b (5)	a^1, a^2 (5)					a^1			
.1 Reduction to annual species-rainy season		a^1, a^2 (5)	a^1, a^2 c (5)					a^1, c			
.1 Areas denuded of vegetation in settlement area								a^1, a^2 (5)	b, c (12)		
.2 Above ground biomass (green leaf biomass) Areas of low biomass (see note **)	e (6,11)	e (6,11) cMSS6 (7)	e (6,11) cMSS6 (7)		e (6,11)		e (6,11)	e (6,11)	e		
2.2 Animals .1		a^2	a^2					a^2	a^2		
.2 Habitat of key species is difficult to determine											

* "Spectral measurements were not predictors of dry biomass, plant height, and canopy cover under drought conditions." (9,p.10)

**"Thematic Mapper sensors TM1, TM2, TM3, and TM4 were found to be very well situated for remote

** continued:

sensing of vegetated targets." (6,p. 1378). And "MSS 7 is superior to MSS 6 for high green biomass situations (reviewed in Tucker, 1979) while MSS 6 has been shown to be superior to MSS 7 for lower (rangeland) green biomass applications. A hypothesis explaning this has been presented by Tucker and Miller (1977) based upon soil-green biomass reflectance contrasts and is in agreement with several Landsat-1 and -2 results (Maxwell, 1976;Rouse et al, 1974). (6, p. 1376).

end of Figure 1.

SPATIAL UNITS, SIZE AND DESERTIFICATION PROCESSES

Much more attention has been paid to discussion of desertification processes and desertification monitoring (which demands temporally organized data sets) than to the spatial extent of desertification processes. How large or how small areas are relative to advancing or retarding the spread of desertification processes is not yet ascertained, as far as I know. Mabbutt suggests the importance of reaching agreement, at least on scale ranges, in this note:

> I (Mabbutt) therefore recommend that the identification of appropriate mapping units be seen as an integral part of the methodology of desertification indicators. The mapping units will need to vary with land use. For rangelands they could be patterns based on topography, soil, and vegetation (cf. the Australian land system as 'pasture'lands'), in the scale range 1:1,000,000 to 1:100,000. For dryland farming, topoedaphic units in the scale range 1:100,000 to 1:20,000 would seem appropriate. For irrigated farming scales greater than 1:20,000 appear to be appropriate. The mapping units should be:
>
> a, "functional units" in a landscape or management sense;
> b, Identifiable on remote-sensing imagery,
> c, described in such a way that they are identifiable in the field by non-specialists;
> d, comparable across significantly large areas.
>
> Mapping and the identification and location of physical, biological and agricultural indicators could go hand in hand. The mapping framework should, through land-use and settlement patterns, also serve the application of social indicators. The need for the establishment of a typology of "topoedaphic environments" and the production of an atlas of such environments was stressed in the United Nations Conference on Desertification Plan of Action (2). I strongly recommend that this be proceeded with, either as part of or in close conjunction with, the establishment of a methodology for the application of desertification indicators. (3)

If the spatial extent of desertification processes were to be taken up for further consideration, two additional observations are relevant: (1) a number of investigators have noted the "patchiness" of desertification -- it begins in localized areas and, if unchecked these patches eventually coalesce, and (2) multiple use is frequently made of the domain, or resource zone, which surrounds settlements (12). In rural, semiarid areas, such settlements are

farmsteads, camps, or villages. In countries where commercial agriculture or commercial animal agriculture (ranching) is practiced, the size of such fields, ranches or domains is much larger than is commonly the case of subsistence regimes. If this discussion continues, Mabbutt's request for agreement and a review of research findings would also be directly relevant to further evaluation of remote sensing data sources of different scales and from different sensors.

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TECHNOLOGY TRANSFER - A NEW APPROACH TO SOLVING PROBLEMS OF DESERTIFICATION

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BACKGROUND

Desertification is a word that has entered the English language from the French literature. Interpretations of what the word means are almost as numerous as those who are concerned with the study of deserts. One definition is that desertification is the process by which arable land is laid waste either through the overriding and burial by wind-driven sands or through an expanding aridity induced by climate changes which result in loss of soil moisture. This has been called "desert encroachment."

A second definition, an expansion of the first, is one which most people think of for desertification. This involves the changes in ecological conditions in arid and semi-arid lands that reduce the capability of the land to support life. These changes may be climatic, but are more likely to be due to the actions of man in over-grazing, cutting down trees and over cropping without replacement of fertilizer. Actually, climate changes can be activated by man's actions, and deserts can spring up almost overnight, if conditions warrant.

A third definition, and one which will be used here includes the first two but adds to them the sociological aspect of desert encroachment. The U.N. figures show that there are about 78 million people living on arid or semi-arid lands from which they have to make a living -- lands which in Africa make up about 50 percent of the continent. The number of people on these lands are increasing rapidly. They need the land for crops and cattle. It is unfortunate that in many places cattle are considered money in the bank, not to be spent, but to be left to increase. Even if the farmers could sell their cattle, there is no market. These facts have put a tremendous strain on the land. Add to overgrazing and over-production of crops, the fact that climatic conditions change for the worse, and the result is irreversible disaster.

It is clear, therefore, that any "desertification" project must be "people oriented," aimed especially at what to do with people whose land is being destroyed.

Conditions in the world today are perhaps best summarized by former A.I.D. Administrator John Gilligan, who wrote in his annual report of 1978 to President Carter.

> "Recent years have seen the world become further divided between the relatively affluent nations of the North and the impoverished nations of the Southern Hemisphere. The poor nations are making progress in their development, but the middle income and affluent countries are developing more rapidly, thus widening the gap between rich and poor."
>
> "Furthermore, global problems which have been festering in recent decades are now commanding new attention. They are no longer abstract issues of academic discussion. They require urgent action."

-- Population growth threatens to outstrip food production in many regions of the world; and inflationary pressures induced by scarcity of agricultural production could well have an increasingly severe impact on the United States.

-- The depletion of natural resources is as much a threat to our own economic prosperity as to the export earnings of poor nations.

-- Rapid urbanization strains the social and political fabric of all nations, not only the industrialized ones. Urban problems are assuming particularly pernicious forms throughout the Third World.

-- Environmental degradation threatens the well-being of all. The pollution of the atmosphere and oceans, the spread of deserts, the erosion of grass lands and croplands, the disappearance of forests are problems that transcend political boundaries.

"The problems are so vast, involve so many hundreds of millions of people, that failure to address them can mean political instability and violence on a global scale, and the repression of human rights and aspirations everywhere.

"Nevertheless, it must be understood that our foreign aid -- indeed, foreign aid from all sources combined -- cannot insure a country's economic development. That can only be done by the country's own dedication to its development."

I think it important to emphasize the last sentence. The country must be dedicated to its own development. We can give them the tools, but the desire to use them must come from within.

One of the most useful tools we have to offer is the knowledge of remote sensing, especially in the use of Landsat imagery. From Landsat the takeover to the land by deserts can be monitored. The best "show and tell" story on this is the one done by the Remote Sensing Institute at the South Dakota State University for A.I.D. (1) in parts of Mauritania and Senegal. This report mentions the short, intermediate and long-term effects of desert encroachment that can be measured from Landsat. The short-term effects show areas of fragile vegetation and streams and rivers which are dependent on rainfall to be seen on Landsat. The intermediate effects are the apparent flooding and presence or absence of burn patterns on the savanna. The long term effects show the encroachment of sand dunes onto arable lands. Thus Landsat has proven useful in mapping those features that will contribute to the sociological problems of the area.

POTENTIAL PROJECTS

The projects envisioned by DS/ST will be based on the uses of remote sensing and will include two main phases: an early warning phase, which will alert A.I.D., and others to impending disaster when crops begin to fail; and a long term phase, which will be aimed at determining alternative sources of land use through Natural Resource Studies.

Phase 1: The most basic needs that A.I.D. and others have is to learn where crops are going to fail soon enough so that food may be sent to forestall starvation.

(1) Worcester, B.K., Dalsted, K.J., and Moore, D.G., 1978, Sahel-Sudano Desertification Study; South Dakota State University, Remote Sensing Institute, Brookings, 62 p.

The method envisioned is based on the short-term effects that can be seen on repetitive satellite imagery, accompanied by ground study viz the filling of the rivers after the rainy season, and the regression of the high water. This will be accomplished by examining four areas in the Sahel.

1. Senegal: At the juncture of the Senegal and Faleme Rivers on the border of Senegal, Mali, and Mauritania (2 Landsat scenes).

2. Mali: The Inland Delta on the Niger River between Seyov and Kara (6 Landsat scenes).

3. Niger: Along the Niger River near Niamey (2 Landsat scenes)

4. Chad: Lake Chad and surrounding area (4 Landsat scenes).

The studies will include examination of river levels and rangeland conditions (other test sites may be needed for the rangeland studies), by interpretation of climatological data and by comparison with events in past years. It is hoped that the short-fall in crops when it comes can be pinpointed so that relief can be sent in time.

Phase II: More important, perhaps is the long-range phase. The sociological aspect of desertification is a necessary consideration to help those who have been displaced find other means of support. The types of help that can be gotten from Landsat can contribute to resource studies of the various countries, which, in turn, can contribute toward a re-style of agriculture and the opening of other jobs.

The Natural Resource studies using Landsat will progress somewhat as follows:

1. Mosaic, in black and white, at a scale of 1:1,000,000 each country of the Sahel.

2. Plot on overlays on the mosaic the various natural features that are already known, or can be interpreted by examination of Landsat imagery, including:

   Biomass
   Geology
   Soils
   Agriculture
   Rangeland conditions
   Land use
   Hydrology
   Mineral resources
   Transportation
   Others to be selected

3. Analyze the mosaic and the overlays to see what data are deficient. From this base, studies can be made to:

   a. Find areas where ground-water might be present,
   b. Determine from imagery and other data if any mineral deposits, especially of fertilizer minerals, might be present,
   c. Find areas where soils might be adequate for irrigation,
   d. Other factors to be determined at a later date.

Fieldwork will be necessary before final interpretations can be made.

TIMING

The work is in its preliminary stage. As soon as final plans are decided, a preliminary project will be started. It is estimated that with training and data-gathering, the preliminary work will be completed within a year. It is planned that all training and preliminary studies will be made at the Ouagadougou Center. It will rely to a large extent on resource managers of the various countries, who will be trained at the Center. The work they do will be supervised by specialists at the center, who will help in the interpretation of the satellite data. The extent of the studies of each country will depend on that country's desire for such studies, and their desire to follow on with the studies after the project is finished. Fieldwork will be an integral part of the studies. Instructors will be expected to go into the field with the students to ensure that their training is complete.

The results of the preliminary project will guide the future of the project. The areas which, for instance, will be pin-pointed for possible groundwater sites will be targeted for field study by the concerned resource managers who will examine the areas from a geologic, soil and sociological standpoint. Additional areas where mineral deposits might exist, where rangeland might be reclaimed, or where advancing dunes might be stopped, will be examined similarly. It will be up to the countries involved to provide the many decisions that will be needed. If water is found, for instance, how it shall be developed will be up to the country.

The work will proceed on a country-by-country basis. Each country must be made to feel the importance of the project and the results that can come of it. It will involve new forms of agriculture which might be tried. This may not be easy, for, in some cases, an entirely different type of life for the farmer may result. For instance, the farmer might have to be taught orchard farming, in hand irrigated almond or date orchards. If these changes are successful, the farmer could expect a cash crop which would involve a labor-intensive force.

I would like to close these few remarks with another quote from John Gilligan's letter to President Carter. This will give you an idea of the thinking of the U.S. Government.

> "Since becoming Administrator of A.I.D. I have had many opportunities to listen to representatives of the developing countries. One conclusion is clear. There is a rising tide of anger and frustration throughout the Third World. They question our understanding of their problems. They are not impressed by our sensitivity to their real needs. And worst, they have begun to doubt our intentions. The disagreements at the recent United Nations Committee of the Whole are but the most recent expression of rising dissatisfaction with the U.S. posture toward the developing world. Because they see the U.S. as the strongest of the developed countries, we are likely to remain a target of most of their resentment."

I would like to add on my part, Let us get with it. Time has run out for many people of the Sahel. Let us try to prevent the disaster from becoming worse.

REMOTE SENSING FOR MONITORING RESOURCES FOR DEVELOPMENT AND CONSERVATION OF DESERT AND SEMI-DESERT AREAS*

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INTRODUCTION

Arid and semi-arid lands cover extensive regions of the earth's land surface. Most of the areas which are of great interest to those concerned with desertification and drought monitoring are in the transition zone between the extremes of sandy deserts and lush irrigated areas. They range from sparsely vegetated desert fringes inhabited by nomadic peoples with their livestock to large areas comprising much of Africa, Asia and Latin America.

Less than half of the world's drier zones are unproductive deserts for climatic reasons, however, land usable for grazing and agriculture is increasingly experiencing temporary or permanent decline in productivity because of a combination of pressures from man and changes in weather. For example the consensus among informed workers is that recent catastrophes such as that in the Sahel of Africa result from various pressures exerted by man on soil and vegetation, especially at times of drought or excessive rainfall (Myers, et al, 1978). The decline in the Sahel and other areas experiencing temporary or permanent degradation of resources are all manifestations of human misuse of the land at times of climatic stress. The effect of this mismanagement of natural resources has a devastating effect on human populations.

Arid and semi-arid lands experiencing temporary decline in productivity require attention because of disasters that may befall populations due to drastic declines in the supply of food, fuel and water. If the detrimental ecological conditions persist, a further decline in resources may result in desertification which is more permanent. Any definition of desertification must recognize that it is a land degradation process involving a continuing change, from slight to very severe degradation of plant and soil resource (Dregne, 1978). The human factor must be considered in discussing desert dynamics since human populations are largely accountable for the problem of land degradation.

The Effects of Adverse Desert Dynamics

There are numerous indicators of resource degradation. Some are subtle and others obvious. Recognition of the indicators is essential to establishing a monitoring program.

In dryland pastoral economies, large numbers of livestock tend to build up during good years-too many to be supported through the inevitably ensuing drought (A CONF. 74/1, 1977). The increased grazing during the wet years tends to compact the soil near water holes and wells and along pathways.
In the ensuing dry years the increased livestock numbers exert excessive

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pressure on plants. These actions result in acceleration of wind and water erosion which still further reduces water storage capacity and reduced fertility by removal of topsoil. The loss of some or all the perennial plant cover substantially lowers infiltration rates. During subsequent rains surface runoff is increased with loss of stored water for subsequent use by vegetation.

In rangelands, excessive grazing in dry periods results in an alteration in the species composition of pastures. In particular a reduction in the proportion of desireable perennial plants is reduced and the proportion of undesireable forage species is increased. The deterioration of vegetative cover increases the extent of bare ground, which is followed by a deterioration in the conditions at the surface of the soil that are vital to plant growth. In addition, soil stability in response to rain deteriorates with the increase in runoff and sheet and gully erosion. All these changes mean a decrease in plant productivity and a decline in the palatability and durability of the native rangeland.

A shortage of firewood is causing an energy crisis in the Sahel (Time, 1977). Firewood is in such short supply that villagers may travel up to 50 kilometers to gather and bring the wood home. Almost all the trees within 70 kilometers of Ouagadougou in Upper Volta have already been removed and consumed as fuel. The removal of woody species increases direct solar heating of the soil. Trees are vital for holding soil intact, and their destruction cannot help but promote destruction of the savannah.

Irrigated lands, also, are subject to the ravages of desertification and exhibit evidence of change that can be detected by monitoring. The principal manifestations of the mismanagement of irrigated lands is the occurrence of high water tables and its associated salinity and alkalinity. Irrigation projects, most frequently constructed in arid and semi-arid areas are generally affected to some degree by excess salt deposits and high water tables when adequate drainage is not present. This results in reduced productivity, and in advanced cases, abandonment of the land. Over-irrigation, impermeable subsoils, absence of drainage, irregular field surfaces, and seepage from higher lands generally are responsible for the high water tables and accumulation of excessive salt.

Dryland farmers show a tendency during good years to extend their cropping onto the marginal lands having higher climatic risks. In doing so pasture lands are plowed which previously provided grazing, but more importantly provided protection from wind and water erosion. Mechanization and population pressures are largely responsible for this trend. Increased cultivation during wet years greatly enhances prospects for wind erosion of fine particles during dry seasons. There is generally pressure on use of moisture stored in the soil and a lowering of organic matter which in turn reduces water storage capacity. The appearance of new sand dunes has been an alarming indicator of widespread plowing for new crop production on formerly grazed lands.

There is a tendency in arid regions for climatic drought to persist through two or more consecutive normally rainy seasons and this immensely aggravates the processes which result in resource degradation. There is also a parallel tendency for groups of wet years to occur which can be equally dangerous because such a sequence permits the unwise increase of livestock as well as extension of cultivated areas.

A farming practice directed toward preserving fertility and maintaining productivity can be a crop rotation in which a crop and fallow (no cropping) alternate in a two year cycle. This practice is important for soil fertility restoration when there is often no means of fertilizing the soil (A CONF. 74/11, 1977). One further advantage of this practice of fallowing is the retention of moisture from two rainy seasons for one crop. In saline soils which are quite

common in arid regions, two years of fallow permit leaching of excessive salts to lower horizons and thus a reduction in the salinity hazard. In contrast to the above, an indicator of impending over intensive land use, possibly leading to land deterioration is a change in the cropping pattern in an area from a crop-fallow-crop sequence to continuous cropping.

The principle effect of all the forces at work in the Sahel that produce disaster is the upsetting of the sensitive balance between human populations and the land. So long as the pressures on the ecosystem are light, there is a rough equilibrium among people, their livestock and the land. With better health care, populations have increased, requiring more livestock and crops. This puts increased pressure on the land. The lack of institutional arrangements in the Sahel means limited controls that might otherwise coordinate movement and activities of pastoralists. Under more ideal circumstances early indicators of impending drought and/or other disasters could provide much needed time to undertake corrective measures to reduce the calamity.

JUSTIFICATION FOR MONITORING THE PROCESSES OF DESERTIFICATION

In areas involving desertification, the major emphasis in collecting earth resources data should be to provide a basis for resource preservation and development. The discussion of resource survey criteria should begin with a consideration of the development level of affected areas and the capacity of the country to finance data acquisition activities and to utilize these results. The intensity and timing of a survey are certainly affected by such factors as intensity of development and size of the area affected, availability of resource data and aerial photography from previous surveys, extent of development or remedial program planned and others.

Following are justifications for a monitoring program.

The Need for Surveys

The desertification process can be halted and reclamation procedures initiated only if there is a physical assessment of the processes involved, an estimate of the magnitude of the problem, and the location of specific problem areas along with potential areas for reclamation.

