AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
BATCH #16

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture — AP00-0000-0000

B. SECONDARY: Natural resources

2. TITLE AND SUBTITLE

Role of remote sensing in developing countries

3. AUTHOR(S)

(101) AID/TA/OST

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1971	99p.	ARC 333.A265

7. REFERENCE ORGANIZATION NAME AND ADDRESS

AID/TA/OST

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(In TA/OST 71-3)

9. ABSTRACT

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-RAA- 834	
12. DESCRIPTORS	**13. PROJECT NUMBER**
Remote sensing Spaceborne photography	**14. CONTRACT NUMBER** AID/TA/OST
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

333
A.265

TA/OST 71-3

ROLE OF REMOTE SENSING IN DEVELOPING COUNTRIES

Office of Science and Technology
Agency for International Development
Washington, D. C.

July 1971

A.I.D.
Reference Center
Room 1656 NS

TA/OST/71-3

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DEVELOPING COUNTRIES

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INTRODUCTION

This report consists of selected papers and task studies prepared by the Office of Science and Technology, Agency for International Development. Economic considerations important to broadened and expanded application of remote sensing technology in the developing countries and suggested steps toward that end are discussed in the first paper by the Director of the Office of Science and Technology.

The remaining papers describe the utility of resource surveys and cite examples where such surveys using remote sensing have been useful for many purposes related to economic development. The papers also describe the ground resolutions of remote sensors and applications of remote sensing technology. An illustrative example of a remote sensing project for game counting and evaluation is also included.

It is hoped that this report will serve as a useful compendium in strengthening understanding of the contributions remote sensing can make to economic development and in giving impetus to remote sensing endeavors which will benefit developing countries.

REMOTE SENSING AND INTERNATIONAL DEVELOPMENT

by

Glenn E. Schweitzer, Director
Office of Science and Technology
Agency for International Development

at

Seventh International Symposium on Remote Sensing
of the Environment, May 18, 1971, Ann Arbor, Michigan

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Many of the developing countries -- from the least developed to the more industrialized -- are genuinely interested in the application of airborne and, hopefully, spaceborne techniques to development problems. Some of the reasons for this interest are quite clear. First and foremost, aircraft sensing activities have paid off in very tangible ways -- ways which are understandable to finance ministers -- throughout the developing world. Secondly, U.S. space enthusiasts have done a good job in selling the concept -- tenuous though it may be at present -- that observations from space may offer many short cuts to economic development. Of equal importance is the desire of almost all countries to somehow be a part of the modern technological age. Finally, the developing countries are concerned lest space photography provide foreign mining and timber interests -- with their sophisticated interpretation techniques -- an advantage in negotiating concession arrangements with their less sophisticated developing country counterparts. One step in this regard by the developing countries is to attempt to understand the technologies through participation in their development.

There have been many recent manifestations of the growing interest of the developing countries in this new technology, including

- -- developing country attendance at the recent International Workshop here in Ann Arbor
- -- proposals from developing countries for ERTS experiments in Latin America and East Asia
- -- experimental aircraft observation programs in Brazil, Mexico, and India
- -- remote sensing symposia being held throughout the world

-- incorporation of photogeology in AID and other development programs in Brazil, Indonesia, and other countries

-- advanced radar and infrared mapping activities from aircraft in Latin America, and

-- increased interest of international agencies concerned with economic development -- including the UN Development Program, OAS, and CENTO

For the sake of brevity -- and hopefully clarity -- I would like to set a few boundary conditions for my presentation. My time perspective will be limited to the 1970's; my geographic perspective to the developing countries; and my subject matter perspective to black and white and color photography, radar, and infrared techniques.

ECONOMIC CONSIDERATIONS

The traditional starting point for considering the potential of any technology in a poor country is cost. But cost cannot be easily measured. It is likely that foreign exchange costs will be involved -- in training, equipment, supplies, or operations. Alternative uses of foreign exchange are manyfold, and judgments by developing countries on use of such a visible political commodity as foreign exchange are not always rational. Indeed, this irrationality is likely to work in favor of remote sensing investments in view of the glamor attached to this field.

Secondly, the type of skilled manpower required for successful efforts in almost every high technology field is in short supply. Furthermore, the value of a technical specialist cannot be measured only by his salary. Frequently, a single specialist provides the buoyancy for an entire laboratory in a developing country, and his diversion to other activities can have many adverse secondary effects.

Thirdly, will diversion of technological resources to remote sensing contribute to stimulating the type of technological infrastructure that best serves the nation's overall development -- both in the immediate future and the longer term? Will the technological resources needed to support remote sensing activities complement or detract from comparable resources needed for agriculture, medical, and industrial advancement?

The fourth type of question that is in the forefront of every meeting of international development experts today is the impact of technology on jobs, and employment is probably the most important development issue of the 1970's. Is development of highly automated data collection techniques -- which are clearly not labor intensive -- consistent with employment concerns, or is there no other alternative means of essential data collection? Ground survey techniques considered totally unrealistic in the United States often become more attractive in an environment where labor is available at ten cents per hour, payable in local currency.

Now let's turn to the use of data, for if information is not used, why collect it? The data we are considering is being acquired within the context of overall technological, economic, and social systems that are slow, sluggish, and very imperfect at best. There is little sense in having a high strength steel rung in a frayed rope ladder. In short, there needs to be a readiness, and capability, to translate data into meaningful economic activity -- activity that must extend all the way through the production or export phase.

The types of data that are useful to a developing, or developed, country, are as varied as life itself. Let me identify just four types of particular relevance to our discussion.

Developing countries invariably have five-year development plans which are usually updated annually. These plans are the principal documents that set forth national priorities and resource allocations. Clearly, the data base on which these plans rest is important. The extent and precision of the data base vary from country to country, but are usually not adequate.