Accelerated Surveys

Progress is being made in many countries in a methodical, conventional manner toward completing natural resource surveys; however, completion of these surveys is generally programmed over a period of many years. A practical method of acquiring resource data is to place priorities on areas where development is most probable. This requires a reconnaissance-scale inventory which can be readily accomplished using space technology. Resource information can then be classified according to high, medium, or low development potential with greatest attention given to the areas of highest potential.

Aerial Photo Coverage

Aerial photo coverage of parts of most developing countries is not available. In particular, recent coverage in color which is important for resource surveys is generally not available. Of more significance, however, is the fact that low altitude coverage, even if available, would be unmanageable because of its large scale and the great quantity of photos required to cover a large area. Also, the photography would not provide the spatial and temporal advantages inherent in spacecraft imagery. Aerial photos may be necessary for coverage of limited-sized calibration sites or for multistage studies. After the lands have been isolated which are problem areas or have a development potential, low altitude or medium altitude photography would be required for the intensive surveys.

Advantages of Landsat

As an aid in recognizing resource boundaries and in classifying resources Landsat imagery has distinct advantages such as the synoptic view, the near-orthographic scenes, the repetitive coverage, and the multispectral coverage. Also, digital data are available.

Costs of Monitoring

Monitoring of arid or semi-arid areas must be done at a very low cost to be feasible. Landsat technology has reduced costs in such a way that it permits the accomplishment of tasks that were previously not feasible in a reasonable time frame.

In connection with the Mexico National Water Plan, as an example, a potential land use study was performed on 45 million hectares at a rate of 4 million hectares per month at a cost of 0.33 cents/hectare (Garduno, 1975).

Integration of Existing Surveys

Existing data related to geology, topography, soils, vegetation, present land use, and climate should be utilized but are usually not in compatible formats. A resource integration and monitoring program provides the methodology for taking resource data at various scales and degrees of accuracy, and placing it on a reliable base map for easy reference and use.

Monitoring for Transient Type Data

Qualitative or quantitative data concerning phenomena such as soil moisture, changing vegetative patterns, detection of periodic or permanent changes, and other phenomena require a relatively inexpensive method of periodic surveillance. Repetitive data can be obtained rather quickly from satellites now in orbit (every 18 or 9 days for Landsat 2 and 3) with fairly good resolution for broad reconnaissance purposes.

National Oceanographic and Atmospheric Administration (NOAA) imagery, at less resolution than Landsat, covers the entire world twice daily. The temperature measuring capability of the NOAA satellites can be potentially useful for monitoring soil moisture which is important for rehabilitation measures in critical areas (South Dakota State University, 1978).

MONITORING OF FEATURES AND CONDITIONS RELATED TO DESERTIFICATION

The objectives of a monitoring program for desertification are to assess existing ecological and resource conditions, to detect physical indicators of desertification, and to observe changes representative of improvement or further deterioration of natural resources.

Certain diagnostic indicators of desertification can be useful as early warning methods for planning disaster relief. Some of these indicators can be observed on Landsat imagery, some on NOAA Synchronous Meteorological Satellite (SMS) imagery, and others might be routinely monitored on the ground by unattended data platforms which can then transmit the data twice each day via satellite to receiving stations.

The principal ecological and population indicators that can warn of imminent disaster or long term resource decline are listed in Table 1. Causes and effects of the indicators are shown, along with remote sensing and ground indicators. This list is not all inclusive since regions vary in landscape, cultural practices, etc., but can be used as a general guide with specifics added according to local conditions. A detailed discussion of desertification indicators is given by Reining, et al., 1978.

Table 1. Ecological and Population Indicators That Can Warn of Immiment Disaster or Long Term Resource Decline.

Indicators

Causes	Effects	Remote Sensing and Ground Indicators
(a) Removal of natural long-term vegetation from uncontrolled grazing, and felding of trees and shrubs for fuel.	Inadequate vegetative cover, leading to large scale soil and nutrient loss due to wind and water erosion.	* High reflectance. * Technicians evaluate ground truth.
(b) Change in type of vegetation from grassland to scrub brush.	Grassland, favorable for cattle replaced by brush, more favorable for goats.	* Change in reflectance pattern.
(c) Building up herds resulting in increased grazing during wet years.	Compact soil near water holes and wells and along pathways. Further increase of livestock numbers put pressure on perennial plants during the dry seasons. Exposes surface soil to wind erosion, increases surface runoff.	* Reflectance and temperature indicators of increased vegetation. * Buildup of livestock. * Population concentrations
(d) Quantity of standing biomass.	Early indication of forage production for grazing.	* Reflectance and temperature coupled with ground measurements.
(e) Change in crop-fallow-crop rotation to every year cropping.	Reduces soil fertility and available moisture. Permits build up of salts.	* Changes in land use patterns.
(f) Crop yields and acreages.	Reduced yields are warning of impending disaster.	* Land use patterns and crop reflectance patterns.
(g) Expansion and intensification of land use during wet years.	Wind erosion during the next dry year or water erosion during the next intensive rainstorm. Also subtle microclimate variations take place. Reduced organic matter from wind erosion.	* Changes in land use patterns. * Wind and water erosion indicated by high reflectance.
(h) Tendency of climatic drought or wet years to persist through 2 or more consecutive seasons.	The effects of drought in dry years and over-stocking in wet years are aggravated by extended periods.	* Sequence of space imagery indicators persistent patterns.

Causes	Effects	Remote Sensing and Ground Indicators
(i) Change in pattern of onset of limited rainfall (occurring once in 2 or 3 seasons).	Early onset of monsoon or late onset of adequate rains may result in reduced crops. Monitoring to determine where rainfalls may provide a more efficient means of utilizing vegetation that is scattered and spotty, dependent on the vagaries of weather.	* Microwave, thermal and reflectance indicators of rainfall patterns.
(j) Poor water management on irrigated lands.	Create high water tables and cause salinity.	* Condition of plants and appearance of salts on surface are indicators.
(k) Extent of or lack of flood on Niger and Senegal Rivers	Flooded areas in high water years, inadequate water for irrigation in low water years.	* Seasonal imagery shows extent of flood and condition of crops.
(l) Water depth in lakes and ponds and occurrence of sediment.	Water conditions indicative of wet or dry season. Sediment appears as result of erosion.	* Appearance of shoreline and color of water.
(m) Dropping water table in wells.	Reduced productivity and abandonment of agricultural areas.	* Ground measurements by technicians.
(n) Wind and water erosion.	Reduced productivity and abandonment of agricultural areas.	* Seasonal and sequential imagery over several years shows effects of erosion.
(o) Population dynamics.	Shifting of populations usually conform with available food and fuel. Drastic shifts mean probable disaster.	* Satellite imagery can indicate population shifts from land use patterns. Ground sampling also necessary.
(p) Sandstorms.	Indication of areas actively eroding and vulnerable to further erosion.	* Appearance of sand storms on imagery.

Recognition of various resources and their quality or condition at various times is the essence of a monitoring and rehabilitation program. Can these features be monitored using primarily space imagery? The answer is a qualified yes -- depending on the particular parameter and considering that study of desertification must be conducted initially on a reconnaissance level. A knowledge of certain features described in this section are essential to a desertification study. The objectives of studying each feature as well as the detection feasibility of each are discussed in the following section.

Features discussed are (1) natural vegetation, (2) soils, (3) land use, (4) soil erosion, (5) high water tables and salinity, (6) groundwater, (7) soil moisture, and (8) energy balance.

Natural Vegetation

The purpose of monitoring natural vegetation is to determine vegetative cover and changes that may occur. An inventory should include rangeland productivity and utilization including ecological condition, successional direction of change, grazing intensity, vulnerability to damage, evidence of mismanagement, and seasonal changes. Monitoring may provide the means for rehabilitation of improvement.

Methods for utilizing remote sensing for evaluating the presence and condition of vegetation have been developed. Landsat imagery as color composites and band 5 alone, at a convenient scale of 1:125,000 or smaller shows the general distribution and condition of vegetation. Desert vegetation must be observed on Landsat imagery at a time most favorable to plant growth to exert a significant influence on the spectral signature. Imagery from different seasons can sometimes provide additional information. Multistage imagery can provide a progressively more detailed analysis of vegetation. Medium altitude aerial photographs (scale about 1:30,000) for sample areas allow verification of Landsat interpretations and provide further information on the vegetation type within relatively homogeneous areas which can be delineated from Landsat. Large scale aerial photographs can be used for specific range type identification. Finally ground samples must be taken to determine vegetative species in plant communities as well as quantitative forage production.

Where vegetation density is low, interpretation and analysis of imagery may be difficult or impossible. Where vegetation is more dense, it is generally the most prominent feature of the imagery and provides useful indirect information on soils and hydrology. Different species of vegetation and their rooting habits can be interpreted in terms of soil conditions. The best soil indicators according to Vinogradov, 1961, are plants. Shrubs, as well as grassy and semishrubby plants, are a reliable and widely used basis for soils interpretation.

Soils

The suitability of soils for various land uses in the more intensively utilized areas is interpreted by soil scientists as time and resources permit. In less populated areas the necessary soils maps are frequently not available or may be outdated. For desertification soil maps would be constructed at the soil association level for determining potential for the various soil mapping units.

In a resource survey, Landsat color composites and band 5 alone, can be utilized for wet and dry seasons. Preliminary soil association maps can be prepared from FAO and other general soil studies using Landsat imagery as a base. Final corrected soil maps can be prepared by synthesizing background material with observations and data obtained in the field. Final descriptions of each mapping unit and complete soil properties and soil interpretation tables are prepared. Finally interpretive maps are prepared showing rangeland potential, agricultural potential, erosion hazard, etc.

Soil landscapes which are interpreted from Landsat imagery are classified and shown on soil association maps. Soil landscapes exhibit a characteristic surface geometry, kind and density of vegetation, and hydrology (Westin and Frazee, 1976). Landsat imagery shows patterns from which inferences must be drawn by qualified soil scientists based on at least limited field studies and sampling.

Land Use

Land use information is essential to a development program involving analysis of alternative uses. A monitoring program would provide present land use, especially in critical areas of desertification and provide basic information for determining potential land use.

A resource survey program would utilize all available maps, air photos and other data concerning land use. Preliminary maps at a suggested scale of 1:500,000 or 1:250,000 are prepared, preferably using the land use classification system of Anderson, et al. (1976), as modified to suit the particular conditions important to desertification. Landsat imagery at the same scale as the preliminary map can then be used to update the map and fill in areas of previously unknown land use. Levels I and II and in some cases Level III land use can be distinguished on the imagery. The updated map can be verified in selected key areas by low altitude flights or ground surveys. Wherever possible imagery for different seasons of the year should be utilized - dry season imagery for soils and wet season imagery for vegetation.

Soil Erosion

The occurrence of erosion and the ability to assess that occurrence deserves much emphasis in desertification monitoring. A program would include monitoring the extent and severity of erosion, identifying areas vulnerable to erosion and identifying areas for erosion control projects.

Methods of erosion detection and assessment are based on the fact that, on Landsat imagery, erosion is temporally apparent as changes in soil color, in appearance of sand and gravel and bare rock, in accentuated dendritic drainage patterns, and others. Ground information needs include a measure of accelerated erosion and of the concentration of gullies and rills. Information regarding the location of blowouts, wind deposits and alluvial deposits is also required.

As in the case of soil maps, preliminary maps are prepared, checked by low altitude aircraft flights and by field work and revised to give final maps. The erosion and erosion vulnerability maps can be used with other ecological and socio-economic information to identify areas where erosion control measures would yield greatest benefits.

High Water Tables and Salinity

The objectives of monitoring high water tables and salinity are to determine the cause and extent of high water tables, to identify areas affected by salinity, and to identify waterlogged and salt-affected areas which can be rehabilitated with leaching and salt tolerant grasses and forage crops.

Since water tables and salinity are not visible except in extreme situations, analysis is generally indirect through effects on vegetation. As the conditions are often seasonal or only seasonally visible, the timing of the imagery may be critical. Research in the United States has shown correlations between crop reflectance and depth to water table and concentration of salinity; however local research will be necessary to determine local correlations. Reflectance in the near infrared has been shown by Myers, et al. (1966) to be effective in estimating the severity and extent of salt-affected areas in cotton fields.

Groundwater

A considerable potential exists for developing ground water sources in many areas affected by desertification. A monitoring program has potential for detecting and mapping shallow aquifers and detecting indicators of deeper aquifers.

For very shallow aquifers the techniques described above for high water tables are applicable. Shallow sand and gravel aquifers can often be identified on the basis of the features that produced the aquifers. These include geologic structures, landforms, old meander loops, scars and others. Keys to detection of deeper aquifers include the occurrence of fracture traces and lineaments on imagery. Discharge areas are indicated by flowing streams during periods of low flow, by lineament locations in topographically low areas, by the continually healthy growth of vegetation during droughts, and by water use.

Soil Moisture

The occurrence of rainfall in arid and semi-arid regions is sporadic and difficult to assess. Repetitive monitoring over broad regions can be the means for providing this information on a timely basis. Ground truth and data platforms may permit quantifying these data. The objective here would be to map and monitor rainfall patterns, estimating soil moisture to a depth of at least 5 cm. Where vegetation is present the intent would be to estimate soil moisture available in root zones based on indirect indicators.

Visible, thermal infrared and microwave techniques each has application for sensing soil moisture parameters. Moist soil is darker than dry soil, thus reflectance patterns may be utilized for estimating surface moisture. Thermal infrared imagery obtained at night on bare soils provides temperature patterns that are interpretable in relation to moisture to a depth of 5 to 10 cm. Also, thermal infrared sensing of vegetation canopies which nearly or totally cover the soil can be used to relate vegetation temperature to soil moisture status, (South Dakota State University, 1978). The thermal sensors aboard NOAA satellites can provide data for moisture detection. Data from the very-high-resolution radiometer (VHRR) are used. Microwave data, although not yet routinely available, will provide estimates of soil moisture under adverse weather conditions.

Energy Balance

A monitoring program for determining energy balance would measure parameters for climatic modeling. The balance between incoming and outgoing radiation is the most important factor that determines local microclimates and regional climates, but the mechanisms are not clearly understood. Since many of the processes of desertification result in increased albedo due to a decrease in vegetation cover or loss of topsoil, a change in microclimate results.

The elements for computing albedo can be obtained from spacecraft if supplemental measurements of incoming radiation are made. Thermal emittance is presently being gathered over broad areas by NOAA satellites.

Ground truth data for energy balance and microclimate studies might include air temperature, net radiation, soil temperature, soil moisture, and evaporation. Data collection platforms may be located in remote areas and have capability for transmitting most of the above information to satellites and back to ground receiving stations on a daily basis.

LIMITED STUDY OF DESERTIFICATION INDICATORS

A limited study was made of short, medium and long term indicators of desertification in a portion of the Sahel (Worcester, et al., 1978). Landsat data were shown to be an effective tool for assessment of desertification. In particular, the study concluded that correlation of Landsat data with ground observations could lead to the development of techniques for predicting the real time and near future reaction of arid and semi-arid regions in relation to desertification related stresses.

INFORMATION DATA BASE

An effective program for monitoring the advance and/or control of desertification requires large amounts of resource data. Management of these data without the use of automated techniques would be unrealistic timewise. A computerized cellular information data base system is therefore implemented to aid in the storage, retrieval, collation, interpretation and tabulation of these resource data.

Data which are input to the data base system may originate from a variety of spatially-oriented sources and scales. Both already existing thematic maps and those interpreted from remote sensing imagery can serve as input. The basic question which must be resolved prior to the input of data concerns the cell size which will be used. Factors such as the complexity of the input maps and the limitations of the sensor resolution need to be considered when the cell size is determined.

Output which results from this basic data base operation consists of a plotter map and frequency and areal tabulations. Additional interpretations may be made from each input resource map with the same output products. For example, once the basic soils data have been entered into the data base system, an interpretation for erosion hazard can be made and the output tabulated and plotted on this basis.

An additional feature of the information data base is the theme overlay capability which is extremely valuable when the interaction among various types of resource data and soil limitations are analyzed. Any combination of resource data sets which are spatially registered and have the same cell size may be combined. Output products are again plots and tabulations. An example of this data base feature is the overlaying of soils and vegetation data for the purpose of establishing the types of vegetation a certain soil type will support. In the case of vegetation, characteristics of high and low potential are based on inputs such as soil capability, erosion, rainfall, stock water availability, and salinity hazard.

Changes in resources over long periods of time are important for recognizing the trends of further deterioration or improvement in desertification processes. The data base information system described here lends itself to updating resource data from any source including temporal Landsat imagery, other ground surveys, and aerial photographs. These same methods can be employed with manual map manipulations when the data are all at compatible scales. If a labor-intensive approach is required these procedures still allow for rapid analysis.

SUMMARY

Desertification is generally not a sudden calamitous or short-term event. Normally, early indications of oncoming desertification may not always be apparent, at a time when early detection might avert human disaster. In formerly productive areas where deterioration of resources is already in an advanced stage, planning for rehabilitation requires an assessment of resources and the determination of their vulnerability to further damage as well as their potential for rehabilitation and development. Remote sensing technology can provide many of the early diagnostic indicators of desertification as well as an assessment of resources and their potential in cases where the processes are advanced.

ACKNOWLEDGEMENT

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APPLICATION OF REMOTE SENSING TO UNDERSTANDING THE DESERT ENVIRONMENT

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Little attention has been given to the desert environment in the past due to the lack of basic information. The vastness, aridity, harsh conditions, and meager development potential of most deserts have hampered the collection of needed data. However, during the past decade remote sensing techniques have provided some new tools to study and monitor the desert environment.

Earth orbital photographs from manned space missions and multispectral images from Landsat satellites show that the reflectance properties of desert surfaces are indicative of their composition. The available data allow: (1) mapping of the vast desert regions at 1:250,000 scale; (2) first-order studies of the nature of the desert environment; and (3) site selection of areas for detailed investigation. Such investigations would help in the selection of remote-sensing methods and techniques to be utilized in the Space Shuttle era.

Application of remote sensing techniques allows monitoring of changes to the desert environment over a season, a year or a decade. For example comparison of photographs taken by the Apollo-Soyuz mission in 1975 with those obtained on earlier space missions indicates: (a) an increase in vegetation west of the Nile Delta of approximately 1108 km^2 in 10 years; (b) an average shift of 2.5 km over a 6-year period in the sand patterns at the border between Egypt, Libya and Sudan; and (c) a considerable reduction in the water level of Lake Chad and dune encroachment upon the lake over a period of 9 years.

Changes in the desert environment with time are always significant to development of arid and semi-arid lands These changes must be understood, taken into account, and monitored, otherwise they are likely to adversely affect development projects. For example, dune migration is the major cause of "desertification" in the Western Desert of Egypt. Migrating sand dunes inundate roads, railroads, telephone lines, plantations, houses, and whole villages. The measured rate of dune migration in this desert is one to 100 meters per year depending on the size and type of the dune.

Remote sensing techniques can also be useful in the collection of meteorological data in the desert environment; the lack or inadequacy of such data hampers a full understanding of the world's deserts. Meteorological stations can be placed in remote, inhospitable areas to automatically collect the data and transmit them to orbiting satellites. These satellites can retransmit the data to central localities for analysis and synthesis.

I maintain that the generalization that the deserts are "man-made" is too simplistic. Field observations indicate that global climatic conditions control the formation of deserts. Furthermore, our limited understanding of the desert environment has resulted in the misuse of arid and semi-arid lands. Proper applications of remote sensing tools will help us better understand the deserts and utilize more of the land area of the Earth for the benefit of mankind.

MONITORING OF DESERTIFICATION ELEMENTS IN EGYPT BY REMOTE SENSING TECHNIQUES

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ABSTRACT

Facilitating the proper programming for halting desertification, and if possible its reversal in deserts and arid areas in the world, is the focal aim of the international effort for combating desertification. The latter leads to the deterioration of the environment which has been suitable for the development of human communities into an environment which is getting progressively less suitable for man to carry out his activities.

Climate, geomorphology, rock substrata and human activities can lead to desertification when man tries to exploit groundwater and soil without prior knowledge of the impact of such exploitation. Sand dune movements, salinization, alkalization and drainage are but few factors which play important roles in accelerating, slowing down or halting the desertification phenomena.

Desertification can be halted and reclamation procedures initiated only if there is a physical assessment of the processes involved, an estimate of the magnitudes of the problem, and the specific problem areas located along with areas of potential for reclamation. Proper assessment of realities of the situation is the only means of ensuring evaluation of any risks that might result from proposed programs against desertification in arid areas.

The best assessment of the resources of arid and desertified areas, and monitoring of changes in such areas, whether they be improvements or futher deterioration, can best be made using remote sensing procedures and indeed may be the only way where large areas are involved. Also, remote sensing may be the only practical means to define the areas of critical concern that justify more intensive monitoring and documentation expense.

Examples will be given in this paper illustrating work carried out by the Remote Sensing Center in Egypt in the application of remote sensing techniques for the monitoring of the processes of desertification and natural resources in various parts of the Western Desert, which are based on Landsat and aircraft imagery interpretation coupled with field investigations and laboratory analysis.

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UTILIZATION OF AN AREA SAMPLING FRAME TO ESTIMATE AGRICULTURAL PRODUCTION*

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The paper described the construction of the Area Sampling Frame in Jamaica. Materials that were used are aerial photography, maps and LANDSAT images. The land areas were divided into homogeneous land use areas and later subdivided into many small parcels. A sample of land parcels was selected for interviewing.

The most crucial step is collection of data in the field and even under good conditions this is not easy. Data collection must be carefully supervised. How the data is handled in the office - edited, summarized, is also important.

Survey results of the last survey were presented showing production totals where possible.

*This paper was presented as a poster session presentation at the Thirteenth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, April, 1979 (in press) entitled Agricultural and Resource Assessment in Jamaica Using an Area Sampling Frame.

INTRODUCTION TO MULTI-PURPOSE AGRICULTURE SURVEYS

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All countries need accurate, current, comprehensive, and objective data for agriculture planning and management. As much as possible the data should also be resource efficient.

The Statistics section of the Economics, Statistics and Cooperatives Service (ESCS) has the primary responsibility to collect and disseminate current agricultural data in the U.S. The methods developed over the years have evolved into an area sampling frame which is used to select a small sample of land areas where people live and farm; and these people must be interviewed. Farmers and producers are asked to report on many items for which data are needed.

The USDA finds the agricultural statistics generated by these techniques to be accurate at the national level and fairly accurate at state levels. Data below state level are not accurate. Further, the data are current; in two weeks data can be collected and two weeks later, these data can be summarized and published. Since data are collected on 120 commodities, including planted and harvested acreage and yields, many livestock items, as well as price data on 200 products farmers sell and 600 items farmers buy, these data are extremely comprehensive.

The data are also objective, since results do not depend upon expert's judgement. All of this can be accomplished without LANDSAT imagery, but LANDSAT can be used to improve the program.

INTEGRATING SATELLITE DATA INTO AGRICULTURAL INFORMATION SYSTEMS*

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ABSTRACT

This paper presents an efficient, practical and accurate information system showing how to use some promising new technology. An agricultural information system can be built on objective ground based data and combined with LANDSAT data to increase the precision of statistics for large areas and also generate local data. The results or statistics produced will be defendable and the accuracy can be stated if care is taken to follow strict laws of probability.

Resource requirements vary depending on accuracy levels needed. However, the system combines ground based and LANDSAT data in a flexible manner depending on materials, equipment available, expertise and experience of personnel involved. The construction of an area sampling frame in the country is assumed to have preceded the time when sampling for making crop estimates will be undertaken.

*See summaries of two presentations made at the Twelfth International Symposium on Remote Sensing of Environment, April, 1978, Manila; "A Guide to Area Frame Sampling Utilizing Landsat Imagery", page 1013 and "A Land Use Information System Based on Statistical Inference", page 429.

AGRICULTURE MONITORING AND ASSESSMENT

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In 1976 a study was conducted on Landsat data taken over Central Iowa throughout the growing season for the corn crop. This study entitled LAMP (Landsat Agricultural Monitoring Program) was a research effort which focused on the problems of designing and implementing a capability to react quickly to a reported agricultural event which was expected to seriously impact production. Two questions were addressed: a) could Landsat detect the event, and b) could Landsat assess the event? The problem of detection may be solved by, a) monitoring the area and observing an unexpected change, or b) acquiring coverage of a reported event after the fact by comparing the acquired Landsat scene of the area against a previously acquired Landsat data base. The first approach is the most error free but also the most costly since the data acquisition strategy must be to collect all the data from pre-planting through harvest. The second approach is questionable since the sensible effect of some of the more important stress conditions is to change the Leaf Area Index (LAI) values, as for example, in wilting. In certain seasons it would be difficult or impossible to tell this effect from surrounding crop since the normal distribution of stand density values would contain indices similar in magnitude to the affected crop. The third approach is certainly the preferred method. It is somewhat difficult to implement since it is difficult to collect a "normal" data base. Normal must be defined as a series of imagery covering the important phenological stages of each of the species included in the program. Results from a recent research report, "Multispectral Temporal Analyses" indicates that MSS alone can detect the pre-bud or boot state, the heading stage and the onset of ripening stage for wheat. In the same report simulated TM data taken over both winter and spring wheat, oats, barley, as well as alfalfa and pasture show that for the cereals the following stages of growth are able to be determined:

1. Bare soil (pre-planting)
2. Emergence
3. Booting or pre-bud (pre-heading)
4. Heading
5. Ripening
6. Harvest (pre-harvest)

The problem of assessment is much more complex, generally requiring a number of yield models, necessarily species specific, in which stress is computed and production discounted. As of this writing all of these models can be said to be in a state of development, some more nearly operational than others. In LAMP we attempted to use Landsat radiance values to infer final yield. The correlation analysis was encouraging, with coefficients of determination of approximately 0.8 between radiance in MSS7 at the time of silking and final yield. Two new techniques were used in yield correlation in the Multispectral Temporal Analyses study both of which show promise and both of which use simple measurement transforms (band ratios). In the one case MSS ratios at heading (maximum green biomass) were compared with the same ratios at an earlier stage of growth such that the earlier date was calculated as a percent of maximum green biomass and used in the regression. In the second case TM ratios for plant water at heading were compared with the same ratios at an earlier stage of growth such that the assumed difference in the amount of plant water between the two dates was calculated and used in the regression. The R values were encouraging; approximately .8 for the MSS case and .9 for TM.

INTERRELATIONSHIPS BETWEEN AGRICULTURE, FORESTRY, AND MAN'S USE OF LAND

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Remote sensing techniques have been successfully applied in solving many real problems. Successful applications in agriculture, forestry, geology, land planning, and water and wildlife management are well documented. Each of these fields has its own set of specialists trained in the appropriate discipline. These disciplines are sometimes referred to as "academic disciplines" because educational institutions seem to take great delight in dividing up the infinite universe into finite areas of study called fields of study or disciplines. In remote sensing, such divisions are truly academic, for remote sensors record whole terrains with all of the academic disciplines interrelated. Interpretations of remote sensor data are much more accurate and complete when these interrelationships are recognized and understood than when they are overlooked or ignored.

The Nature of Remote Sensor Data

Remote sensor data are simply records of energy characteristics (including intensity, polarization, and/or phase in some wavelength band) at a given time and place. Electro-magnetic sensors such as cameras, line-scanners, and radars record the energy flux reaching their detectors within a defined field-of-view. When such records of Earth terrains are presented in image form, certain shapes, sizes, tones, patterns, and textures are readily interpreted as lakes, streams, forests, roads, cities, rock outcrops, farm fields, and other familiar features. Experience has shown that what is familiar to one person may not be familiar to another. Differences in condition of crops in different fields may be recognized by an agronomist, but the fact that the spatial pattern in which those differences occur reveals the presence of a subsurface geologic structure, or possibly the buried remains of an ancient civilization, may not be recognized except by a geologist, or possibly an archeologist Likewise, small differences in the energy flux from vegetated areas that permit localization of ore bodies may go unnoticed by the geologist who does not understand vegetation-energy interactions.

Photographic records of the flux of visible light from terrain objects were among the earlier remote sensor records, and were readily interpreted on the basis of human visual experience with bright, dull, and dark features. Photographic records on non-visible radiation came later and were not as readily interpreted on the basis of human experience, for these new records contained data that humans had never perceived before. Infrared and ultra-violet sensitive emulsions made it possible to extend our perceptions of the world around us and overcome human visual limitations. Much of remote sensing consists of finding newer, better ways to overcome human limitations.

Newer photographic films, thermal line-scanners, and several microwave devices have given us powerful tools with which to push back human limitations and obtain more and different "views" of the environments in which we live. Coupling this array of sensors with low flying aircraft, high flying aircraft, and spacecraft has given us many exciting views of our planet and its parts. Finding the right view for a given task is one of the challenges of remote sensing.

Finding the right view for any task requires an understanding of the task itself. Since different sensor configurations record energy fluxes in different parts of the electromagnetic spectrum, it is often necessary to carefully select the spectral band, and hence the sensor, that is best fitted to the task at hand. The right spectral band is not always easy to identify from visual experience alone. Figure 1 shows four curves of light reflectance over wavelength for a single leaf that was permitted to air dry between the times that the four curves were obtained on a single afternoon. Relatively little change in reflectance occurred in the visible region between 0.4 and 0.7 micrometer (μm), but major changes in reflectance were observed in the infrared region between 1.0 and 2.5 μm, as the leaf dried. Photographic films available for aerial use today are not sensitive to energy with wavelengths longer than approximately 0.98μm, but optical-mechanical scanners can be configured to record energy in this spectral band. Why would we want to record energy that helps differentiate vegetation on the basis of differences in foliar moisture content? We might want such data because differences in moisture content can indicate the need for additional irrigation water, the presence of an insect or disease that could reduce plant yield, or the presence of an anomolous soil condition of importance to the geologist, engineer, or archeologist. It is often unfortunate that the remote sensor record does not indicate which of the several possible causes of different tones in the image was actually responsible in any given case. It is up to the interpreter -- be it man or machine -- to infer this causual relationship. If the interpreter arrives at the wrong answer it is not because the terrain is wrong or the sensor made a mistake. An error probably means that the interpreter did not understand, or appreciate, all of the factors affecting the energy fluxes from different parts of the scene represented by the remote sensor record being interpreted.

Utilizing Remote Sensor Data

To be valuable, remote sensor data must be used. Identification and classification of features are common uses that often lead to the interpretation of the significance of features identified or classified. In many cases identification, classification, and interpretation of features from remote sensor records requires knowledge of the context within which the features are located. Land use and agricultural practices vary both between and within countries, at least partly as a result of variations in climate, elevation, soils, depth to bed rock, and local heritage. It is not enough to know that you have a feature of a given size, shape, color, and texture. You must also know where it is located, and with what it is associated, before you can accurately assess its significance.

An area of open water with small amounts of green vegetation emerging from it may be a marsh in Canada, a rice field in Thailand, or a fish pond someplace else. All three features may result in similar energy fluxes to the sensor, but contextual information can be used to select the correct identification.

Rice, an important crop in many parts of the world, is grown in both wet and dry fields. Wet rice and dry rice cultures image differently in a single country, and fields of wet rice in Bangladesh or India may not have the same spectral characteristics as wet rice terraces in Japan. Terraced hillsides characteristically support rice crops in some areas, but wheat, vineyards, orchards, and other crops in other areas.

My first visit to Costa Rica occurred during the 1963-64 eruption of volcán Irazú. Although primarily an eruption of ash, a flow of molten material was considered possible by some. A question often raised was: If a flow occurs, what volume of material should we expect?" The volume of material extruded during the most recent flow, the Cervantes Flow, was identified as one possible indicator. To determine the volume of material extruded in the Cervantes Flow, it was necessary to determine the areal extent of the Cervantes material as well as its average thickness. Aerial photographs were used to define the area covered, and the interpreters observed three characteristics of land use on the Cervantes Flow that were reliable clues permitting separation of the Cervantes from older material (Olson and Sáenz, 1965):

1. Size of agricultural fields was two or three times larger off of the Cervantes Flow than on it.

2. Agricultural fields located on the Cervantes Flow were most commonly in pasture, with cultivated crops largely absent.

3. Coffee plantations, generally found to elevations of 1,500 meters above sea level, were not present on the Cervantes Flow except at the toe of the flow below 1,200 meters where the lava was thin and fractured.

In January 1979 it was my priviledge to visit India and review a number of forestry projects near Dehra Dun in the north, and others near Bhopal in the center of the country. In both regions I was impressed by the interrelationships between forestry, grazing, and land productivity. Foliage of many native trees is regularly lopped off and fed to livestock Tree growth is sharply reduced by lopping, but the foliage is an important substitute for the almost non-existant forbes and grasses in overgrazed pastures and forest stands. When forest stands are heavily grazed, bushes, herbaceous growth, and leaf litter are eaten or trampled; soils are compacted by animal hooves, and the compacted soils retain less moisture than the same non-compacted soils would retain; air currents move freely along the forest floor and wind erosion may occur when the soil surface dries. As the top soil blows away, productive potential declines, the tree stand thins, wind velocities increase, and erosion accelerates, even on level ground.

Reforestation with Eucalyptus brosonettia appears economically desir-

able in some parts of India, but Eucalyptus foliage is not palatable to livestock. Areas planted to Eucalyptus do not provide the forage previously provided by many native species and local populations must find other ways to feed their stock. Land near villages is intensively used and neither pasture nor forage may be available. Reduction of the number of animals is seldom feasible, for these animals are essential to agricultural plowing and harvesting operations on which local food supplies depend.

The Indian examples just cited reveal a paradox. Multiple use for forest production and intensive grazing lead to site deterioration. Single use for Eucalyptus forest disrupts local tradition and fosters local resistance to economic development. Failure to appreciate these interrelationships can result in significant misinterpretation of development potentials when remote sensor data are used without adequate ground information.

Two examples from the United States illustrate other interrelationships that affect remote sensing success. In the 1970's populations of an endemic insect reached epidemic levels in the pine forests of the southeastern U.S. The southern pine beetle (Dendroctonus frontalis) is attracted to trees under stress. This stress may result from a number of causes, including drought, flooding, or overcrowding, all of which result in physiological water shortages in trees. This moisture stress reduces the resin pressure within the tree making it more difficult for the tree to resist attack by the beetles. A successful attack by one female can initiate a mass attack by thousands of male beetles, for the waste products of the female contain an aromatic sex attractant. Death of the tree usually follows a mass attack. Control of this beetle requires knowledge of where the beetles are located, but remote sensing systems have been strikingly unsuccessful in providing early indications of beetle location. Seven generations of this beetle have been reported in a single growing season (Thatcher and Pickard, 1967), and tree foliage may remain green for several months after the tree has died and the beetles move on. In several cases, computer classification of remote sensor data resulted in dead stands being classified as healthy pine. The key to early detection of the southern pine beetle appears to be early detection of the tree stress that is the initial invitation to beetle attack. To reach an answer to this forest problem it is necessary to have detailed knowledge of insect as well as tree behavior. Foresters and entomologists must work with remote sensing specialists in such situations.

In many parts of the northern United States salt is used to remove winter ice from roads and city streets. Salt spray is splashed onto street-side trees by vehicular traffic and some common street trees are highly susceptible to salt injury. Symptoms of salt injury often do not appear in deciduous trees until the middle of the next growing season when high temperatures are more apparent than winter salt. Salt accumulates in street-side soils when road salts are used winter after winter. The cause of subsequent tree mortality has been difficult to confirm, providing another example of the importance of interrelationships between human activities and plant growth.

In many parts of the world ancient human activities continue to influence agricultural and forest use of land. Buried walls and building foundations affect crop yeilds, and differences in crop yield (often expressed as reduced or increased plant height) are used by archeologists to locate sites of ancient human habitation (Riley, 1946). Natural revegetation of abandoned city sites hides these sites from from direct view. Land and forest development plans are not infrequently delayed when such sites are uncovered during construction and an attempt is made to preserve the site for historic purposes. Planning activities need to consider such possibilities, and remote sensing activities should assist in providing the information required by planners.

Summary and Concluding Remarks

With the several examples just presented I have tried to illustrate some of the ways in which the interrelationships between agriculture, forestry, and man's use of land affect remote sensing activities. I hope the need for interdisciplinary, or whole terrain, awareness in remote sensing activities is apparent to all. Remote sensors do not spearate terrain elements into the neat packages academicians call agriculture, forestry, geology, etc., but portray them in their full integration.

Remote sensors do nothing but portray intensities of energy fluxes at their detectors at a given mement. People like you and me interpret those records, often with the aid of special equipment. As we interpret these records, we attempt to divide the record up into terrain components we call agriculture, forestry, geology, soils, water, etc. Sometimes we forget that these divisions are manmade and limiting. Overcoming such limitations is the subject of this paper, but it would be inappropriate to leave this subject without considering ways in which we can make the records of energy fluxes more meaningful, or more interpretable.