"Discovery data" -- data which provides significant leads to mineral resources, agricultural blights, ground water resources, etc. -- is of interest to developing countries. However, our experience has shown that the lack of "discovery data" is far less of a constraint to resource development than the lack of a capability to use "discovery data."

Adequate data relevant to new engineering projects -- dams, roads, irrigation systems -- is of continuing interest. Engineering organizations need and use such data,

particularly information concerning the physical conditions of the immediate locale of the project. However, they are often poorly equipped for consideration of attendant broad ecological ramifications which extend over larger geographical areas.

Resource management data can be many faceted. In developing countries this term frequently means the basis for leasing agreements. It often concerns land demarcation for tax purposes. There are also many other aspects of resource management data. However, the term seldom refers to regional management in the comprehensive sense to which we have become accustomed.

Before turning away from these general economic considerations, I would like to re-emphasize several points. As discussed above the approach to costs and benefits in developing countries must be entirely different than the approach to which we have become accustomed in the United States. While data -- of some quality and quantity -- is the lifeblood of every developing economy, the shortage of adequate data is only one of many constraints to economic progress, and in my judgment it is not at the top of the list of constraints.

AIRCRAFT PROGRAMS

I am pleased to report to you a number of success stories in the use of remote sensing from aircraft in recent years. While we would like to report this information in dollar and cents terms, remote sensing data is always used together with other information, and determination of its exact contributions is difficult. Nevertheless, we need to define its value more precisely.

-- In the Dominican Republic aerial photography played an important role in an integrated resource survey that served as the basis for preinvestment and feasibility studies of (a) development of the Yuna River Delta, (b) modernization of farming practices in the Azua Plain, (c) drainage of the Atlantic Coastal Plain, (d) citrus fruit production, and (e) several irrigation projects.

-- In Ecuador, aerial photographs were a significant part of the resource surveys which provided the basis for a $192 million plan for development of the Guayas River Basin.

-- In the Philippines, infrared measurements and aerial photographs contributed to warnings of volcanic eruptions and subsequent evacuation of people and property from danger areas.

-- In Jordan, aerial photography was a key factor in locating ground water drilling sites, developing phosphate deposits, classifying soils, and planning highway, rail, and water routes.

-- In Honduras, recent aerial surveys of timber resources provided the basis for contract negotiations designed to develop paper, pulp, and plywood industries in two areas.

-- In the Sudan, crude aerial photography of Khartoum provided the basis for determining the least disruptive building condemnation schemes necessary for expanded city traffic patterns.

-- In Tanzania, aircraft surveys are being used in delineating local jurisdictions and determining tax patterns and have also assisted in studies of mosquito breeding habitats.

-- In Venezuela, Colombia, and Panama radar surveys are significantly enhancing the quality of maps available in areas currently being opened for settlement and exploitation.

You may have noted that black and white photography played a prominent role in these success stories. This obviously reflects the current and near term state of the art in most developing areas.

However, we have also had some setbacks in the aircraft field. The most serious problem is the under utilization of the data that has been collected. There are thousands of aerial photographs of Latin America and Africa that have never even been examined by developing

countries, let alone utilized in an economically productive fashion. The principal constraints have usually been lack of local governmental interest in the projects that have led to the photographs, over-zealous photographers, and the lack of manpower to interpret the photographs.

This brings me to my second criticism of past aircraft programs -- and particularly programs supported by the United States and other donor countries -- namely, over-reliance on the "turn key" approach. The objective of assistance projects should not be to collect data -- which is straightforward and relatively simple -- but the harder task of assisting the developing country to achieve a capability to collect and use the data.

In summation, aircraft have proved their worth when two conditions have existed: existence of a clearly defined problem of narrow scope and of economic significance, and a readiness and capability of the concerned government agency or private investor to incorporate the data into an action program.

Local capabilities and resources to carry out aircraft surveys for operational purposes are growing, and sensitivities to the value of such activities are spreading. These are healthy trends.

WHAT ABOUT SATELLITES

The potential role of satellites is less clear but is certainly worth considering.

Satellite imagery will obviously be useful as an educational tool for students of geology, oceanography, hydrology, and other disciplines. Also, judging from Apollo photography, this type of imagery should be of interest to topographic mapping agencies in some countries where improved base maps are needed. Probably in most cases the transposition of data from photographs to existing maps will be done in a rudimentary manner, with occasional revamping of entire maps based on the photographs.

Other uses of satellite imagery are, in my view, linked to the quality of the imagery -- and specifically the resolution. You are fully familiar with the discussions on the resolutions that will actually be attained from satellites and the relevance of various resolution levels to economic activity. To be sufficiently interesting to developing countries and to attract scarce investment funds, the imagery will have to represent a major advance over the quality of currently available data. Most countries will await delivery of the imagery and then make judgments concerning commitment of resources in country-specific situations. This seems to be a prudent approach.

It is likely that in the years ahead satellite imagery will be particularly interesting to regional economic planners since they are ideal consumers of broad scale reconnaissance data. To formulate sensible development plans they need an understanding of the resource potential related to the geography of their nations, and satellite data should help considerably in targeting detailed exploration activities.

Much has been written as to how resource managers will use satellite data. However, keeping in mind that developmental problems which are susceptible to solution are usually confined to quite limited geographical areas, the economically competitive applications in developing countries remain to be demonstrated in hard, cost terms. I am hopeful that imagery of adequate quality, frequency, and reliability will be available at an attractive cost, and then - and only then - will past rhetoric be translated into operational reality.

Two additional areas of application which are worth considering relate to the settlement of new territories -- and particularly shortly after the decisions have been made to open the areas -- and redevelopment of large areas struck by typhoons, floods, or earthquakes. In both cases the local government and perhaps international agencies are presumably prepared to invest substantial resources in development of sizeable geographic regions. Well-interpreted satellite imagery might contribute substantially to insuring that these resources are invested wisely.