Operational camera, line-scan, and microwave systems (both active and passive) provide an impressive array of equipment to record energy fluxes. Mounted on satellites, high flying aircraft, low flying aircraft, and moving or fixed platforms on the ground, these sensors provide capabilities to conduct remote sensing activities from many distances and in many parts of the electro-magnetic spectrum. Our ability to utilize these capabilities is dependent on how well we understand the energy fluxes we record, and on how well we understand our recording and processing equipment. Reflectance and emittance research described by previous speakers provides the basis for these understandings.

Information on light reflectance of tree foliage under water stress, such as that in Figure 1, has been used with digital computers to produce better LANDSAT images for manual interpretation. It can also be used to assist in automatic classification of vegetative cover. Despite the drammatic improvements we can achieve by using such information when we process LANDSAT data, spatial and spectral resolution limits prevent derivation of some kinds of information from LANDSAT records. Each of our other sensors, including low flying aircraft with small format (35mm) cameras have roles to play in meeting resource information needs. These needs become more

pressing every day, and answers are needed to today's questions today. We can only get these answers if we use today's equipment and today's capabilities. Let us not become so enamored with satellites and computers, and what we think they may be able to provide in the future that we stop using proven techniques we already have available. LANDSAT and computers represent only a small, but important, part of what remote sensing is today. Let us use all of our sensors and all of our capabilities and fit the sensor system to the task at hand. Forcing all remote sensing activities into the same sensor, vehicle, or processing system will not meet our urgent needs for better resource information today.

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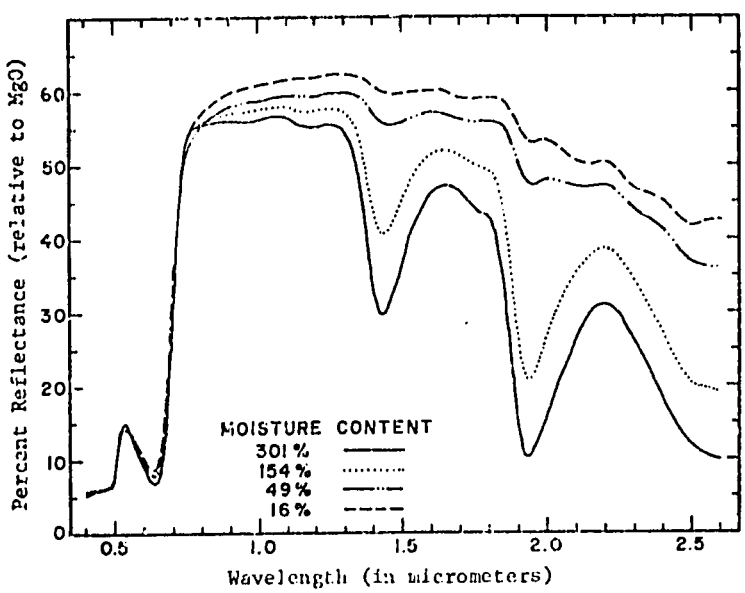

Figure 1. Change in reflectance of a sycamore leaf at four different oven-dry-weight moisture contents as it dried in air. (Olson, 1967)

THE USE OF REMOTE SENSING IN FOREST INVENTORY

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ABSTRACT

Periodic inventories are essential to the orderly development of forest resources and to assess their economic potential. For many years, aerial photographs have been employed effectively to aid in the implementation of broad forest surveys covering large areas as well as local management plan inventories.

Historically, features interpreted on aerial imagery which describe the tone, texture, shape, density and spatial distribution of forest trees have been used to partition large forest areas into homogeneous forest stand units. Stands of like classes have been grouped into strata to increase the precision of forest sample estimators. More recently, additional data obtained by means of image interpretation have been used to formulate supplementary variables for use in many kinds of sampling methods including single, double, one-stage, two-stage and multi-stage designs. These supplementary variables have also been used to formulate various kinds of sampling rules for use in regression, probability proportional to size (p.p.s.) and ratio sampling methods.

With the advent of high-altitude aircraft and spacecraft and their new methods of data acquisition, there has been an increased interest in the development of sampling designs which incorporate data from high- and low-altitude platforms simultaneously. This has led to the development of multi-stage sampling designs which have the characteristics of utilizing remote sensor data from all levels simultaneously. In addition to cameras, Landsat multispectral imagery and Side-Looking Airborne Radar (SLAR) have been employed effectively to obtain data from visible and non-visible parts of the spectrum and to penetrate cloud cover. These data have also been employed as integral parts of formalized sampling procedures. Their use in sampling designs generally leads to obtaining estimates of greater precision for a lessor amount of data collection on the ground. Optimum allocation procedures are used at different levels of the sampling design to obtain the greatest precision for the least overall cost.

After valid estimates of forest parameters have been obtained, they are often entered into a computer-oriented resource management information system for storage and selective use in planning the development of forest resources more effectively. As time goes on, information in the system can be utilized in more intensive inventories in local areas as they are needed. In this way, the expenditure of funds is more intelligently allocated to those areas where the information is most needed in relation to space and time.

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AN INTEGRATED REMOTE SENSING SYSTEM FOR RANGELAND INVENTORY AND MONITORING

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This presentation emphasizes the importance, when designing a remote sensing approach to meet information needs about rangeland and related resources, of drawing on the full capability of remote sensing technology. The optimum system is project specific, or unique to each project and set of information needs; and it is nearly always constrained, particularly in the developing world, by local working conditions, logistical and staffing problems. Five critical challenges in this area are briefly discussed.

The concern about rangeland encompasses all of the fodder-growing vegetations of the world, including even the deserts, tundra regions and marshes as well as to concern the open forests and woodlands that are or may potentially be used by domestic and/or wild animals and birds for food and cover. Since the concerns for managing these kinds of land involve problems of land use conversion as well as management of the grazing animals, an adequate resource inventory must be ecological in nature -- i.e., it must provide information on the natural ecosystems comprising the landscape and also on the activities of man in converting lands to new uses as well as his impact on the "natural" ecosystems.

The specific goal of remote sensing is to provide these information needs in a timely and sufficiently accurate manner to enable rational, informed decisions to be made. The general goal is to meet the specific information needs in the most cost-effective manner possible. This means designing a remote sensing system that reduces dependence on the most costly elements of the system. In practically every case this is the ground work -- which incidentally, cannot and should not be completely eliminated. Maximum efficiency is generally achieved with some kind of multistage system that always includes a remote sensor and ground or low-level aerial observation. New space, or Landsat, technology is not always an element. Its role depends on the information need and availability of alternate systems such as recent aerial photography of adequate quality. The unique advantages of Landsat in many developing nations, where appropriate aerial photography of whole project areas is difficult to obtain, are pointed out along with the compatible roles of both visual and computer analysis of Landsat data. The use of Landsat as the first stage in a design that greatly decreases dependence on aerial photography is both discussed and illustrated.

Slide and viewgraph illustrations show the approach and results from (1) a range, land use and groundwater investigation of the Masai Steppe region in Tanzania; (2) a band ratioing evaluation of grassland productivity from the United States; and (3) a multistage evaluation in Iran using Landsat, two stages of aerial photography, ground work and proportional probability sampling theory to derive estimates of current and potential productivity of Iranian rangelands.

In conclusion, the importance of providing continuity of capable personnel between the inventory or monitoring work and the process of information use and decision-making is strongly emphasized as a mechanism to ensure effective application and full benefit from the investment in inventory. The importance of heavy involvement of citizens of the country, their own scientists and managers, in actually doing the inventory or monitoring interpretations, ground studies, compilation and reporting cannot be overemphasized. Of all, this, in the writer's experience, is the single most important ingredient to ensure successful use of information derived from remote sensing projects.

REMOTE SENSING APPLICATIONS FOR DETERMINING POTENTIALS OF GROUNDWATER RESOURCES IN EGYPT

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ABSTRACT

The Remote Sensing Center has been actively engaged since the launching of Landsat-1 satellite in space, in the various applications of spaceborne imagery interpretation techniques especially regarding the mapping and investigation of natural resources. The groundwater potential of large areas lying in arid, semi-arid, sub-tropical and tropical climatic zones in Egypt and the Sudan has been elucidated through the utilization of Landsat imagery together with pertinent field, laboratory and subsurface investigations. The spaceborne techniques proved to be important tools in mapping on a regional scale the lithological units which act as aquifers and aquicludes, in delineating the structures imposed on these units and the drainage lines imprinted on them. The latter lines serve as channels for rain water and they could be computed into drainage basins which collect water in appropriate locations. Landforms are defined also on the basis of Landsat imagery interpretation in conjunction with topographical maps.

For the purpose of illustrating the use of Landsat imagery interpretation techniques in groundwater potential studies, the cases of Gattara Depression and Tushka Basin areas are given in this communication. The first area lies in the Northwestern Desert and is studied as a solar hydro-electric project where the Mediterranean Sea waters are allowed to fall in the depression to generate electricity. The second area, on the other hand, lies mainly in the Western Desert of Egypt on the western fringes of the part of the River Nile which lies between Aswan and Wadi Halfa and acts as a reservoir for Aswan High Dam. Tushka Basin area is studied in the light of the utilization of this basin as a flood escape for Nile waters filling the Aswan High Dam Reservoir.

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USE OF RADAR FOR GROUND WATER EXPLORATION IN NIGERIA, WEST AFRICA

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SUMMARY

Side looking airborne radar (SLAR) was used to locate potential sources of fracture-controlled ground water in Pre-Cambrian crystalline rocks of north-central Nigeria. The study area encompasses about 3080 square kilometers centered on the village of Malumfashi, Kaduna State. Rainfall is seasonal; villages in this area experience severe water shortages during the dry season. Weathered rock is at or near the surface over much of the area, residual soil is thin and permeability is low.

Lineaments of three kilometers or greater in length were interpreted from the imagery, statistically analyzed and classified to determine potential well-site locations at the intersections of, or along, preferred tensional fracture sets. The method used is a modified, computer-assisted lineament analysis program developed by MARS, Inc. for oil, gas and geothermal exploration. The success ratio is significantly increased by concentrating on the primary regional lineament set.

MARS, Inc. teamed with a Nigerian water-well contractor who used high-speed pneumatic drill rigs capable of penetrating rock at rates of 20 to 30 meters per hour. Drill holes ranged in depth from 48 meters to a maximum of 210 meters, average actual drilling time per hole was eight hours. Twenty-six wells were drilled in rock with twenty-four resulting in productive water wells yielding in excess of 10,000 liters per hour.

CONCLUSIONS

The use of fracture analysis in ground-water exploration has once again been shown to be a successful technique. The method outlined in this study enhances the chances of successfully locating well sites. Side looking airborne radar, with its synoptic format, and the proper use of depression angles is superior to other sensor systems for mapping lineaments and other structural features. The potential offered by SLAR for ground-water exploration and development in the drier regions of the world has been clearly demonstrated.

PROSPECTING FOR GROUND WATER WITH LANDSAT IMAGES *

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ABSTRACT

The features on Landsat images that are indicators of ground-water occurrence are landforms, drainage characteristics, snowmelt patterns, vegetation types and associations, outcrop patterns, soil tones, lake patterns, and land-cover types. Some features imply the occurrence of shallow sands and gravels; other features indicate rock types or the presence of folds and fractures. A color-composite image is the most useful for ground-water interpretations, but lineaments and some drainage characteristics are seen best on a black-and-white band 7 (near infrared) image.

Time of year is critical for obtaining maximum hydrologic information from Landsat images. Some features are enhanced by a low sun-elevation angle. Other best times of year depend on local cycles of wet to dry, warm to cool, and bare soil to mature agricultural crop.

Various forms of Landsat data processing and enhancement are possible by photographic and digital methods. The most widely used methods are contrast stretching and color additive viewing. The advantages of digital processing must be balanced against the higher costs.

INTRODUCTION

General principles of photograph interpretation may be applied to Landsat (formerly called ERTS) images to (1) recognize landforms, drainage and cover patterns, lithologies, and geologic structures that are favorable for ground-water occurrence, (2) delineate some of the limits of shallow aquifers, and (3) study some phases of aquifer operation, such as recharge and discharge. Landsat data thus may be used as an aid in solving specific problems such as water supply or pollution, to plan field work or reduce the need for field work, and as a source of information on regional aquifers. This paper lists a number of interpretation keys and describes several simple procedures that have been useful in obtaining ground-water information from Landsat data.

The only prerequisite for interpretation of Landsat images is a basic knowledge and understanding of ground-water hydrology. For beginning users, however, it is desirable to have some knowledge of the information content of aerial photographs, the characteristics of the Landsat multispectral scanner, and the format and geometry of the images. Reviews of the principles of geomorphology and the relations of landforms to ground-water occurrence also are helpful in obtaining the maximum information from the images.

One of the main characteristics of Landsat images is a broad, regional view of the landscape. The study of Landsat data usually is most effective in the early phases of an investigation, when field data collection effort can be planned to test or confirm the regional geologic environment as well as to determine local conditions. However, a recent idea is that structurally controlled linear trends on Landsat images have continental or even global importance (several papers, for example, in Hodgson and others, eds., 1976); to test this hypothesis it is necessary to test field fracture patterns and other structural trends for regional significance on Landsat mosaics and then to extrapolate the results to structures on a continental scale.

* A paper presented at the Technical Session on "Hydrologic Applications of Remote Sensors", at World Water Conference, Mar Del Plata, Argentina, March 17, 1977

A common mistake is to assume that all significant remote-sensing information can be obtained from either aerial photographs or Landsat images. Actually, these are complementary sources of data and information, as are manned-spacecraft photographs, meteorological satellite images, and field work on the ground. From extensive studies in the USSR, Makarov and others (1974, p. 398-400) concluded that as the resolution of photographs or images decreases, structural elements representing progressively deeper levels in the earth's crust become apparent. "For example, in the eastern Caucasus lines interpreted on medium scale pictures from manned spacecraft correlate with the structure of the Konrad [Conrad] surface and to some extent with the surface of the pre-Jurassic basement, whereas the results of interpretation of TV pictures (lower resolving capacity) basically give us an idea of the structure of the Mohorovicic surface" (Makarov and others, 1974, p. 399).

OCCURRENCE AND LIMITS OF AQUIFERS

For the purposes of this report, aquifers are divided into two groups--shallow sand and gravel types and other types. The "other aquifers" group includes all rocks in which fracture porosity is more important than intergranular porosity in determining permeability as well as tubular basalt flows.

Shallow Sand and Gravel Aquifers

Most well-sorted sands and gravels are fluvial deposits, either in the form of stream-channel deposits and valley fills or as alluvial fans and bajadas. The remainder are cheniers, beach ridges, beaches, and some wind-deposited dunes. The shapes, patterns, tones, and textures that imply the presence of shallow aquifers are those that indicate coarse materials and a near-surface water table (table 1). All interpretation keys on table 1 have been detected on Landsat images. Locally, other keys may be important, and it should be realized that many hydrologically significant features are too small to be visible on Landsat images.

Landscape features that have a characteristic shape or form can be used to detect shallow aquifers with reasonably accurate results. Best results generally are obtained by manual interpretation of a band 7 (near-infrared energy, 0.8 - 1.1 micrometers)[1] or a color-composite image. A low sun-elevation angle (November 1 to February 15 in the northern hemisphere and May 1 to August 15 in the southern hemisphere) is desirable or necessary. A thin snow cover enhances the topographic shadowing produced by a low sun elevation, and large landforms are more apparent; on the other hand, snow obscures fine topographic detail.

Patterns are less reliable than landforms as indicators of shallow acquifers on Landsat images. Nevertheless, large areas can be examined for distinctive patterns in short periods of time. Landsat images also provide a good format for detection of patterns covering large areas and for delineation of major boundaries. Fewer drainage lines are visible on Landsat images (visible drainage lines vary with season and sun-elevation angle) than on aerial photographs, but gross patterns can be delineated quickly. Band 7 images generally are best for detection of streams, lakes, and ponds, but lakes with emergent vegetation may be recognized easiest on band 5 (red light, 0.6 - 0.7 micrometer) images. Color-composite images are best to study snowmelt and vegetation patterns. Digital processing commonly is helpful to enhance small local differences in vegetation. Many small vegetation patterns that indicate ground-water discharge or springs are below the resolution limits of the scanner, however.

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[1]/The terminology is confusing, but near-infrared energy is sunlight reflected from the land surface; heat or thermal infrared energy is not emitted from the land surface at wavelengths shorter than 3.0 micrometers.

Table 1. Keys to detection of shallow sand and gravel aquifers on Landsat images

Shape or form:

1. Stream valleys; particularly wide, meandering (low gradient) streams with a large meander wavelength and with broad and only slightly incised valleys.
2. Underfit valleys represented by topographically low, elongate areas with ponded drainage or with a stream meander wavelength smaller than that of the floodplain or terraces.
3. Natural levees (levees themselves may be fine-grained materials).
4. Meander loops showing location and relative thickness of point bars.
5. Meander scars in lowland; oxbow lakes; arcuate dissection of upland areas.
6. Braided drainage-channel scars.
7. Drainage line offsets; change in drainage pattern; or change in size or frequency of meanders (may be caused by faults and cuestas as well as by changes in lithology).
8. Arc deltas (coarsest materials) and other deltas.
9. Cheniers; beach ridges; parabolic dunes.
10. Alluvial fans; coalesing fans; bajadas.
11. Alined oblong areas of different natural vegetation representing landlocked bars, spits, dissected beaches, or other coarse and well-drained materials.

Patterns:

1. Drainage patterns imply lithology and degree of structural control; drainage density (humid regions) and drainage texture (arid regions) imply grain size, compaction, and permeability.
2. Snowmelt: if everything else is equal, anomalous early melting snow and greening of vegetation show areas of ground-water discharge; ice free areas on rivers and lakes.
3. Distinctive types of native vegetation commonly show upstream extensions of drainage patterns, areas of high soil moisture, and landform outlines (humid regions); abrupt changes in land cover type or land use imply landforms that may be hydrologically significant but do not have a characteristic shape.
4. Elongate lakes, sinuous lakes, and alined lakes and ponds representing remnants of a former stream valley.
5. Parallel and star dunes.
6. Splay or parallel linear patterns representing old alluvial fans or landlocked chenier complexes.

Tone:

1. Soil type; fine-grained soils commonly are darker than coarse-grained soils.
2. Soil moisture; wet soils are darker than dry soils.
3. Type and species of native vegetation; vegetation is well adapted to type and thickness of soil, drainage characteristics, and seasonal period of saturation of root zone.
4. Land use and land cover; for example, percent bare soil may correlate with drainage density; also for example, native vegetation in lowlands and agriculture on uplands may indicate periodic flooding.
5. Anomalous early or late seasonal growth of vegetation in areas of high soil moisture, as where water table is close to land surface.