NEXT STEPS

The results of the ERTS and Skylab experiments, and particularly those that involve the developing countries, should have a major impact on the views of development specialists. Meanwhile, modest efforts will continue in the aircraft field -- targeting on specific high-priority development problems and opportunities. Also, additional research and experimental activities in tropical areas emphasizing cost aspects may be initiated. Insofar as training is concerned, a little caution is in order concerning appropriateness of the training. I would be particularly concerned if the trainees are unable to use their training when they return home. One encouraging recent development is a growing recognition of the need to develop high quality training institutions in the developing countries themselves, and thus shift much of the training activities to institutions which relate more effectively to actual development problems.

Insofar as our domestic programs are concerned, I would suggest the following emphases:

-- Economists should be brought more directly into the mainstream of current experimental activities, thus adding an economic analysis dimension to the current test programs run by technologists.

-- Experimental activities ahould be more deliberately structured to generate the cost data essential to decision making concerning the utility of remote sensing techniques.

-- More attention should be given to a very limited number of the more promising applications of worldwide significance, with efforts directed to reducing the costs of these applications.

-- Special attention should be given to small-scale applications in limited geographic areas to find cheaper ways to solve very specific problems.

While the international development aspect cannot be the only determinant in shaping the character of domestic programs, the commitment of the United States to share its

technology with other nations will have real meaning only if the technology is responsive to the practical problems of the developing world. Concurrently, design of simple and direct systems for enabling developing countries to acquire useful space-derived data on a timely basis should be a high-priority aspect of the overall program.

REMOTE SENSING TECHNOLOGY

AND

APPLICATION TO DEVELOPING COUNTRIES

A Report on Phases I, II, III, and IV of AID/TAB Project #995-902: "Application of Remote Sensing Technologies" to LDC's

The attached report was developed in response to requirement of Phases I, II, III, and IV of subject project on remote sensing applications. It should be considered to be subject to revision and amendment from time to time as new technologies, methods and policies are developed.

The terms of reference for Phases I, II, III, and IV are as follows:

Phase I - Describe how the limiting factors - institutions. human resources, government policies and and attitudes - which have influenced the extent of utilization of data developed in IAGS natural resources surveys and other AID programs, will be mitigated sufficiently to yield reasonable prospects that remote sensing technology would be utilized so as to have significant development impact. Explain how these nontechnological factors would be taken into account in each applicable successive phase of the project.

Phase II - Review past efforts in selected developing countries to acquire and use information from remote sensors with particular attention to how data acquired from sensing has been integrated into economically oriented activities. Describe the costs involved in these efforts and identify the reasons why such efforts were or were not cost-effective approaches in solving specific development problems.

Phase III - Describe the estimated costs and capabilities of sensing technologies likely to be available during the 1970s that appear relevant to the problem areas described in Section IV. Identify the key manpower, facility, and institutional requirements for a developing country to be able to make use of these capabilities. Describe the differences in utilizing these technologies in the U.S. and in developing countries.

Phase IV - Review the methodologies that have been developed in the United States for relating opportunities for using remote sensing capabilities to solving specific development problems and for demonstrating under what conditions remote sensing is a cost-effective approach to solving such problems. Develop a modified methodology suitable for solving such problems in the developing countries.

The purpose of these studies is to determine whether it is useful for AID to carry on investigations of (1) the utility of remote sensing as an aid to resource development and management and (2) the most effective

application of the techniques which exist now or will be come available in the 1970s. In considering whether AID should carry on investigations in the area of remote sensing it is important to also consider remote sensing activities which are being supported by other agencies.

NASA and other federal agencies now support remote sensing research and development projects costing more than $20 million annually. About $100 million worth of contracts have been awarded for the construction of two Earth Resources Technology Satellites (ERTS A and ERTS B) and associated launch vehicles and ground systems. These satellites will be launched in 1972 and 1973.

The UN supports earth resource surveys costing approximately $100 million annually. Much of the data collected in such surveys has been and is being obtained directly or indirectly from airborne sensors. Several commercial organizations are engaged in profit-making enterprises which involve the collection and analysis of remote sensing data collected through the use of airborne cameras, radar, infrared scanning devices and radiometers.

In recent months AID has had several opportunities to make recommendations concerning the application of the remote sensing technology in the developing countries in addition to operational programs supported by AID. We have made recommendations on the disposition of the IAGS Cartographic School in Panama. We are participating in the planning for the International Workshop in Remote Sensing to be held in May, 1971. We are members of an interagency task force commissioned by the Office of Management and Budget to make recommendations on program and management aspects of the U.S. national effort to develop and implement the remote sensing technology. We have also made recommendations concerning developing country participation in ERTS A experiments. Finally, we have answered questions which have arisen within AID with regard to remote sensing technology and are receiving an ever-increasing number of inquiries and proposals from the private sector about the prospects for remote sensing programs (particularly those involving satellites) in developing countries within the technical assistance framework.

In summary, irrespective of AID involvement there is going to be major remote sensing activity both in the United States and in developing countries. The developing countries will continue to allocate scarce funds and manpower to resource surveys. AID has the opportunity to help channel such funds and manpower in the most productive direction.

PHASE I

THE UTILITY OF RESOURCE SURVEYS

The following pages contain brief descriptions of selected resource surveys in developing countries. All of these surveys were based at least in part on maps derived from aerial photography. The information which was obtained has been of varying degrees of utility as an aid to decision making in the management and development of natural resources. Analysis of these past surveys leads to the following conclusions.

1. Resource surveys are an essential and inseparable element of a wide variety of development projects and should be considered as such.* While a survey is of considerable importance, the cost of conducting it will generally be a disproportionately small fraction of the total amount invested in the project to which it relates. For example, a resource survey typically represents 1% of the total investment in a development project. Of the funds expended upon a resource survey, approximately 10% are to cover data acquisition costs and 90% are for data analysis.