Texture:

1. Uniform or mixed types of native vegetation; some species and vegetation associations are indicators of wet versus dry sites, thick versus thin soils, or particular mineral compositions of soils.
2. Contrast between sparse vegetation on topographic highs and denser vegetation in low (wetter) areas.
3. Texture contrasts at boundaries of grass, brush, and forest cover types; possible boundaries of soil types or moisture conditions.

Unless ground information is available, image tones and textures are the least reliable keys as indicators of shallow aquifers. Nevertheless, in some cases the combination of tones and textures form shapes or patterns that, in turn, are distinctive indicators. Digital processing of magnetic tapes on an interactive man-and-machine system has proven useful for enhancement and classification of Landsat multispectral data. An alternative is manual interpretation of either a color-composite image or black-and-white images. Textures generally must be detected and delineated manually, although the complex spectral signatures of some areas are distinctive and may be classified by machine processing. The main problem with tones and textures is that an area underlain by a shallow aquifer may have a variable appearance; no single indicator occupies an area large enough to form a diagnostic shape or pattern. An underfit valley in early spring, for example, may have some areas that show the dark tones of high soil moisture next to other areas that have an early growth of native vegetation. Such cases may be enhanced by machine processing, but the significant pattern (the valley) must be recognized visually. Early spring and fall images commonly are best for detection of differences in soil type, soil moisture, and type of vegetation.

Boundaries that are gradational on the ground commonly are sharper on Landsat images. Hydrologically significant landforms, patterns, tones, and textures can be delineated easily on Landsat images. On the other hand, more detail is visible on aerial photographs. In some areas, Landsat images can be used to select locations for test wells. In other areas, Landsat images can be used to select locales which can be examined in more detail on aerial photographs or on the ground.

Other Aquifers

Virtually all consolidated rocks contain some ground water at depths ranging from 1 meter to 1,000 meters, but ground-water abundance depends on rock type and amount and intensity of fracturing. Previous experience or previous knowledge of an area is necessary for good results, when attempting to identify rock types from shapes and patterns on Landsat images. Keys (table 2) can be used, however, to detect differences in rock types on Landsat scenes. All keys in table 2 have been seen on Landsat images, but the list is not intended to be all inclusive. Other factors could be important locally.

Color-composite images probably are excellent for identification of rock types, although drainage patterns are seen best in many areas on band 7 images. Each of the four black-and-white images has been reported by various authors to be superior to the other bands for lithologic delineations; the best single band probably is determined by factors such as atmospheric conditions, time of year, and type and amount of vegetation cover. Little geologic information is lost when making a color-composite image, and the composite combines data in 3 of the 4 Landsat bands.

Folds that may concentrate or block ground-water flows can be detected and delineated with relatively accurate results on Landsat images. Vegetation patterns are seen best on color-composite images, but band 7 images may be best for delineating drainage patterns. Vegetation patterns are prominent on band 4 (green light, 0.5 to 0.6 micrometers) and band 5 images as well as on color-composite images; these patterns can be distracting to the eye, wher the image is being interpreted for other features. Vegetation patterns are least obvious on band 7 images.

Lineaments are all types of natural straight-line features on images. It is well to remember that lineaments are not necessarily rock features and that they do not necessarily localize ground-water occurrence. A few lineaments can be correlated with faults; the physical nature of most other lineaments must be investigated by indirect means (by comparing lineament

Table 2. Keys to detection of other aquifers on Landsat images

Outcropping rock type:

1. Landforms; topographic relief.
2. Outcrop patterns; banded patterns for sedimentary rocks (outlined by vegetation in some regions); lobate outline for basalt flows; curving patterns for folded beds.
3. Shape of drainage basins.
4. Drainage patterns, density and texture.
5. Fracture type and symmetry (as implied by lineaments); triangular facets above fault or fault-line scarps and alluvial fans below; discontinuities in bedding patterns, topography or topographic texture, and vegetation types.
6. Relative abundance, shape, and distribution of lakes.
7. Tones and textures (difficult to describe; best determined by study of known examples).
8. Types of native land cover.

Folds:

1. Cuestas and hogbacks; asymmetric ridges and valleys; flatirons on dip slope and irregular topography on back slope; uniform distribution of vegetation on dip slope and vegetation banding parallel to ridge crest on back slope; bajada on dip slope and separate alluvial fans on back slope.
2. Banded outcrop patterns not related to topography; closed to arcuate patterns; U-shaped to V-shaped map patterns of ridges; sedimentary rock patterns with an igneous core.
3. Trellis, radial, annular, and centripetal drainage patterns; partly developed patterns of these types superimposed on drainage patterns of other types.
4. Major deflections in stream channels; changes in meander wavelength or changes from meandering to straight or braided patterns.
5. Asymmetric drainage; channels not centered between drainage divides.

Lineaments:

1. Continuous and linear stream channels, valleys, and ridges; discontinuous but straight and alined valleys, draws, swags, and gaps.
2. Elongate or alined lakes, large sinkholes, and volcanoes.
3. Identical or opposite deflections (such as doglegs) in adjacent stream channels, valleys, or ridges; alinement of nearby tributaries and tributary junctions.
4. Elongate or alined patterns of native vegetation; thin strips of relatively open (may be rights-of-way) or dense vegetation.
5. Alinement of dark or light soil tones.

trends with joint trends), because of the small scale of Landsat images (few landmarks are visible), and because residual material cover many rock outcrops.

An association of lineaments and ground-water occurrence is dependent upon the presence of dense heterogeneous aquifers, rock fractures, and the surface expression of these fractures. Dense heterogeneous aquifers do not yield water from the rock fabric under gravity drainage. The only space for storage and movement of ground water is in fractures enlarged by brecciation, weathering, solution, or corrasion. Corrasion in dense rocks occurs by solution of the rock cement (generally 5 to 10 percent of the fabric and physical removal of loose grains by turbulent flow).

It is logical that many fractures, which localize the occurrence of ground water, also have an expression at land surface. The same processes of weathering, solution, and corrasion operate at land surface, as do additional processes such as frost wedging and mass wasting. A fracture that is a plane of weakness for enlargement by ground water therefore may be represented by a topographic depression, a different soil tone, or a vegetation anomaly at land surfaces.

Many fractures are vertical; in this case, lineaments may represent favorable locations for water wells. Other fractures are oblique; well locations must be offset to intersect the fractures below the water table but at a shallow depth (nearly all fractures are progressively smaller at increasing depths). In some limestone terranes and probably in other areas of bedded sedimentary rocks, sheetlike solution cavities form along bedding planes. If the rocks are flat-lying, the hydrologically significant openings nearly parallel the land surface. In these cases, however, vertical joints commonly control the locations and trends of the horizontal sheetlike cavities; the same vertical joints may have a topographic, tonal, or vegetation expression at land surface.

A number of reports have shown a good correlation between lineaments detected on aerial photographs or satellite images and the occurrence of ground water in dense, fractured limestones.[2] There is good reason to believe that many lineaments are related to ground-water occurrence in other types of dense, fractured rocks.

A few lineaments can be identified as the faults or fault lines shown on published geologic maps. In unmapped areas, some lineaments are associated with other features such as triangular facets or discontinuities in topography and bedding-outcrop patterns.

Hydrologic interpretations of most lineaments can be made with only a relatively low degree of confidence. Several previous studies have shown, for example, that some lineaments are not related to ground-water occurrence. The relationship between lineaments and ground water generally can be established only by test drilling.

Carter (1976, p. 92-93 and fig. 64) suggested the compilation of a relative confidence map for lineaments, in which (1) linear features noted on published maps are shown in red, (2) those noted on Landsat images by two or more interpreters are shown in green, (3) linear features noted by one interpreter but believed to be mostly faults and other fractures are shown by

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[2]/Some of the more significant reports are Lattman and Nichelson, 1958; Hough, 1960; Boyer and McQueen, 1964; Lueder and Simons, 1962; Lattman and Parizek, 1964; Trainer, 1967; Trainer and Ellison, 1967; Moore and others, 1969; Powell and others, 1970; Sonderegger, 1970; Siddiqui and Parizek, 1971; Tomes, 1975; and Moore, 1976.

long dashed black lines, and (4) other linear features are shown by short dashed black lines.

The best format for detection of lineaments is partly a matter of personal preference and generally is a band 5, 6 (near infrared light, 0.8 to 0.9 micrometers), or 7 black-and-white image or a color-composite image. Vegetation patterns are least prominent and distracting on band 7 images. Many lineaments are enhanced by a low sun-elevation angle. Manual interpretation is necessary, and unaided manual interpretation commonly produces adequate results. Recent work (for example Goetz and Billingsley, 1973; Pincus, 1969; Rowan and others, 1974) has shown, however, that machine processing such as contrast stretching, Fourier transforms, high spatial-frequency filtering, and fine-scale detail enhancement is helpful. Such enhancements may be necessary in otherwise featureless areas. Manual enhancement of linear features is possible by viewing or projecting the images through a Ronchi ruling (Pohn, 1970) with about 5.9 lines per millimeter. Slightly offset film sandwiches of a negative and positive image (in the manner of Weller, 1970) also have been used to enhance linear features.

Some basalt flows contain tubes which serve as conduits for ground water. Discharge of ground water occurs at or near the edge of the outcrop area. Basalts at land surface commonly can be recognized by dark tones on black-and-white images and by dark (generally gray or bluish gray) hues on color-composite images. In undeveloped arid regions, areas of discharge are indicated by patches of reddish (on color-composite images) vegetation. In developed regions, such as the Snake River plain of Idaho, discharge is mainly by pumpage for irrigation.

Coarse-grained aquifers may occur at depth beneath lineaments visible on Landsat images. A number of previous workers[3] have detected and mapped lineaments in thick unconsolidated materials; almost all of these workers note that many lineaments are formed by drainage lines and patterns. Evidence relating the origin and orientation of lineament sets and systems to fractures in underlying consolidated rocks is impressive, although not conclusive. Several scientists, reasoning independently, have suggested informally that lineaments represent fractures that propagated upward from basement rocks during depositional periods (instead of at some undetermined later date). If lineaments controlled stream-channel positions during depositional periods as well as at present, then coarse stream-channel materials might be found at depth in alluvium-filled valleys, glaciated terranes, and coastal-plain deposits--beneath lineaments on the present land surface.

PROCEDURES

One of the most important things that has been learned since Landsat imagery became available is that time of year is critical for obtaining the maximum geologic and hydrologic information from the images. The exact best time depends on local conditions and weather patterns as well as interpretation objectives. Approximate best image dates for selected objectives in the United States are shown in table 3. Obviously, times other than those listed might be better in other areas of the world. Changes in sun-elevation angle can be calculated from local latitude, but the best times to observe features such as soil moisture and vegetation differences depend on local cycles of wet to dry, warm to cool, and bare soil to mature agricultural crop. The best times for Landsat images must be determined from a local knowledge of these cycles and from experience in working with the images.

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[3]/Gilbert (1882), Russell (1885), Crosby (1885), Fish (1947), Mollard (1957), Plafker (1964), Martin and others (1973), Drake and Vincent (1975), O'Leary and Simpson (1975), and Withington (1976).

Table 3. Suggested best periods for Landsat images in the United States of America (actual best time may vary because of local conditions or weather patterns).

1. Low sun-elevation angle:
   a. Best: Nov. 20 - Jan. 20 (less than 25° at 35° N. latitude)
   b. Good: Nov. 1 - Feb. 15 (less than 30° at 35° N. latitude)
   c. Fair: Oct. 15 - Mar. 1 (less than 35° at 35° N. latitude)

2. Maximum area of bare soil:
   a. March - May (spring crops)
   b. Oct. - Dec. (winter crops)

3. Drainage patterns:
   a. Best: Nov. 20 - Jan. 20 (low sun angle)
   b. Good: April - May (high stream stages)

4. Soil moisture patterns:
   a. Best: April
   b. Good: March - May

5. Snowmelt patterns:
   a. Best: March
   b. Good: Feb. - June

6. Native vegetation types and differences:
   a. Best: Oct., April
   b. Good: Sept. - Nov., April - May

7. Small lakes and ponds:
   a. Best: after heavy, intense showers
   b. Good: March - May; after seasonally heavy rains

8. Native-vegetation density: June - July (April - May for annual western grasses)

9. Areas beneath deciduous overstory: Dec. - March

10. Irrigated crops vs. dry-land farming: dry period; crop grown enough to cover bare soil; crops of one type or several types with distinctive signatures (spectral reflectances)

11. Lithologies in glaciated terrane: April - May

12. Desert vegetation: April

The single most useful image is the color-composite. The black-and-white Landsat images that generally contain the most ground-water information are band 7 and 5. However, band 6 images are useful for detection of soil moisture patterns, and some information on vegetation may be extracted from band 4 images.

All Landsat images and digital tapes obtained by United States receiving stations[4] are available from the EROS Data Center, Sioux Falls, SD, 57198, United States of America. About 5 percent of the Landsat scenes are available as color-composite images as well as black-and-white separates. All available color-composite images have been made from bands 4, 5, and 7 and are near-equivalents of color infrared photographs. Color-composite images of any desired scene can be made by the EROS Data Center at extra cost. Color composites also can be made in field offices with color diazo materials.

The Instituto de Pesquisas Espaciais (INPE) began processing and distributing Landsat data within 3,000 kilometers of the receiving station at Cuiabá, Brazil on January 1, 1976. Almost complete coverage of South America between latitudes of about 7° N. and 40° S. is possible from this station. These data presently are not available from EROS Data Center but may be ordered from:

Dr. Nelson J. Parada, Director
Instituto de Pesquisas Espaciais
C. P. 515
12.200 Sao Jose dos Campos
Sao Paulo, Brazil

Computer compatible tapes (CCT's) as well as black-and-white prints and transparencies are available.

Ground receiving stations presently are operating in Canada and Italy as well as in Brazil and the United States. Argentina plans a receiving station at Mar Chiquita, and a station is under construction in Iran. Two future receiving stations are planned for Africa.

The selection of transparencies or prints is entirely a matter of personal preference and the plan for reproducing and viewing the images. Transparencies may be projected (overhead projector for monimally sized 9-inch film and lantern slide projector for 70-millimeter film) or viewed on a light table. Paper prints also may be viewed by transmitted light to avoid glare from overhead lights. Some scientists feel that transparencies have more detail than paper prints, but there is no inherent reason why this should be so.

A vertical view of the image is best for detection of most features. Viewing at a low angle and slowly rotating the image may enhance lineaments. Viewing at a distance decreases resolution and decreases the distraction of cultural patterns; this may help to detect large features or regional trends. Similarly, a projected image may be viewed close to the screen or at some distance, as well as in focus or out of focus.

Consecutive images in an orbital path have about 10 percent endlap. Because the images are from a multispectral scanner, however, no parallax occurs in this area (some scan lines are repeated for end-matching purposes), and this area cannot be viewed in stereo. Sidelap on adjacent orbits (consecutive days) increases from about 22 percent at 25° N. or 25° S. latitude to about 45 percent at 50° N. or 50° S. latitude. The parallax for this situation produces a fair stereo model (vertical exageration is small because of satellite altitude). Also, the Landsat orbit drifts slightly and is periodically corrected; over a

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[4]/Scenes for areas outside of the range of a receiving antenna must be tape recorded. Typically, 3 to 6 Landsat scenes are available for these areas; these scenes may be ordered from EROS Data Center.

period of time, orbital drift results in an additional 10 to 15 percent of sidelap.

Composite viewing may be worthwhile. The theory of composite viewing is that features, which may not be apparent on a single image, will be obvious on a composite of two images obtained at different seasons of the year. The images may be viewed together with a mirror stereoscope or projected together on a screen (with a different colored filter for each image). A large number of input formats and dates are possible, as for example:

1. Two color composite images.
2. Two positive band 7 images.
3. One positive band 7 image and one negative band 7 image.
4. A band 7 image from one date combined with a band 5 image from another date.
5. A winter image combined with a fall image.
6. A fall image combined with a spring image.

The best material for different objectives has not been determined, but a very few tests of composite viewing have suggested that more lineaments can be detected than on a single image and that lithologies and formation boundaries are enhanced.

Contrast stretching (improving the contrast between features and their surroundings) generally is helpful and may be necessary on a few hazy and other low-contrast Landsat scenes. Stretching also may enhance otherwise obscure shapes and boundaries. This process, however, may eliminate detail in very dark and very light parts of the scene. Thus, a scene should not be stretched routinely if, for example, the features of interest are water turbidity patterns, snow boundaries dark wet soils, or playa deposits. Instead, the dark or light feature may be shifted to the center of the gray scale by photographic processing (see, for example, Moore and others, 1974, p. 9-10 and fig. 5) or scaled up or down by digital processing. Contrast stretching may be done either by photographic or digital processing.

Photographic or digital enlargement and display aid in the recognition of small landforms but can obscure large landforms; the size of the feature of interest must be considered. Some large landforms and regional lineaments are visible only on mosaics of 20 or more Landsat images.

Band-ratio images (such as the image obtained by dividing the digital values of a group of Landsat picture elements in band 5 by the digital values of the same picture elements in band 7) may be obtained either by photographic (Lockwood, 1975, p. 22-26) or digital processing; in some cases, landforms, patterns, and boundaries that were not apparent on the raw images are obvious on the ratio images. In most cases, however, band-ratio images are less interpretable than either contrast-stretched or raw images.

Classification[5] and density slicing of areas of bare soil and vegetation generally have not been useful procedures to enhance or delineate landforms. Most landforms and lineaments consist of several different land-cover types or of discontinuous shapes, lines, and patterns. The human eye can merge these features but a machine cannot. Also, only a human interpreter can recognize a pattern or shape that consists of several elements. Classification can be used successfully to locate, delineate and measure all areas in

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[5]/Classification is a type of digital processing. In the simplest form of classification, a signature is determined in a training area by the range of digital values in the four Landsat bands; this signature is then applied to the remainder of the scene. Basically, the computer is instructed to show all areas that have the same ranges in digital values as those that occur in the training area.

a scene where a particular soil or vegetation type (which may be an indicator of ground-water occurrence) is present. Density slicing (either digital or film images) is best applied to fairly simple problems such as delineation of snow-covered areas or color coding of water turbidity patterns.

Color additive viewing consists of projecting three of the black-and-white Landsat images on a screen through colored filters and superimposing the images. The result is a color-composite image in which the bands, filter colors, and the projection-light intensities can be varied to enhance selected features. Good geologic and hydrologic enhancements have been obtained (Falconer and others, In Press, 1976) by using photographically contrast-stretched images for projection. Separate enhancements generally are needed for dark toned and light toned features.