2. It is particularly important that resource surveys in developing countries be conducted with specific objectives in mind and with a good idea of exactly what data is needed, when the information will be required, and how the results will be used. Inadequate management and organizational arrangements can lead to poor coordination between those who are in charge of the survey and those who must use the results. In some instances information obtained in resource surveys has been of minimal utility because the government involved had not established the institutions necessary to implement measures suggested by the survey. In other cases there have been insufficient funds to carry out projects based on information collected in resource surveys. There are examples of resource surveys which were of such a general nature that the information contained therein was of little use when specific projects were considered. For example, mapping might have been conducted at too small a scale, certain types of necessary data by the time the project was actively considered, or vital information, may have been lost. (See conclusion #11)

3. A survey may be useful even though it does not lead to a specific project. A result may have been the conclusion that a proposed project was not feasible. The value of a survey in such a case is real but intangible.

*For extensive discussion of the economics of resource surveys see Natural Resource Information for Economic Development by Orris C. Herfindahl, John Hopkins Press, 1969

4. A survey may not be of immediate use because data must be collected over extended periods before meaningful conclusions can be inferred. For example, data on river flow must be collected over a 15 to 25 year period before it is possible to have confidence in the design of hydroelectric projects, roads or bridges based on that data.

5. In some cases resource survey data can be used for purposes other than that for which the survey was undertaken. In order that survey data be of use to the maximum number of "customers" it is desirable that there be a "central program office" which can influence the design and implementation of surveys and the dissemination of results.

6. Survey data of seemingly little use may eventually assume substantial value. This is not to argue for the conduct of surveys for which there is no specific need but it does suggest that useful information can be salvaged from surveys which were badly timed or improperly managed. Moreover, the experience gained from surveys of low utility can be used to enhance the benefits from future efforts.

7. Because the resource survey component represents such a small fraction of the total investment in a project, small increments in the magnitude of the survey can pay large dividends in the form of decreased costs of the projects or increased benefits from it.

8. Resource surveys should be conducted in a manner which yields required information at minimum cost and with the most effective use of scarce manpower. This means that proper management structures should be established to insure that the survey is being conducted by the right people and is employing the most efficient techniques.

9. It is not meaningful to consider the cost-effectiveness of a particular survey except to consider the cost-effectiveness of a particular survey technique or prodedure in comparison with alternative techniques or procedures. Rather than consider the cost-effectiveness of a survey, consideration should be given to the cost-effectiveness of the project of which the survey is part; that is, the costs and benefits of the entire project should be compared with those of other projects which are competing for investments.

10. Because of hidden factors, it is difficult even to get a a good idea of the costs of a resource survey. A major intangible is the cost incurred in not investing manpower and funds on a competing resource survey or on some other type of project.

11. The low utility of some past surveys has little bearing on the current remote sensing project to better understand remote sensing opportunities. The purpose here is to help assure that AID countries obtain maximum benefit from the use of existing remote sensing techniques and from those which might be developed in the future. At the same time AID can make every effort to insure that the potential of advanced remote sensing techniques will not be exaggerated; that remote sensing will not become a "tool in search of a job". AID countries should not expend valuable human and economic resources upon the collection and analysis of data for which there is no well defined need. The utility of advanced techniques of data acquisition, analysis and dissemination will be predominantly in the area of reducing the cost of information required by planners and managers.

12. There is no central facility in AID where the results of past surveys are readily accessible. Nor is there a comprehensive effort to collect information on how surveys have been used and on why some have been of great utility and others have not. Many important results and conclusions are carried around in the heads of AID employees. Such information fades with memories or is lost when the employee goes elsewhere.

While AID is in no position to eliminate all the above causes for non-productive surveys, it can adopt guidelines, both in the present remote sensing project and in future activities, that will help to mitigate the factors which have limited the usefullness of past surveys.

A pre-requisite for AID support of a survey in a developing country, whether that survey be considered the first step in a development project or whether it be a field test of newly developed survey techniques, should be the existence of a clear idea of what purpose the proposed survey is supposed to serve; that the survey should be planned and carried out in a way such that its objective will be met in the most cost-effective manner; and that there be a substantial probability that the developing country will be able to implement follow-on activities recommended by the project.

AID should undertake to gather in one central and accessible location, a cross-referenced collection of all resource surveys of which AID has knowledge. This reference collection should also include evaluations of the utility of these surveys and information on why they have or have not been used.

If AID is to be in a position to help insure that developing countries obtain maximum benefit from the remote sensing technology while at the same time such countries are not oversold on the capabilities inherent in the technology, it is important that in-house expertise be developed in the various aspects of remote sensing and resource surveys. The in-house capability should include an understanding of present and prospective remote sensing capabilities. There should be awareness of the ways in

which past surveys have been successful and of the ways in which they have failed. Institutional, manpower and training needs should be studied and a store of knowledge developed. One result of the present remote sensing effort will be the development of a capability to provide assistance to other offices or to developing countries which are considering the application of remote sensing.

PHASE II

SELECTED RESOURCE SURVEYS

Panama - Radar Mapping of Darien Province

Prior to 1965, the U.S. Air Force and numerous private contractors attempted to acquire optical photography of the Darien Province. These attempts were not successful because of persistent cloud cover. In four hours flying time 6600 square miles were covered by side-looking radar. The cost of acquisition of this data, if it had been on a commercial basis, as part of an extensive program, would have been on the order of $50,000.

Colombia - Radar Mapping

In a project partially funded through the IAGS, the Westinghouse Corporation obtained radar imagery of an area of Western Colombia between the Andes and the Pacific Ocean. This is an area with nearly perpetual cloud cover and has been previously unmapped at a scale which the radar data made possible. (There are approximately 4,000,000 square miles, mostly in equatorial areas, which are cloud covered to the extent where conventional aerial photography is not practical.)

The Government of Colombia is using the data in planning for a canal and hydroelectric project in the Choco River Valley. Oil and mineral exploration companies are purchasing the data for their own use. (As a result of its having provided part of the funding for the project, Westinghouse is allowed to sell the data to whomever is interested in purchasing it. A further indication of the practical utility of radar imagery is the fact that the Automatics Division of the Raytheon Company has sold approximately $12 million of radar interpretation services related to this data.)

Peru - Disaster Assessment

Aerial photographs and infrared scanner date were obtained over the areas which suffered damage from the great earthquake of May 31, 1970. The data was acquired by a NASA aircraft in overflights requested by the Government of Peru.

The data is being used to assess damage and to assist in the management of the reconstruction progress. The extent to which the Peruvians have been able to make use of these photos has been limited by the fact that there is an insufficient photo interpretation capability in Peru. The Government of Peru has requested assistance of the U.S. in the interpretation of this photography.

The data was collected in three flights on July 14, 15, and 16, 1970 (approximately 45 days after the event).

The project costs are approximately $50,000 and have been assigned to NASA's Earth Resources Aircarft Project. The results are incorporated in 18,000 photos covering about 3000 square miles.

Ecuador - Survey for the Development of the Guayas River Basin

In 1963, an OAS-supervised team conducted a survey of the climate, geology, geomorphology, water resources and irrigation systems, soils, forests, land use, and population distribution over a ten thousand square mile area in the Guayas River Basin and its watershed. Data was obtained from aerial photographs and field surveys as well as from existing studies and maps.

Part of the funding for this survey was provided by AID to the Ecuadorian Planning Board. The latter entered into a $24,000 contract with the OAS to assume responsibility for the conduct of the survey.

This survey is the basis for a $192 million plan for the development of the Guayas River Basin.

Dominican Republic - Survey of the Natural Resources

Between January 1965 and April 1966 the OAS conducted an integrated survey of the natural resources of the Dominican Republic. The purpose of this survey was to map and evaluate for national and regional planning purposes the country's geology, climate, soils, forest resources, land use, water resources and population distribution. In the course of the work maps based on aerial photography were used. Ground observations were conducted where necessary. The total cost of this survey was $335,000.

This survey made it possible to select resources with high development potential and to recommend specific projects which should be undertaken. Among the latter were a preinvestment study for the development of the Yuna River Delta, a preliminary feasibility study of irrigation and modernization of farming practices in the Azua Plain, a feasibility study of drainage in four areas of the Atlantic Coastal Plain, a feasibility study of the development of large-scale citrus-fruit production north of Santo Domingo, a feasibility study of irrigation in the Enriquillo-Oviedo area, and a preinvestment study of agricultural development of the Southeast Dajabon Area.

Other recommendations have not been implemented. This may have resulted from there being insufficient technical expertise at the decision making level to permit maximum use to be made of the survey results.

Nepal - Hydrological Surveys

Stream gauge measurements have been made with the assistance of the USGS. Stream gauge data, which must be acquired over a 15 to 25 year period if it is to provide necessary information, is essential for the proper design of hydroelectric projects. Such data is also of considerable use in road design since it helps to determine the size of culverts and bridges.

The Nepal stream gauge data and analyses of maps based on aerial photography have been used in a preliminary survey which is the basis for Japanese interest in the Kernali hydroelectric project.

Philippines - Disaster Warning

In 1966, at the request of the Government of the Philippines, the U.S. Geological Survey monitored thermal activity at the Taal volcano in the Philippines. The survey included the collection of data from infrared sensors flown over the volcano. In addition, conventional aerial photographs were obtained. Partly as a result of these surveys, sufficient warning was obtained of a forthcoming eruption to permit evacuation of persons residing in the danger zone. Lives and property were saved as a consequence of this warning. The cost of the survey was on the order of $5,000.

Mekong River - Regional Survey of Natural Resources

The Corps of Engineers conducted in 1965-68 a survey of natural resources in the Mekong River Valley in South Vietnam, Cambodia, Laos and Thailand. The cost of this study was approximately $335,000. The study has become a major source of information for the national and regional planning agencies in the riparian countries, for AID, and the IBRD.

Central America and Venezuela - Regional Survey of Physical Resources

In the mid 1960's, under an agreement between the Permanent Secretariat of the General Treaty for Central American Economic Integration (AIECA) and AID, a set of atlases were prepared based on resource surveys by the Corps of Engineers with the cooperation of the IAGS. Atlases were compiled for Costa Rica, El Salvador, Hondura, Nicaragua, and Panama. A similar atlas of Venezuela was prepared under an agreement between AID and the Government of Venezuela. The atlases include information on surface configuration, drainage, surface water resources, soils, vegetation, climate, geology, mineral resources, ground water resources, construction materials, suitability for road construction, population distribution, and land use.

In compiling these atlases, existing aerial photography and other data sources were exploited. The cost of the six atlases was approximately $250,000.

The prime users of the product have been U.S. engineering companies active in these countries and groups investigating investment opportunities. The atlases have not received as much attention from national planning agencies in the six countries. There is some disappointment over this. The reasons for the lack of use are not quite clear but seem to be based upon bureaucratic inertia, lack of continuity in AID, and interagency frictions. There is also a belief that the information is too general and that the investment in the survey would have been better used in other projects.

One specific result of the Costa Rica survey was the development of useable water supplies at a time when the existing supplies had been contaminated by ash from eruption of the Irazu (sic) volcano.

Colombia - Survey for Hydroelectric Project

In 1968, the IAGS assisted the Government of Colombia in a special survey to collect information vital to a planned hydroelectric dam on the San Juan River. In the basis of this survey, a reestimate of project costs was undertaken.

Peru - Survey for Hydroelectric Project

Maps produced with the assistance of the IAGS were the basis for the 1962 design of a hydroelectric project on the Montaro River. The Government of Peru initiated construction which includes a tunnel through a narrow mountain peninsula.