Most processing and enhancement procedures may be done either manually (with film products) or digitally. The main advantage of digital processing is the capability of using the full spectral and spatial resolution of the Landsat scanner; working with digital tapes and interactive man-and-machine computer systems, the scientist can go slightly beyond what is possible with film products. The objectives of a study must be considered to determine whether this advantage is worth the higher costs of digital tapes and processing (as much as US $250 per hour). Some scientists use only manual processing techniques and feel that virtually all the available information can be obtained by these means.

A suggested procedure is to first examine the raw black-and-white images and a color-composite image. Second, try photographic contrast stretching, enlargements, and variations in color additive viewing. If the features of interest cannot be detected at this time, they probably cannot be further enhanced by digital processing. On the other hand, if some hydrologically significant features are enhanced, then additional results are possible by digital processing. If the equipment for color additive viewing is available, total cost for this procedure (including time for examination of the images at each step) may be less than the cost (US $200) of one digital tape for the same scene.

CONCLUSIONS

General principles of photograph interpretation may be applied to Landsat images to recognize features that are favorable for ground-water occurrence. These features are landforms and landform patterns, drainage characteristics, snowmelt patterns, vegetation types and associations, outcrop patterns, soil tones, lake patterns, and land-use and land-cover characteristics. Some detected features directly imply the presence of shallow sands and gravels; other features indicate rock types of the presence of folds and fractures. The features that imply the occurrence of shallow aquifers may be characterized as having distinctive shape or form, pattern, tone, and texture.

A number of reports have shown a good correlation between lineaments detected on aerial photographs or satellite images and the occurrence of ground water in dense, fractured limestones There is good reason to believe that many lineaments are related to ground-water occurrence in other types of dense, fractured rocks. It is well to remember, however, that lineaments are not necessarily rock fractures and that they do not necessarily localize ground-water occurrence. The compilation of a relative confidence map for lineaments is a good idea, because it aids geologic and hydrologic interpretations.

A color-composite image generally is the single most useful Landsat image for ground-water interpretations; lineaments and some drainage characteristics are seen best on a band 7 image, however. A few other features are seen best on band 4, 5, or 6 images. The best black-and-white image

for any purpose may depend on factors such as time of year, type of vegetation cover, and atmospheric conditions as well as on objectives of the study.

One of the most important things that has been learned since Landsat imagery became available is that time of year is critical for obtaining the maximum geologic and hydrologic information from the images. Through experience, the approximate best times have been determined for various objectives in the United States. In other countries, the best times depend on local cycles, such as these for wet to dry, warm to cool, and bare soil to mature agricultural crop.

Most landforms, lineaments and drainage patterns are enhanced by a low sun-elevation angle. Thus a Landsat image from November 1 to February 15 in the northern hemisphere or May 1 to August 15 in the southern hemisphere is desirable or necessary for some interpretations.

Various forms of processing and enhancement are possible by either photographic or digital methods. The most widely used methods at present are color additive viewing and contrast stretching. The advantages of digital processing must be carefully balanced against higher costs. A manual analysis and interpretation of images is recommended before proceeding with digital processing. Landforms, patterns, and lineaments can be detected and recognized only by the human eye. A final manual interpretation for these features is necessary regardless of the processing and enhancement methods.

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THE ROLE OF REMOTE SENSING IN GROUND-WATER EXPLORATION

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GROUND-WATER EXPLORATION METHODS

1. REGIONAL

   a. Satellite images or mosaic
   b. Geological reconnaissance
   c. Hydrologic reconnaissance
   d. Magnetic prospecting
   e. Gravity prospecting

2. LOCAL

   a. Aerial photographs
   b. Detailed hydrologic mapping
   c. Detailed geologic mapping
   d. Electrical prospecting
   e. Seismic prospecting
   f. Shallow test drilling
   g. Deep test drilling

REGIONAL EXPLORATION METHODS

METHOD	PROCEDURES	PERSONNEL REQUIREMENT	AREA COVERAGE RATE	RESULTS
Interpret Satellite Images or Mosaic	Analyze Tones, Textures, Shapes, Patterns, Location and Association.	One Scientist in Office	7,000 to 34,000 km^2/day	Interpretation of lithology, structure, and ground-water occurrence based on landforms, drainage patterns, land use, soil tones, and vegetation types and patterns.
Geologic Reconnaissance	Examine Lithologies, Orientations, and Fracture patterns.	One Scientist, in field	250 km^2/day	Generalized geologic map and sections showing lithology, stratigraphy, and structure.
Hydrologic Reconnaissance	Inventory largest wells and springs. Examine rock types, orientations, and fracture patterns	One Scientist in field	100 km^2/day	Generalized hydrologic map showing aquifers, aquitards, and areas of recharge and discharge.
Magnetic Prospecting	Measure differences in the earth's magnetic intensity	One scientist and pilot for aerial studies	250 to 2,500 km^2/day	Calculation of sedimentary rock thickness and interpretation of basement structure.
		One scientist and helper for ground studies	2.5 to 250 km^2/day	
Gravity Prospecting	Measure differences in the earth's gravitational force	One scientist, one surveyor, and two helpers	2.5 to 250 km^2/day	Interpretation of shallow structures and lateral changes in rock density

LOCAL EXPLORATION METHODS

METHOD	PROCEDURES	PERSONNEL REQUIREMENT	AREA COVERAGE RATE	RESULTS
Interpret aerial photographs	Analyze tones, textures, shapes, patterns, location, and association	One scientist, in office	100 to 500 km^2/day	Interpretation of lithology, structure, and ground-water occurrence based on landforms, drainage patterns, land use, soil tones, and vegetation types and patterns
Detailed hydrologic mapping	Inventory all wells and springs. Determine nature of ground-water occurrence. Determine aquifer characteristics	One scientist, in field	10 km^2/day	Information on ground-water occurrence, well yields, and water quality. Description or model of targets for test drilling.
Detailed geologic mapping	Examine lithologies, orientations, and fracture patterns. Trace contacts.	One scientist, in field	2.5 km^2/day	Detailed geologic map and sections, showing lithology and structure; based on rock outcrops, soils, and vegetation.
Electrical prospecting	Measure earth's electrical potential and resistivity	Two scientists and two to four helpers	2 to 12 km^2/day	Interpretation of vertical stratigraphy, lateral changes in lithology, and structure
Seismic prospecting	Measure travel time of elastic energy	Two scientists and one to four helpers	0.5 to 5 km^2/day	Interpretation of vertical stratigraphy, lateral changes in lithology, and structure (including locations of rock fractures)
Shallow test drilling	Soil auger or jetting rig	One scientist, one driller, and two helpers	0.5 to 5 km^2/day	Lithology, porosity, and permeability of unconsolidated materials.
Deep test drilling	Cable-tool or rotary rig and geophysical logs	One scientist, one driller, and two helpers	0.1 to 1 km^2/day	Lithology, porosity, and permeability of subsurface materials. Well yield and aquifer characteristics.

BENEFITS OF REMOTE SENSING IN GROUND-WATER EXPLORATION

1. Remote sensing is a fast, cheap method of obtaining some ground-water information.

2. Interpretations of aerial photographs and satellite images can be used to select promising areas for more detailed investigations. There is less need for field work and less need for more expensive methods.

3. New or better geologic and hydrologic information might be obtained from remote sensing data. This information may aid the interpretation of data obtained by other exploration methods.

4. Remote sensing is the only practical method of recording instantaneous soil-moisture and vegetation patterns (which may be indicators of ground-water occurrence or ground-water quality) over large areas.

For these reasons, remote sensing should be considered for use in all ground-water studies.

REMOTE SENSING IN OPERATIONAL GROUND-WATER STUDIES

1. Some costs and time are needed for remote sensing. These items should be included in the study plan. Total cost and total time for the study should be lower.

2. Benefits are greatest when remote sensing is used near the beginning of a study. However, remote sensing also may be useful at later times in a study. Some information that is obtained at a point on the ground may be extended over an area by reference to aerial photographs or a satellite image, or similar features may be found elsewhere. Study plans should allow for these capabilities.

3. The need for use of special equipment or facilities should be included in the study plan.

4. Some scientists may need training in the analysis and interpretation of remote-sensing data. Plans for the use of remote sensing should include this training.

PROCEDURES TO OBTAIN GROUND-WATER INFORMATION FROM REMOTE SENSING DATA

Image Processing Steps

1. Selection and Acquisition

2. Enhancement

3. Analysis

4. Interpretation

    a. Image
    b. Geologic
    c. Hydrologic

CONSIDERATIONS FOR IMAGE SELECTION

FOR LANDSAT IMAGES BUT MOST PRINCIPLES CAN BE APPLIED TO OTHER TYPES OF REMOTE SENSING DATA

1. LOCATIONS OF IMAGE AND STUDY AREA
   a. May need more than one scene
   b. Stereo viewing may be possible because of image sidelap

2. PERCENTAGE AND LOCATION OF CLOUD COVER

3. SUN ELEVATION ANGLE
   a. Large angle for even illumination of scene
   b. Small angle for enhancement of topography by shadows

4. AMOUNT OF HAZE IN ATMOSPHERE: TOTAL SCENE CONTRAST; RANGE BETWEEN MINIMUM AND MAXIMUM FILM DENSITY IN EACH BLACK AND WHITE IMAGE (BANDS 4, 5, 6, and 7).

5. CONTRAST BETWEEN OBJECTS-OF-INTEREST AND THEIR SURROUNDINGS

6. HIGH OR LOW SOIL MOISTURE
   a. Maximum vegetation near end of rainy season
   b. Minimum vegetation near end of dry season

7. TIME OF DAY AND TIME OF YEAR WHEN TEMPERATURES (LANDSAT 3) ARE MOST LIKELY TO INDICATE DIFFERENCES IN THERMAL INERTIA (CAUSED MOSTLY BY MOISTURE CONTENT) OF ROCKS AND SOILS

8. FARMLAND IN PLOWED GROUND (BARE SOIL), GROWING CROP, MATURE CROP, OR HARVESTED CROP

9. IF A PARTICULAR TYPE OF VEGETATION IS A KEY TO GROUND-WATER OCCURRENCE, THE TIME OF YEAR WHEN IT CAN BE MOST EASILY DETECTED AND DELINEATED.

10. TRANSPARENCIES HAVE LOWER CONTRAST THAN PRINTS; TRANSPARENCIES MAY HAVE BETTER COLOR BALANCE THAN PRINTS

11. MISSING PORTION OF SCENE; BANDS WON'T REGISTER; MISSING LINES OF DATA; SCRATCHES ON FILM; MISSING PICTURE ELEMENTS

12. STRIPING PROBLEMS CAUSED BY DIFFERENCES IN RESPONSE OF THE SIX DETECTORS IN EACH BAND

IMAGE ENHANCEMENT

Enhancement almost never shows features that cannot be seen on the original images. The objectives of enhancement are (1) to make analysis and interpretation faster and easier, and (2) to help ensure that significant information is not missed or overlooked.

METHODS

1. Computer processing and color television display (or film copy) of results.

2. Photo-optical processing and display.
   a. Photography and photographic processing
   b. Color-additive viewing
   c. Color diazo processing
   d. Density slicing

PROCEDURES

All procedures, except where indicated, may be used by either digital or photo-optical processing.

1. Enlarge image; large objects are easier to see and identify than small objects.

2. Density change; objects are easier to see and identify if they are not very light or very dark.

3. Color composite image; contains, for example, most of the information in any three of the Landsat bands.

   a. Conventional; composite image may be equivalent to a color or color infrared photograph; hues generally are easy to interpret because of previous experience.
   b. Other; color and brightness may be changed to enhance objects of interest.

4. Contrast change: Increase the contrast between objects and their surroundings. Complex and segmented contrast stretches must be done by digital processing; linear stretches may be done by photo-optical methods.

5. Density slicing; generally useful only for simple problems such as area of snow cover and differences in water color or turbidity.

6. Ratios: Dividing the digital values or film densities in one band by those in another band; reduces effects of topography and differences or changes in solar illumination; also used to show changes from one time to another. Photo-optical methods may be used for simple ratios; digital techniques may be needed for more complex processing.

7. Edge and spatial frequency enhancements: Enhance (or suppress) boundaries between features which have small differences in brightness values.

8. Principal component or canonical analysis: statistical procedures that can be used to produce new images. Must be implemented by digital processing.

9. Stereo viewing; most objects are easier to identify by 3-D viewing; elevation and slope information are important for geologic and hydrologic interpretations. Must be done manually, at present.

IMAGE ANALYSIS

An image may be analyzed manually or by digital processing. Manual analysis includes the following steps:

1. Detection
2. Identification
3. Classification
4. Delineation

Analysis by computer processing is called classification, but this process includes the equivalent of detection and delineation. Identification must be done by a scientist, either before or after the classification process.

Manual analysis is based on image tone (or hue), texture, pattern, location, and association. Digital analysis uses image brightness values (the equivalent of tone) or a statistical representation of these values; a few algorithms also use some characteristic of texture. Digital analysis generally is much faster and results in more accurate separations of brightness values than can be achieved by manual analysis. However, manual analysis generally results in fewer classification and delineation errors.

The result of image analysis is information on the patterns formed by land-cover types. Land-cover patterns may infer lithologies or ground-water occurrence, but these relationships must be proven on the ground.

IMAGE INTERPRETATION

Shapes and patterns on an image determine the landscape characteristics:

1. Landforms -- Recognizable physical features on the earth's surface; formed by the size, shape, location, and association of topographic elements in the landscape.

2. Drainage -- Basin size and shape, drainage pattern, drainage density (texture), valley geometry, and channel position and geometry.

3. Cover types -- Size, shape, pattern, location, and association of landscape cover elements.

4. Lineaments -- Straight to slightly curing lines, formed by any combination of landscape elements.

5. Curvilinears -- Symmetrical lines with circular, elliptical, and arcuate shapes, formed by any combination of landscape elements.

An image interpretation can be used for geologic and hydrologic interpretations. Keys to hydrologically significant landscape characteristics are useful to ensure that all available information is obtained from an image.

GEOLOGIC INTERPRETATION

A geological interpretation includes four elements or phases, which depend on the relationship between surficial landscape features and the processes that produced these features:

1. An interpretation of surficial lithology, stratigraphy, and structure.
2. An interpretation of surficial geomorphic processes.
3. An interpretation of subsurface geologic relationships.
4. An interpretation of sedimentary, diagenetic, metamorphic, igneous, and tectonic processes.

The result of a geologic interpretation is a three-dimensional, conceptual geologic model which explains the results of image interpretation. It also may indicate the possibility of additional geologic features; the finding of such features on the image or on the ground is partial confirmation of the model.

HYDROLOGIC INTERPRETATION

A ground-water interpretation builds on the conceptual geology by inferring:

1. Primary and secondary porosity and permeability characteristics of the materials.
2. Aquifer boundaries.
3. Depth of water table and probable saturated thickness of aquifers.
4. Relationships between topography and hydrology; recharge and discharge areas.
5. Relationships between ground and surface waters.
6. Estimates of well production, based on previous experience.
7. Estimates of ground-water quality; fresh or saline.

The results are a hydrologic model of aquifer limits, ground-water occurrence, aquifer operation, and ground-water quality. Other techniques then may be used to confirm this model or to indicate the need for changes or revisions.

A REVIEW OF THE CURRENT STATUS AND FUTURE NEEDS FOR REMOTE SENSING TRAINING AND TECHNOLOGY TRANSFER IN LATIN AMERICA

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Background Information

Since the beginning of the ERTS Program in 1972, the United States, through NASA, has been in contact with the Latin American countries, so that they too may benefit from data collected by satellites and other airborne craft. In 1968 the United States agreed with Mexico and Brazil on an experimental remote sensing program to train technicians from other Latin American countries; NASA has also helped Mexico to establish an important remote sensing center which uses satellite imagery to inventory and plan its resources.

Brazil has established two receiving stations of satellite imagery which also benefit neighboring countries. In 1971, the Directors of the National Geographical Institutes of the Latin American countries met in the Canal Zone, Panama, where they expressed the need to utilize satellite imagery as a means to better identify and study their land resources. As a result, the Inter-American Geodetic Service (IAGS) of the Canal Zone informed NASA of its willingness to serve as liaison so that the Latin American countries could use skylab images.

Besides NASA efforts, there are also international and technical development agencies assisting various Latin American countries. For example, the United Nations has been cooperating since 1970 through its space and technology application program in aspects related to information in the latest developments and the application of space technology practices.

Since 1971, the Program has held various meeting of experts, seminars and training courses in different countries.

Since 1974, the Science and Technology Office of the Agency for International Development (AID) has shown continued interest in the training of technicians from developing countries in remote sensing aspects. In addition AID has specific projects underway in various countries. Thus, Bolivia has been utilizing LANDSAT images to assess iron deposits and changes in land use. In general, AID programs abroad consists mainly in training and technical assistance to LANDSAT image users.

In January 1976, the Inter-American Development Bank (IDB), upon request of the Central American countries, started a project in order to carry out a regional study of natural resources based on the use of remote sensing techniques.

IICA's Project in the Field of Remote Sensing

The VII Inter American Conference on Agriculture, held in Tegucigalpa, Honduras, September 5-10, 1977 recommended that:

The Inter American Institute of Agriculture Sciences, IICA-OAS, foster the creation of an Inter American Program to provide the countries of the region with support in their efforts to make the most of remote sensor information to inventory, analyze and evaluate existing natural resources. Efforts would also be made to seek the improved management, planning, administration and maximum

utilization of these resources.

The Program should have the following objectives:

a. To inventory natural resources as per priorities established and zones selected by each country;

b. To carry out regional land use studies;

c. The localization and delimination of existing agricultural forestry, soil, mining, hydrological resources and zones subject to flooding or affected by erosion, over-grazing and over-cultivation;

d. The definition of agricultural, forestry, animal husbandry and mining potentials.

To achieve these goals IICA should:

a. Train personnel at the different levels in scientific and technical aspects as needed for the adequate interpretation and use of information which has been made available through the use of remote sensors.

b. The coordination and exchange of information between interested countries, between specialized institutions, and between the countries and the institutions that work with remote sensing images.

c. Provide advisory services to the Governments of the region on:

   (i) organization of the necessary operational offices or units to get the planned work underway;

   (ii) preparation of the necessary national or regional projects for the same purpose.

For the purpose of this Program the term natural resources includes whatever man finds of value in his physical environment such as soil, water, vegetation, minerals, energy sources and terrain.

The process of economic development consists largely of organizing the development and productive exploitation of natural resources in the interests of the entire community. Therefore, in order to make better use of these resources the countries need to know what resources they have, where they are and what the surrounding physical environment is.

For many developing countries, this basic knowledge is limited, fragmentary, dispersed and less than adequate for the purpose of sound national development. At present, most developed and developing countries are seeking to acquire better resource information; this can now be obtained more efficiently with the aid of modern methods and technologies.