Central America - Transportation Study

In 1964 and 1965, the Central American Bank for Economic Integration financed a detailed transportation study for Central America. This study was based on maps in whose production the IAGS played a substantial role. Without these maps, meaningful study could not have been accomplishe

Colombia - Mining and Mineral Survey

Base maps previously produced with the assistance of the IAGS were the basis for a 1960 mining and mineral survey being undertaken by the U.S. Geological Survey at the request of the Government of Colombia. The existince of these maps made it possible to reduce the budget for this survey by $500,000.

Brazil - Soils Survey

This survey was done in 1967 under the auspices of the Soils Department of the Brazilian Ministry of Agriculture with some support from U.S. funds. The survey was conducted by Brazilians with aid from a team of U.S. soils scientists.

Data was collected from observations made on the ground. Maps based on aerial photography provided input information.

The resultant data was used to produce soils maps which have been sent to regional and state experiment stations and to universities. The maps will be used for crop and fertilizer planning. It is believed that the maps are not as sufficiently detailed as is desirable. On the other hand, they are better than no maps at all. This experience points up the necessity of conducting surveys which are carefully tailored to the need.

Brazil - Timber Survey

As part of a UNDP/PAO project, a timber survey was conducted in 1967 and 1968 in the State of Parana in southern Brazil. Data obtained from aerial photographs and ground measurements were the basis for an inventory of Auraucaria pine. The survey showed that this valuable timber resource was being depleted at a rate such that it would be virtually gone in ten years.

As a direct result of this survey, the Government of Brazil enacted laws providing tax relief for reforestation. The survey also pointed up the inadequate nature of forest management in Brazil. This led to reorganization of forestry management agencies within the Brazilian Government.

The costs of this project were absorbed in the parent activity which included the establishment of a forestry school and a forest research organization.

Nicaragua - Road Location

The location of the Rama Road was based on aerial photography and mapping which resulted from a collaborative effort by the IAGS and a Nicaraguan mapping agency. The route was laid out in the early 1950's.

Honduras - Timber Survey

This survey was financed by the UNDP and was completed in 1970. Information was obtained on the extent of forest resources in eastern Honduras from aerial photography and ground measurements.

The survey data is now providing a valuable input to negotiations between the Government of Honduras and two timber companies. The object of one negotiation is to establish a permanent pulp and paper industry. The object of the second is to establish a plywood industry which uses local labor.

Liberia - Offshore Aeromagnetic and Gravimetric Survey

A 7-year collaborative Geologic Exploration and Resource Appraisal Project, jointly conducted by the U.S. Geological Survey and the Geological Survey of Liberia, is beginning its sixth field season in 1971. One element of this project was a geophysical survey supported by a $1 million AID loan. While this survey was directed primarily at land areas, it also included aeromagnetic and gravimetric investigations of Liberia's continental

shelf and nearshore waters which resulted in the discovery of a sedimentary basin offshore of Monrovia which possesses structures favorable for the occurrence of petroleum. As a result, the total cost of the survey has been amortized by income from permits awarded to the petroleum industry for exploration in the basin.

Pakistan - Geological Investigation of Coal Fields

A systematic study of the geology, structure and coal beds of the Lakhra coal field in West Pakistan was undertaken by USGS and Pakistan geologists during the period 1961 through 1966, and a mining operation study was made in 1969 by USGS, USBM, and Government of Pakistan personnel. As a result of these studies coal reserves were estimated for an 80 square mile area. In millions of long tons, measured reserves are 22 million tons, indicated reserves are 44 million tons, and inferred reserves total 174 million tons. By June 1969 four mining companies were active in the area, and production averaged 200 tons per day.

India - Geochemical Survey for Phosphate Deposits

The Geological Survey of India initiated a large-scale phosphate exploration program in 1961 and subsequently discovered promising deposits in several locations. In 1968, under AID sponsorship, the U.S. Geological Survey and the U.S. Bureau of Mines collaborated with the Indian Survey on a detailed study of these deposits. Exploration techniques, including geochemical analysis, used successfully in locating phosphate environments in other countries, (for example: in Turkey and Saudi Arabia) were employed. It was established that large deposits indeed were present, but that lower than anticipated grade, technological problems in using the ore, high mining costs, logistics, and other economic factors will retard development for some years to come. However, using the newly acquired exploration techniques, the Geological Survey of India discovered more promising deposits in the State of Rajasthan in 1967. The following year the Rajasthan State Directorate of Mines and Geology located the largest commercial phosphate deposit so far found in India in the same area. Preliminary study indicates that at least 100 million tons of minable phosphate ore are present. The State Government began mining operations which average 500 tons per day. Plans are to increase production to 3,000 tons per day within the next year.

India - Mineral Survey (Operation Hardrock)

Aerial surveys using airborne geophysical instruments along 90,000 linear miles of flight lines, in conjunction with aerial photography, assisted in the location of numerous anomalies indicating the possible presence of mineral deposits. Follow-up ground surveys proved the existence of mineral deposits in a number of cases.

Jordan

In the 1950s the U.S. Government provided substantial assistance to Jordan for exploration for water resources. This effort, which was conducted primarily from the ground without the aid of aerial photography, was only marginally successful.

In the early 1960s AID sponsored further exploration for water resources. In this case aerial photography combined with detailed geological mapping led to substantial success in locating sites for drilling and production of ground water. These same photographs were used as the basis for the development of a phosphate deposit at El Hassa (one of the most important phosphate deposits in the Middle East and a major source of Jordan's foreign exchange), for classification of soils, and for planning highway, irrigation canal and railroad construction projects.

Afghanistan - Mapping

Aerial photography has been used for soils classification in Helmand River Valley. These photographs were also used in the design of the Kabal-Kaneaar Road. The Kabal River Gorge Road from Kabal to Pakistan was designed partly on the basis of the same photography.

PHASE III

GROUND RESOLUTION OF REMOTE SENSORS

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GROUND RESOLUTION OF REMOTE SENSORS

BACKGROUND

Earth orbital photographs provide a data base which in detail and scale compares favorably to imagery to be collected from future earth resources satellites. Optical and photogrammetric analysis of earth orbital photography leads to understanding operational parameters which impact mission data yield. Of particular interest is resolution, generally defined as an inherent image property permitting image analysts not merely to distinguish but to identify phenomena of earth resources interest. This definition is consistent with ultimate ERS program and user task objectives, which most often imply that the image analyst discover new data rather than merely confirm the presence of known phenomena. System resolution (R_s, lines per millimeter) may be expressed as

$$\frac{1}{R_s} = \frac{1}{R_f} + \frac{1}{R_o} + \ldots\ldots$$

or the summation of film resolution (R_f) and optical resolution (R_o) of the photographic system. Ground resolution (G, feet) indicates the smallest object on the ground which can be resolved by a given photographic system at a given scale expressed as

$$G = \frac{SF}{304.8.R}$$

where SF is the scale factor, 304.8 mm/foot and R in lines per millimeter. Geometrical variations of the above basic formula exist for oblique images.

A basic factor for computing ground resolution is scale number, defined as the focal length of a viewing lens over the distance from the sensor system to the object viewed. An image obtained with a camera focal length of 12 inches at an altitude of 300 miles (300 miles times 5280 feet per mile) provides a scale number of 1,584,000. This means that a unit distance on the photograph multiplied by scale number is equivalent to a unit distance on the ground, or, in this instance, 1 inch equals approximately 25 miles.

The resolving power of a lens-film combination may be defined as the reciprocal of the smallest observable separation of adjacent lines in a photographic test pattern consisting of parallel black lines of equal size separated by white lines of the same size. Resolving power is expressed in lines per millimeter. Despite a theoretical resolving power, the capability of an imaging (camera) system to resolve detail varies operationally with conditions such as the shape of the object to be photographed, target-to-background contrast, the place of the target within the field of view, and variations in exposure and darkroom development.

Ground resolution is often based on the size of an object which can be seen on the ground, when in fact it is the ground size equivalent of one line of resolving power. If the resolving power of a photographic system is 30 lines/mm and image scale number 2,700,000, ground resolution (GR) may be estimated as

$$GR = \frac{\text{Scale Number (S)}}{300 \times \text{Resolution (R) in lines/mm}}$$

where 300 is $\frac{25 \text{ mm}}{\text{inch}} \times \frac{12 \text{ in}}{\text{feet}} = 300 \text{ mm/foot}$

$$= \frac{2{,}700{,}000}{300 \times 30 \text{ lines/mm}} = 300 \text{ feet}$$

The above computation parallels actually hand-held camera performance as determined using sample Gemini images, although resolving powers of up to 80 lines/mm and ground resolutions of 100 feet have been obtained. Ground resolutions of 50 to 100 feet have been computed using rocket and Apollo images.

Ground resolution has sometimes been used as a measure of an earth survey satellite capability to collect useful data and indirectly to suggest a working

level for effective task-oriented photoanalysis. For example, although ground resolutions of several thousand feet are suitable for meteorological surveys, ground resolutions of 100 to 300 feet are essential to many earth resources survey applications.

For purposes of discussion, two TV lines are considered equivalent to an optical line pair.

Related parameters of importance for assessing image data yield are angle of view (or obliquity) which is defined as the angle (degrees) between the spacecraft nadir and the camera axis, and solar altitude, defined as the angle (degrees) between local horizontal and a line drawn from the target to the sun. Consideration of the azimuthal relationship of the sun (expressed in degrees) and spacecraft with respect to the target is inferred.

Optical and photogrammetric techniques can be used with basic formulae to assess principal mission-related parameters (resolution, angle of view, and solar altitude) and with earth orbital photoanalysis used to assess impact on task data yield. Computation of ground resolution using earth orbital images requires that edge density function data be extracted at selected points, and resolution (lines/mm) obtained. Computed ground resolution can then be compared to task data yield. Angle of view is determined from data describing (1) spacecraft position, (2) camera statistics, and (3) maps with accurate ground check points. This information is used with photogrammetric procedures developed for high altitude photography to determine angle of view, and consistency checked using camera location and the other orientation angles computed by the same procedures. To determine solar altitude, the date, local time of day, principal point of the image, and latitude and longitude of principal points are consecutively determined. With these data and using appropriate tables, solar altitude data for specified orbital images can be computed.

Ultimately, an ERS (or EOS) System should achieve low-contrast ground resolutions of around 200 feet, a one-year orbital lifetime with repetitive surveys approximately twice per month, near-global coverage every 30 days, and sun synchronous orbit with illumination of 30 degrees or more. Imaging in three selected spectral bands (multispectral imaging) with potential supporting radiometry provides a means of differentiating vegetation, rock and soil moisture.

ORBITAL IMAGE DATA BASE

An adequate orbital image data base, applicable to earth resources survey satellite-planning, has been developed over the past 23 years. Orbital altitude photography was first collected by camera-carrying rockets at White Sands Missile Range between 1946 and 1950. Scientifically-successful space photographic missions include V2, Aerobee, Viking, and manned Mercury flights through 1963. Aerobee sounding rocket photography obtained by terrain-pointing cameras (for the principal purpose of assessing rocket attitude control and stabilization) has also provided useful data. Meteorlogical satellite imagery, while readily available in the last decade, contains insufficient detail for the majority of scientific earth surface investigations. It should, however, be emphasized that examination of existing meteorological satellite images contributes to mission planning and, specifically, provides evidence as to thresholds beyond which earth survey data cannot be usefully collected.