A large number of countries have already entered in the remote sensing arena, and surprisingly, the large majority belong to the less developed ones. No country in Latin America or the Caribbean has adequate facilities, trained personnel or institutional capability at present to utilize or take full advantage of the information furnished by LANDSAT or other future satellites. This situation would seem to excessively widen the existing technological gap between the industrialized or developed countries, which are able to assimilate any new technology, technically and operationally at a faster rate than the developing countries.

However, and strange as it may seem, remote sensing techniques appear to offer a better prospect of utility to the developing countries than to the industrialized ones, though it will require a coordinated and sustained program of assistance to improve their technical and physical capabilities to identify

and delineate sound projects for research and development and to obtain and help allocate financial resources of both bilateral and multilateral agencies; this is precisely what IICA hopes to achieve in Latin America and in the Caribbean.

IICA's Actions

No country or regional programs can be delineated without a knowledge of existing and potential conditions, both technical and physical in the countries involved.

Therefore, the first action carried out by IICA, besides that of organizing a technical working group, was to make a survey of the current status in Latin American and Caribbean countries in the field of remote sensing. Secondary information sources provided a first approximation of information on the "state of the art", though it was rather incomplete showing a need for a more thorough investigation, preferably in situ.

Consequently, a decision was taken to let the members of the working group visit selected countries individually and interview selected persons in key national agencies.

The countries visited were:

Region 1: Paraguay, Chile, Argentina

Region 2: Panama, Bolivia, Peru, Ecuador, Colombia and Venezuela

Region 3: Guatemala, Haiti, Dominican Republic, Jamaica and Mexico

Region 4: Honduras, El Salvador and Costa Rica.

A questionnaire was prepared in order to simplify data collection by the working group members in the countries. The questionnaire was intended to identify the following main aspects:

I Current activities in remote sensing

II Planned activities in remote sensing

III Identified needs

IV Possible role of IICA

I. Current activities in remote sensing

1. Technical personnel

Most of the national agencies qualify as users of remote sensing information while very few are producers or processors of remote sensing data, such as the National Geographical Institutes or governmental agencies responsible for promoting and coordinating national research activities, namely the National Councils for Space Research in Argentina and Brazil. The great majority of national agencies use conventional aerial photography and scarcely use other advanced remote sensing techniques, such as SLAR or satellite imagery.

Consequently, technical personnel are adequately to highly skilled in cartography, photogrammetry and photo interpretation techniques. The Central American countries have also a few technicians with some training at Purdue University (LARS) within the IDB training program, in digital analysis and interpretation of Landsat images.

Mexico is probably the country where user agencies as well as research agencies have highly trained personnel in applying digital techniques for interpretation of Landsat images.

Brazil's highly advanced program, located at the National Institute of Space Research (INPE) is well equipped and has a well trained staff in Landsat imagery interpretation; INPE operates a ground station which records more than 350 images a day providing data to various national agencies and to neighboring countries as well.

Finally, Bolivia appears to be the country that makes the best use of Landsat imagery for agriculture, geology and mining purposes, with a highly trained inter-disciplinary staff, mostly trained abroad. Two centers have been operating in Latin America for quite a few years, training personnel in various remote sensing techniques. One is operated by the Inter American Geodetic Service (IAGS) at the Canal Zone, Panama, which gives basic instruction in conventional aerial photography, Landsat imagery, space photography (skylab) and SLAR through short courses, seminars, conferences, etc.

The other center is the Inter American Center of Photointerpretation (CIAF) located in Bogotá, Colombia. This Center is attached to the Ministry of Public Works, and since 1967 has been providing training to technicians from all over Latin America in photointerpretation, and more recently in the basics of other remote sensing techniques through regular courses, nine months duration; besides other special courses of shorter duration. CIAF probably trained over a thousand technicians. CIAF receives technical support from the International Institute for Aerial Survey and Earth Sciences (ITC) of the Netherlands to supplement CIAF's capabilities in various areas of specialization.

2. Areas of use

Remote sensing techniques in Latin America and in the Caribbean have a variety of uses, though mainly in the area of natural resources, namely forest inventories, land use studies, resources conservation, water resources, geology, mining, and climate. Other uses include land settlement, disaster assessment, water pollution and others. Mexico does research in the use of digital interpretation on Landsat images for purposes of land use, land settlement, soil salinity, fertilizer use, crop yields and water resources.

3. Infrastructure

Infrastructure in terms of equipment and facilities necessary for the production and/or utilization of remote sensing data and information is quite variable according to the level of work performed. Where photointerpretation is the prevalent technique, equipment and facilities can range from the basic minimum equipment required to highly sophisticated and modern units. Additional basic equipment is existent where other techniques are in use, namely radar and/or satellite imagery, such as digitizer computers and others. Few countries, namely Bolivia, make use of facilities abroad, i.e., LARS center in the United States to develop work based on satellite imagery, since no such facilities are available in the country.

II. Planned activities in remote sensing

Training of personnel appears to be the main concern in the majority of the countries, in order to fulfill the needs to conduct projects presently underway, or future projects to be developed.

Undoubtedly, there is pressure in the countries to train personnel as a consequence of the increased awareness of the potential uses of remote sensing techniques, especially as a tool for natural resources inventories. Formerly, training was an unplanned activity and subject to the donations of occasional scholarships which were given out somewhat haphazardly depending on who was available at that time.

The area of training received depends on the priorities established by each agency in the country, whether it is for agricultural purposes, mining, fishery or other.

Low priority is given to planning for future infrastructure, perhaps due to the fact this is a very costly item, that cannot be financed by the agency itself and consequently outside resources are needed but not always specified, when plans are prepared.

III. Identified needs

In every country the major identified need is training of personnel at all levels including administrators and high level-decision makers. No clear differentiation is made regarding the training needed or which techniques to be trained on, which clearly shows the need for training in the whole range of techniques available.

As to where to be trained and for how long, there is usually not much choice; in fact and as already stated before, training abroad, is subject to availability of scholarships and to the technicians present at that moment, and very rarely is training a planned activity as to where, what for, and who is to be sent.

Various institutions in Latin America are well known as training centers for national purposes as well as for countries abroad, chiefly in the field of conventional aerial photography, cartography and photogrammetry; some of them have also started giving basic training in radar and satellite imagery, digital data interpretation and other advanced techniques. Examples of this type of Centers are the Military Geographical Institute in Chile, the National Councils for Space Research in Argentina and Brazil, the IBM Scientific Center for Latin America in Mexico, the Inter American Geodetic Service in Panama and the Inter American Center of Photointerpretation in Colombia.

Again, training is not a priority activity for many institutions; and advantage for purposes of training is taken only when seminars or other kinds of technical meetings on these subjects are scheduled on a national or international basis.

An exception perhaps, is the CIAF Center in Bogotá, Colombia, which has a regular training program on a yearly international basis for Latin American applicants, besides additional short courses programmed mainly for national applicants and/or upon request of official agencies. Technical and financial support is the second important need specified by the countries, mainly for project identification, delineation and implementation. Potential projects are basically in the use of satellite imagery for natural resources inventories as a basis for agricultural and rural development schemes.

Directly linked to the above is the need for organizing the operational offices or units to support the work planned.

Coordination and exchange of information at all levels within each country and between countries appear to be the third major need which clearly emphasizes the need for creating a national and regional mechanism to fulfill existing gaps.

IV. Possible role of IICA

The countries have identified the possible role of IICA in the field of remote sensing in Latin America and in the Caribbean as the organization capable of promoting, developing and channeling the means to ensure the improvement of country capabilities in remote sensing techniques towards the identification and knowledge of their resources and their better utilization.

Consequently, IICA should provide or develop training programs for country or regional agencies in the various remote sensing techniques.

IICA should also assist in the inventory of the production and use of remotely sensed data and upgrade the skill levels involved in order to make possible the formulation of a more effective and less costly organizational structure for data production and use.

IICA must also study the current institutional structure with respect to natural resources data and propose steps for purposes of reorganization.

Also, IICA should provide, or cause to be provided, the necessary means to ensure adequate exchange of information between agencies and countries in the area.

Based on the information collected in the countries, the working group was able to identify certain relevant problems that one way or another appear to play an important role in knowledge and utilization of remote sensing techniques (See Annex).

Taking into consideration the identified problems, the total amount of information collected by the working group and other additional information that might be obtainable from secondary sources, IICA will be in a position to prepare a sound program on the use of remote sensing to study and evaluate natural resources in Latin America and in the Caribbean.

The Program should be submitted to its Board of Directors by July-August, 1979, in order to obtain necessary approval to proceed to a second phase; namely, the acquisition of funding to implement activities in this area.

The mechanisms and strategies to be followed are at this point under careful study.

ANNEX I

Main common problems in the use of remote sensing identified in the countries

1. Scarcity of qualified human resources (technical).
2. Lack of planning for training personnel.
3. Lack of knowledge of the possible uses and limitations of remote sensing (techniques: current, future and being researched).
4. Lack of applied research to actual problems in the countries.
5. Limited basic infrastructure (equipment and physical facilities).
6. Lack of and adequate mechanism for the exchange of information:

   Between producer agencies
   Between producer and user agencies
   Between user agencies
7. Limited financial resources.
8. Lack of knowledge of existing centers and sources for technical assistance.
9. Limited capability to identify, delineate, and evaluate programs and projects on the use of remote sensing at the national and regional basis.
10. Lack of coordination between national and regional institutions working in remote sensing.
11. Lack of coordination between international agencies working or related to remote sensing.
12. Lack of planning and definite policies on the use and management of natural resources.
13. Scarcity of literature on remote sensing, in Spanish.

SUMMARY

The document here presented focuses on the possible role of the Inter American Institutes of Agricultural Sciences, IICA-OAS, in a program on the use of remote sensing to study and to evaluate natural resources in the countries of Latin America and the Caribbean, as a consequence of the mandate of the VII Inter American Conference in Agriculture, held in Tegucigalpa, Honduras, September 5-10, 1977.

Objectives of the Program should be:

a. To inventory natural resources according to priorities established and zones selected by each country.

b. To carry out regional land use studies.

c. The localization and delimitation of existing agricultural forestry, soil, mining, hydrological resources and zones subject to flooding or affected by erosion, over-grazing and over-cultivation.

d. The definition of agricultural, forestry, animal husbandry and mining potentials.

A working group was organized by IICA to advise in the preparation of the Program. In order to gather the information required, countries in Latin America and the Caribbean were visited by group members. The information thus collected identified the following aspects:

a. Current activities in remote sensing

b. Planned activities in remote sensing

c. Identified needs

d. Possible role of IICA

Each of these aspects was in turn discussed. Based on all information gathered about country activities in remote sensing, relevant problems common to all countries were identified. In turn, based on those problems IICA will be in a position to elaborate a sound program, capable to assist country members to better use remote sensing techniques to identify, study and evaluate their natural resources.

REMOTE SENSING TECHNOLOGY AND NEW DEVELOPMENT TRENDS IN LATIN AMERICA*

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ABSTRACT

Visual and digital analysis of remotely sensed data provided by earth resources satellites are being used in many development projects in Latin America. By outlining the basic remote sensing activities which have taken place in recent years and continue to increase in the continent, this paper surveys the progress achieved by the countries of the region and points out new development trends occurring in various sectors of these nations.

OVERVIEW

Interest in the development and rational utilization of the natural resources of Latin America has stimulated over the past decades the involvement of various United States federal and international organizations in remote sensing activities. This institutional support aimed at implementating national and regional development schemes was conceived in terms of promoting regional economic stability and steady rate of growth. Constant efforts being made to use modern techniques of remote sensing to obtain data required for preparing development projects have created new development trends in Latin America. In maintaining and increasing these trends, Latin America will be able to increase its participation in worldwide economic progress.

*Taken from paper presented at the Twelfth International Symposium on Remote Sensing of Environment, Manila, Philippines, April, 1978.

THE UNITED NATIONS ROLE IN SATELLITE REMOTE SENSING

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Introduction

Since the early days of the space age, the United Nations has exercised a unique role as a focal point for international cooperation on the peaceful uses of outer space. It has also been the forum for the development of an entire new body of law governing the exploration and use of the world's last frontier - outer space.

International cooperation in the field of outer space activities has followed technical progress closely. This was all the more so as it became soon evident that any potential application of space technology could only be beneficial if its inherent international character was recognized. The need for a fundamentally international approach towards the many questions and problems of outer space was soon generally recognized.

Outer Space Committee

As most of you are aware, the United Nations is an inter-governmental body consisting of 151 Member States as at present. The General Assembly is the supreme body to make decisions in accordance with the wishes of the Member States. Recognizing the international importance of the prospect of the conquest of outer space and the need for international cooperation in an arena that clearly transcended national boundaries, the United Nations got involved in dealing with matters connected with outer space activities. For this reason the General Assembly at its 14th session in 1959 adopted a resolution which established a Committee on the Peaceful Uses of Outer Space. This Committee which had 24 Member States to start with was expanded gradually and it now consists of 47 Members States who are elected from various regions of the world.

The present Committees' tasks are to review the scope of international cooperation in the peaceful uses of outer space, to devise programmes in the field which could be undertaken under UN auspices, to encourage continued research and disseminate information on research, and to study legal problems arising from the exploration of outer space. There are various sub-bodies of the Committee each of which has the same membership as the Committee. The Scientific and Technical Sub-Committee deals mainly with the exchange and dissemination of information, the encouragement of international programmes of space research, and making the results of exploration accessible to countries which are not engaged in it. This Sub-Committee also operates in education and training in the field of space and in the evaluation of the work done by the specialized agencies engaged in space research. The Legal Sub-Committee is entrusted with the task to study legal problems which may arise from the exploration and use of outer space. The new dimension, like those which man penetrated earlier, could not remain a legal vacuum.

On 20 December 1961, the General Assembly adopted a resolution initiated by the Outer Space Committee in which it declared that:

- "The exploration and use of outer space should be only for the betterment of mankind and to the benefit of states irrespective of the stage of their economic or scientific development;"

- "States should be guided by the principles:

  (a) International law including the Charter of the United Nations applies to outer space and celestial bodies;

  (b) Outer space and celestial bodies are free for exploration and use by all states in conformity with international law and are not subject to national appropriation".

The two main landmarks in the legislative work of the United Nations as the focal point in the development of space law are the Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space unanimously adopted by the General Assembly on 13 December 1963, and the Treaty on Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space including the Moon and Other Celestial Bodies. Consequent to this, three more international agreements to implement the basic rules laid down in the two instruments just mentioned were established. These are the agreements on the Rescue of Astronauts, Return of Astronauts and the Return of Objects Launched into Outer Space, the Convention on International Liability for Damage Caused by Space Objects, and the Convention on Registration of Objects Launched into Outer Space.

Current items on the agenda of the Sub-Committees

Presently the substantive items on the agenda of the sub-committees are:

- questions relating to remote sensing of the earth by satellites;
- consideration of the United Nations Programme on Space Applications and coordination of outer space activities within the United Nations system;
- question of convening a United Nations Conference on Outer Space;
- Examination of the physical nature and technical attributes of the geo-stationary orbit;
- Definition and delimitation of outer space.

I do not wish to go into detail over all the above items in this presentation. Rather, I would like to deal with the questions relating to remote sensing and the convening of a United Nations Conference on Outer Space as these are only relevant to the topic of my presentation. In particular, I would like to mention some of the efforts made by the United Nations to promote education and training to the developing countries which concerns the transfer of technology.

Remote Sensing

Ever since experimental satellites were launched for the survey of earth resources and its environment using a variety of instruments, it became apparent that it involves a number of sovereign states whose resources were sensed. Naturally, it was a matter of concern to many who, although aware that it helps to a large extent to explore their resources in this way, had some anxiety to ensure their own security. The questions were: What is remote sensing from space: How does it contribute to the development of countries using it? What are the likely problems that this might create for national security if any? And, what is the role of the United Nations and its bodies in assisting Member States to derive benefits from this technology during the experimental and operational phases of remote sensing systems and so on. These questions arose in the committees when remote sensing satellites started orbiting the earth.

Transfer of technology

In 1969 the General Assembly first took note of "remote earth resources surveying techniques" and asked the Committee to study the possibility of

international cooperation in this field so as to assure that, as the practical benefits of the technology are achieved, they were made available to both developed and developing countries. Since 1970, the legal, scientific and technical aspects of the development of remote sensing have been given extensive consideration by the Committee and its two Sub-committees. The General Assembly in 1971 noted that "the potential benefits from technological developments in remote sensing of the earth from space platforms could be extremely meaningful for the economic development of all countries, especially the developing countries and for the preservation of the global environment". A special working group of the Outer Space Committee was established in 1971 to deal with the various questions related to remote sensing as stated above and to make specific recommendations of the Committee.

This working group, which was attended by experts representing a number of countries, organizations and agencies dealing with remote sensing, had series of meetings in which, in depth consideration was given to all aspects of remote sensing from space. This working group found in 1974 "that remote sensing of the earth from space has very great potential for meeting national, international, regional and global requirements for data relating to earth's natural environment". It is known that among the fields to benefit from the technology would be agriculture and forestry, geography, geology, mineral resources, hydrology and water resources, oceanography and mineral resources, study of the atmosphere and meteorology. Their recommendations suggested that all possible assistance should be given to the developing countries in order to benefit from this technology, and, in particular they emphasized the need to give priority for education and training of personnel.

The Scientific and Technical Sub-Committee found that satellite remote sensing systems will one day, like weather and communications systems, become an integral part of the planning and production of national economies, and that international cooperation would be essential at that stage as the only cost-effective approach for the majority of countries. Further detailed discussions have taken place in both the Committee and Sub-Committees on questions related to the use of remote sensing from space.

Now I would like to mention some important topics that were discussed:

1. Dissemination of data. At first the Committee defined data and information for the purpose of their own discussions. The data was taken as the primary data obtained by the space-borne instrumentation and information as the analysed information obtained from the data. The question of wide dissemination of data collected by the sensing countries to the various users irrespective of which country they belonged to, has been under consideration. One opinion among members is that there should be free dissemination of data to potential users who may be interested in receiving them. Another opinion is that the data of the sensed country may be distributed to a third country with prior consent of the sensed country only. Those who advocate free distribution of data without any restriction opined that it does not involve any danger to the sensed country and in fact it would be in the interests of all to have such information instead of only the sensing country. They also stated that this will be in conformity with the Outer Space Treaty of 1967 which, according to them, had provided for free exchange of information on activities in outer space. However, the other opinion, which was shared largely by the developing countries and the socialist countries, is that the data obtained by remote sensing satellites could contain information of economic and strategic value of their natural resources and, in view of this, such information should only be given to a third country with the consent of the sensed country.

In this connection a proposal was made to classify remote sensing data into three categories: global, regional and local - based on spatial resolution. During the discussions on this subject several views were expressed that one should consider not only the spatial but also the spectral and radiometric resolutions or a trade off among these in the design of optical remote sensing

instruments. However, it is generally agreed that at this time is is not easy to classify the data based on any one criterion. However, there appears to be a general view that primary data within a limit of photographic resolution of 50 m may be freely exchanged and those which are of finer resolutions should be discussed further.

2. Coordinating role of the United Nations. For a number of years the Committees were considering the extent to which the United Nations can play a coordinating role in future operational remote sensing systems fostering further international cooperation in the field of remote sensing. In this connexion, a proposal was before the Committee to create a panel of experts on remote sensing, representing the launching states, the user states and other specialists. Having discussed the matter in depth the Sub-Committee concluded that it was not in a position to recommend the establishment of the proposed panel at this time. Consequently, the Sub-Committee urged those nations or agencies operating or planning ground or space segments of satellite remote sensing systems to continue and expand the cooperation and coordination of their activities.

If such a panel is agreed upon at a later stage, it may undertake the following task: study and report on existing and proposed formats of data and index systems; procedures for exchange of data and information among Member States and data users; procedures for information retrieval and other related matters. The panal may also examine and report on the characteristics of future systems based on experience to date.

3. International Cooperation. The members of the Sub-Committee are of the opinion that remote sensing from outer space should be carried out with the greatest possible international cooperation. In this context the need to provide assistance to developing countries was recognized. The United Nations, through its space applications programme, and the remote sensing centres of the Food and Agriculture Organization (FAO) and the Centre for Natural Resources, Energy and Transport (CNRET) and other interested agencies could play an important role in providing such assistance.

The Committee recommended the establishment of two international centres on remote sensing for the purpose of providing large-scale technical assistance to Member States especially the developing countries. One such centre is the expansion of the remote sensing unit of the FAO in Rome dealing with agriculture and related resources and the other at the CNRET of the Department of International Economic and Social Affairs (IESA) at United Nations Headquarters in New York, to deal with non-agricultural resources and related subjects. These centres could have four main functions: (i) to catalogue, store and interpret remote sensing data providing facilities for examination by interested parties; (ii) to circulate available information and to direct requests by countries for remote sensing data to proper sources; (iii) to provide impartial advice and assistance to technical assistance projects, Member States and United Nations bodies; (iv) to organize specialized training courses for users, managers and decision makers.

These international centres could undertake training courses in various disciplines where remote sensing data could be applied, and also develop capabilities for on-the-job training.

4. United Nations Programme on Space Applications. The need for a widespread exchange of information regarding space research and applications of space technology was recognized by the United Nations at an early stage of its activity and it was considered essential to call for an international scientific conference for this purpose. The first United Nations Conference on the Exploration and Peaceful Uses of Outer Space was held in August 1968 in Vienna. It was conceived not only to be a meeting for exchange of information on a world-wide scale but also to examine the practical benefits of space exploration and the opportunities available for international cooperation with special

reference to the needs of the developing countries. It was attended by 78 Member States, nine specialized agencies and four other international organizations, and provided an excellent opportunity for dissemination of information on practical applications of space research.

Following this conference, the Scientific and Technical Sub-Committee decided to promote more energetically international cooperation in the applications of space technology for the benefit of developing countries. A programme designed to create awareness of the practical applications of space technology and to provide training and education in this field was initiated under the guidance of an expert on space applications within the Outer Space Affairs Division in 1970. During the past 7 years the UN has sponsored a world-wide programme of panels, seminars and workshops to inform governments of developing countries of the benefits available through the applications of space technology for national development and international cooperation and for transfer of relevant technology in space applications. These seminars have dealt with remote sensing, meteorology and the use of satellites for communications, education and development. Over 1,400 participants from developing countries have attended these programmes held in various parts of the world on a regional or inter-regional basis.

The first phase of this programme was devoted to creating awareness on the status of the art and dissemination of information among the developing countries and also to provide information on the activities and types of assistance offered by the various bodies within the UN system. In the second phase of this programme, which is now current, the principal focus of its activity is on transfer of technology to the developing countries, particularly in the area of remote sensing from space. This programme is conducted with the assistance of Member States, developed and developing, and a number of specialized agencies and other bodies of the UN system. Emphasis is given to the particular needs of developing countries and training, using inexpensive and simple equipments. Funds allocated by the UN and other specialized agencies are used to provide financial assistance to participants from developing countries. Experts from various user countries serve as instructors in these seminars and workshops.

5. United Nations Conference on Outer Space. It has been a decade since the first UN Conference on the Exploration and Peaceful Uses of Outer Space was held. This decade has seen rapid progress and growth in space exploration, the development of space technology and its applications. Over the years, a confidence has been attained in the use of space technology, and the larger areas of potential use have become clear. There is a need to assess these developments, to exchange information and experience on their present and potential impact and to assess the adequacy and effectiveness of institutional and co-operative means of realizing the benefits of space technology. There is a need to examine the requirements such as training and infra-structure for improved utilization of available applications, the priority needs of developing countries and present obstacles for optimum utilization. The Outer Space Committee having examined these needs recommended to the General Assembly that a second United Nations Conference should be convened at an appropriate date and this conference should focus on needs of global nature and utilization of space technology with respect to regional and economic development, education, communication, resources management and environmental protection.

The General Assembly at its 33rd session held in 1978, endorsed these recommendations of the committee to convene a second UN Conference on Exploration and Peaceful Uses of Outer Space and asked the Committee on the Peaceful Uses of Outer Space to act as the preparatory committee for the conference. Subsequently, the Scientific and Technical Sub-Committee, acting as the advisory body to the preparatory committee, which met in New York during February 1979, has made recommendations regarding the agenda of this conference, and necessary preparations for the organization of the conference. The agenda has the following topics:

(a) State of Space Science and Technology; review and projection of the current and future state of space science and technology and its applications, and evaluation of major developments in this area and their usefulness for development so far;

(b) Applications of Space Science and Technology; to undertake evaluation of the current and potential applications of space technology, to examine possibilities and mechanisms, choices and utilization of space technology at various stages of technological growth, to examine existing infra-structure in developing countries and appropriate measures to augment their capabilities to develop space technology etc.;

(c) International Cooperation and the Role of the United Nations; consideration of existing bilateral and multi-lateral cooperation, activities of the UN and other international organizations in outer space matters, and evaluation of the role of the UN in this connexion.

The venue and date of this conference is not yet decided. At the last meeting of the sub-committee, India and the Soviet Union offered to host the second UN Conference which may possibly take place in the second half of 1982 or in early 1983. I believe this conference would be an appropriate forum for all countries interested to discuss specific issues related to the peaceful uses of outer space, and, to consider appropriate action to be initiated by all concerned. It is possible that prior to holding this conference the UN would assist Member States in organizing regional conferences to focus their attention on the various issues connected with space science and applications of space technology relevant to their own needs.

6. Legal Aspects of Remote Sensing. Various legal issues connected with the use of remote sensing through satellites are being considered by the Legal Sub-Committee. These mostly relate to the questions concerning dissemination of data and the principles to govern operational remote sensing systems. The question of definition and delimitation of outer space is also a subject of consideration by this sub-committee. As of now there is no legal definition of "outer space". Some countries have expressed views that it is desirable to have such a definition while some feel that there is no need to do so. The various criteria on which this could be based are being discussed in the sub-committee.

Conclusions

Any technological innovation leads to changes in the way man lives and works. Some of the changes may be inevitable and, all too often the possibilites of technology influences man's condition in a deterministic way. Yet, there are choices to be made in building, adopting and moulding new technologies to desirable ends. And these ends need not be universally the same.

The earthbound uses of space technology pertain largely to the areas of communications and remote sensing. The novelty of both these applications arises out of the quality that a platform in space enables us to see a large part of the earth at one time. One can also get a synoptic view in various wave lengths of a large segment of land, its features, land forms, clouds, water, snow, soils, plantation, crops and forests; we call this remote sensing of resources. Opportunities of space have something special to offer the developing countries.

Satellite remote sensing provides us with a potentially powerful tool for socio-economic development and for extending cultural horizons of man if carefully developed and inter-faced with relevant innovations. On the ground it can become an "appropriate" technology of revolutionary significance for all developing countries. This special development will require the active participation of developing countries in wide ranging creative efforts at a total systems level, encompassing science, technology, management, human inter-face and utilization. While one thinks of transfer of technology, one should consider

the development of technology at the country's level first and the transfer of appropriate technology next.

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WHAT'S APPROPRIATE ABOUT REMOTE SENSING TECHNOLOGY?

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Is modern remote sensing a "high technology" and if so, is it "appropriate" for use in developing countries? Should developing countries be engaged in acquiring remote sensing facilities and expertise and should the industrial countries of the North promote its transfer to the less-developed Third World countries? There are many that would suggest that remote sensing is a highly advanced technology and, therefore, by definition, inappropriate for use in developing countries. However, recent experience indicates otherwise. The results of an AID-sponsored Small Grant Program demonstrate tha remote sensing can be and often is an intermediate and entirely "appropriate" technology for developing countries. As such, the technology can make significant contributions to national economic development, or at a minimum to the planning and monitoring of such development. In answering the question, "What's appropriate about remote sensing technology?" we must first define what we mean by the terms "appropriate" and "technology".

Definitions

First: technology. (It's amazing the different ways the term is used and frequently misused.) Technology is a technical method or capability for achieving a practical purpose. In other words, it is a methodology or system for employment of tools (or process) to accomplish some task or create some product. Technology is not a passive state, an inert object or a philosophy. Technology is the working arm of human experience and scientific inquiry, but is essentially different from either by virtue of its direction at a material result -- a result that is identifiable and of practical significance.

If we talk about "technology" but cannot identify a product or practical result, then it's not technology; it may be engineering, it may be science, it may be research or philosophy -- it may be good, but it's not technology. Technology is not a demonstration; it's not a building, not a corporation, not a seminar or research report.

Technology is a system for pumping groundwater, generating electricity, growing more food or perhaps locating oil. Technology may be tangible, such as a plow or dam, or intangible, such as a new crop rotation scheme. The point is that technology is a dynamic activity that requires an identifiable practical result -- it's not knowledge for the sake of knowledge or the process of acquiring new knowledge. It is not the institutionalization of some activity that has no definable result.

Now, "appropriate". This is a more difficult term and one that clearly means different things to different people, legitimately it is a value judgement. But for our purpose, let's look at "appropriate" in the sense that the so-called "appropriate technology movement" defines it.

"Appropriate technology" or simply AT, is a child of the "small is beautiful" movement that originated in the late 60s. In that movement the late British economist, E. F. Schumacher and his colleagues began to question the role of scale and infrastructure in relation to the objectives of using technology. Specifically, Schumacher said that you help people by developing technologies that they can use directly. This means concentration on

improving such primary economic activities as subsistence farming, nearshore fishing, and small-scale manufacturing. His point was that the scale of the technology must be related to the scale of the institution and social organization of the people you are trying to help, and not vice versa. In applying this definition of "appropriate" several principles emerge:

1. AT is adaptable and location specific -- different societies and cultures have different environments and ways of satisfying their basic needs for food, shelter, and clothing. The technology must be adapted to local conditions to be successful. Africa is not Asia and Asia is not Latin America. The technology must be designed or adapted to reflect these differences.

2. AT is labor intensive and capital saving. Since capital is the most scarce resource and human labor is the most plentiful resource in most developing countries, the technology should be designed to take advantage of that fact. Maximize the local inputs and especially create jobs.

3. AT is directed at helping the poor majorities directly. For that reason it is sometimes perceived as subversive by elites in power and labeled by them as "second rate technology". Appropriate technology tends to decentralize the means of production, is oriented toward primary production using local resources, and often produces products locally consumed.

Recently many politicians and social reformers have come to use the term "appropriate technology" as a catch phrase for a variety of social, economic, and political programs (almost a religion). They claim that "inappropriate" technologies or technological failures are the proof of bad social, economic, or political philosophies. The result is that irrelevant issues such as the pedigrees of the technologies (traditional versus new, northern versus southern, indigenous versus imported) and the "modivations" of the users become intertwined with such legitimate issues as: does the technology work? who benefits? and what is the effect of the technology on the society or environment?

The Grant Program

Is remote sensing an appropriate technology? The answer is: Not always, but yes it can be. Specifically remote sensing can 1) rely primarily on local resources; 2) be adapted to specific local conditions and requirements; 3) provide products of considerable use and importance; and 4) ultimate effect the well being of the poor majorities. These conclusions are based on the results of the AID-sponsored Small Grant Program to test and promote applications of remote sensing technologies by developing-country individuals and user agencies.

In 1974 U.S. AID initiated an experimental Small Grant Program directed at transferring "appropriate" remote sensing technology to developing countries. To date the Program has provided 13 grants and technical assistance to investigators in 11 countries: Bolivia, Chile, Peru, Haiti, Lesotho, Zaire, Bangladesh, Pakistan, Philippines, Sr. Lanka and Thailand. The individual results have been generally successful; eight of the ten grant projects completed to date have provided locally-generated information that has been found useful for national development planning. Equally important, grant projects have generated efforts on the part of local users to continue to use certain remote sensing technologies. A list of the AID grant countries, the grantee organizations, and the projects are listed in Table I.

TABLE I. AID GRANT PROJECTS

COUNTRY	GRANTEE	PROJECT
South America:		
Bolivia	Dr. Carlos Brockmann Servicio Geologico de Bolivia (GEOBOL), La Paz	Detect and identify iron ore deposits of economic significance in eastern Bolivia.
Chile	Messrs. German Errazuriz & Arnoldo Ortiz-Riveros Instituto de Investigacion de Recursos Naturales (CORFO), Santiago	Inventory the natural resources of Tarapaca and Antofagasta Provinces.
Peru	Mr. Walter Danjoy Arias Oficina Nacional de Evaluacion de Recursos Naturales (ONERN), Lima	Identify and map the extent of the economically important Aguaji Palm in the eastern jungle.
Africa:		
Lesotho	Messrs. Anthony Jackson & Edwin M. Seitlheko National University of Lesotho, Roma	Investigate snowfall, drainage patterns, and vegetation in relation to soil conservation requirements.
Zaire	Dr. Sendwe Ilunga, Director, ERTS-Zaire Bureau de President, Kinshasa	Develop annotated Landsat images as cartographic substitutes by Institute Geographique du Zaire.
South Asia:		
Bangladesh	Prof. M. I. Chowdhury, Chairman, Department of Geography, Jahangirnagar University, Savar	Provide agricultural and land-use information for further development of the Haor areas in northeast Bangladesh.
Pakistan	Dr. M. Shafi Ahmad, Director, SPARCENT - Pakistan Space & Upper Atmosphere Research Committee (SUPARCO), Karachi	Provide geomorphological information concerning vegetation and littoral conditions for construction of a new industrial port for the City of Karachi.
Sri Lanka	Mr. Chris Nanayakkara, Survey Department, Ministry of Agriculture & Lands, Colombo	Develop digital analysis techniques for obtaining agricultural crop information.
Southeast Asia:		
Philippines	Mr. J. C. Fernandez, Director, Bur. of Mines, Department of Natural Resources, Manila	Provide natural resource information for integrated economic development of Island of Mindoro.
Thailand	Dr. Somnuk Striplung, Dept. of Agricultural Economics, Ministry of Agriculture & Crops, Bangkok	Provide acreage statistics to annual crop surveys of corn, rice, and sugar cane.

The Grant Approach

For remote sensing technology to be "appropriate" it must be adapted to the aims of development. The fundamental questions are: what kind of technology, and for what kind of development? The answers vary with the country. With the Grant Program it was recognized that educated personnel within developing country institutions are often in the best position to determine their country's priority development needs and that western technologists (scientists and engineers) are necessary to help identify the types of new technology that may contribute to alleviating these needs.

Thus the approach was to support individual investigators in developing countries in testing and subsequently applying remote sensing technology. The mechanism was a small cash award to the investigator plus technical advice and assistance from U.S. remote sensing specialists. The cash awards were available at the direction of the investigators for data, supplies, training, and data processing in support of their proposed projects. Grant funds were not used for salary or expenses incurred in connection with the investigators normal duties.

It was recognized that these developing country investigators attempting to use new remote sensing techniques for the first time usually need considerable technical support. At the time of the grant award a U.S. technical monitor was assigned to respond to requests for advice and assistance from the investigator. Technical assistance included monitoring the progress of the grant activity, providing individual advice and training (if necessary), and assisting in the acquisition of data, supplies, and equipment. Emphasis was on the use of Landsat earth resources data since those are the data that are universally and cheaply available for developing countries - although a number of investigators collected new aerial photography in support of their Landsat data analyses.

Technology Transfer

This small grant approach to technology transfer allowed knowledgeable developing-country investigators direct access to a range of remote sensing technologies. From these, they could pick the elements most appropriate to their countries, institutions, and resource applications. In most cases, the grant investigators recognized the severe limitations imposed on technology in developing country environments and requested relatively simple, labor-intensive equipment (such as diazo-printers, Zoom Transfer Scopes, field equipment) and commercially-available data products. In several cases they asked for help in making use of existing in-country equipment such as general purpose computers. The small size of the grant awards required that the investigators be very careful in the selection of assistance, supplies, and equipment to complete their projects - however, the final choice was theirs.

Communication was a key element in the technology transfer process. In large measure the most successful projects were characterized by frequent informal communications between the investigator and his technical monitor in the U.S.; lack of communication seemed to signal a lack of significant progress. In several cases effective communication required languages other than English -- French for Zaire and Haiti, and Spanish for Chile, Bolivia, and Peru. While periodic formal reporting was stipulated under the basic grant agreement, this requirement was relaxed when frequent informal communications occurred. All of the investigators were urged to make the results of their activities known through professional papers (see bibliography), lectures and seminars. When the projects were successful, this was usually done and the result became widely known.

Conclusions

The experience of this Small Grant Program showed that remote sensing technology can be "appropriate" for developing countries. Experience showed that the primary ingredients for successful transfer of the technology are (1) high-level management support; (2) an enthusiastic and resourceful investigator; and (3) involvement in operational programs of direct concern to the developing country. The final reports of the grants completed to date provide clear evidence that remote sensing, especially with Landsat data, can supply important information in agriculture, mapping, forestry, geology, and coastal zone development within developing countries. The technologies utilized need not be costly or sophisticated in order to obtain useful results and they can be adapted to local environments and a wide range of user needs. Developing countries frequently have dedicated personnel who are capable of recognizing appropriate applications of the technology and, with very limited technical and financial assistance, can institute projects of a level consistent with their countries needs and capabilities. Many other countries could benefit from this approach to remote sensing technology transfer and technology adaptation.

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