Photography collected as part of the Mercury, Gemini, and Apollo synoptic terrain experiments has provided particularly useful date for resource satellite planning. During Apollo 6 and 9 spaceflights, high resolution 70 mm color infrared and multiband images were successfully obtained at

levels of detail two or three times better than previously available. Supporting these orbital images are suborbital X-15 aircraft photographic records which reasonably simulate orbital capabilities. Low altitude multisensor records from the NASA aircraft program have proven the utility of a variety of remote sensor systems, and use of sensors from high-altitude aircraft to more closely simulate orbital survey scales is being planned. Although aerial sensor testing experience can be broadly extrapolated to the space environment, it is difficult to extrapolate analysis of high resolution sensor data to low resolution (small scale) space records.

Substitution of aerial photographic mosaics for individual space images is not feasible considering mosaics cannot be equated to or duplicated by orbital photographs. For example, the large area coverage which a single orbital image provides would require the mosaicing of several hundred individual aerial photographic prints to obtain the visual synthesis of a single orbital image. Furthermore, the difficulty of matching aerial photographs of varying tone or color caused by, for example, changes in solar illumination between successive flightlines, reduces data yield. Aerial photographic mosaics can sometimes be used to simulate images of up to 1:1,000,000 scale, and ground resolutions varying from 20 to 100 feet. Such black and white mosaics are useful for assessing reduced resolution but fail to provide the element of color which increases the ease and scope of earth orbital image analysis. Mosaics do, however, somewhat demonstrate the importance of pattern and tone for analyzing small-scale imagery.

As a specific example, a basic geomorphological (geological) concept is that the erosive action of water is more significant than that of wind in an arid or desert environment. Studies of Gemini images indicate that wind erosion is a more critical landscaping agent in arid areas than formerly believed. Further evidence is suggested by the abundance of dust storms and wind-transported particles, the extent of which was quite probably not fully understood prior to the synthesis which orbital images provided.

Orbital photography could now be used to develop more meaningful interdisciplinary sampling programs. By using available space photographs, samples could be collected at preselected marine or terrestrial sites determined to warrant increased sampling density; for example, an oceanological program concerned with locations of commercial marine bottom fauna might benefit from sampling points based on a knowledge of distributary currents patterns. Furthermore, opportunities for high data yield are increased with more than "hit-and-miss" sampling programs.

Orbital photography is useful as preliminary working material for scientific personnel engaged in activities potentially to be addressed using orbital remote sensing. The importance of image analysts making full use of available earth orbital photography may be inferred from the fact that high-resolution panchromatic and color aerial photographs, which may contain detail in excess of that needed to solve some problems, are now almost exclusively in worldwide use. It may also be difficult for the image analyst to objectively assess reduced resolution data, since he has

been exposed totally to high levels of image detail. Perhaps the most immediate value of available space photographs is to bridge the gap between interpreter working experience, sometimes biased toward high-resolution data, and data to be provided by orbital survey missions in the 1970's.

Preliminary experiments using earth orbital images indicate that the task of orbital image interpretation requires more than a shallow understanding of the scientific discipline to which it may contribute and the skillful use of deductive reasoning to extract valuable scientific information. To guarantee efficient and cost-effective orbital photographic utilization, therefore, requires either an increasing integration of discipline specialists into orbital image analysis or advanced training programs for available image analysts.

For aerial image evaluation, interpreters integrate the factor of shape, size, pattern, shadow, tone or color, texture, and relation to surroundings to data yield. For orbital image analysis, many of these principles may be difficult to apply directly. For example, shadow becomes less significant for detection of objects using orbital images while relative color variations, pattern, tone, and texture increase in importance.

RESOLUTION

Resolution as a requirement for successful task fulfillment has often been used as a relative measure of image quality. Data quality, however, has been too often confused with high resolution when quality is better expressed as sufficient-not excessive-detail for effective data yield.

Considering atmospheric and climatic degradation, it is difficult to define specific data elements which can be collected at a specific ground resolution, or that at a given resolution optimum data yield is automatically guaranteed. Nevertheless, task data elements repeatedly falling within a range of resolution values provide a measure of detail necessary for task fulfillment, and guidelines for operational earth resources survey imaging sensor selection. There are, however, few quantitative data which relate specific space-detectable phenomena for detection, identification, and analysis functions of earth survey tasks.

As determined from sample high altitude rocket, Mercury, Gemini, and Apollo photographs, the resolution required for earth survey is particularly dependent upon target shape and whether a target consists of a single element or is part of a general pattern.

The resolution of the average orbital photograph which ensures useful resources data yield varies from 100 to 500 feet for vertical images and up to 900 feet for selected low oblique photographs. Images with ground resolutions of 100 to 200 feet (comparable to those projected for the earth resources satellite) are relatively uncommon, although Apollo images obtained over haze-free areas have estimated ground resolutions of 100 feet or less from which resources data can be extracted. In general, resolutions in excess of 500 feet prove satisfactory for

regional oceanographic and geological surveys and, to a limited degree, for studies of land use. For both oceanography and geology, it is significant that many phenomena of interest are of a size and distribution that can readily be studied at coarse resolution. For hydrological, agricultural, and forestry studies, including a survey of acreage under cultivation and production estimates, resolutions of less than 100 (and probably 50) feet are essential.

Regarding operational uses, resolution studies provide a basis for determining effective data collection and at the same time for sizing telemetric data loads. It is unrealistic to project data return at levels of detail in excess of those operationally needed considering probable data transmission and ground handling limitations during early earth survey missions or, more likely, systems or data retrieval constraints.

As resolution variations exist between different orbital images and missions, so also do changes in obliquity which can be assessed with relation to their impact on effective collection. Where high frequencies of observation or rapid response time are inherent to task success, a critical concern involves acceptable target angle of view. Assessment of earth orbital images to determine changing data yield at varying angles of view (considering that there may be insufficient time to await the next period of direct satellite overpass) provides data as to viewing angles which may be tolerated without reduction in data yield. In some instance, e. g., detection of air pollution plumes, oblique viewing apparently increases

data yield. Although often disregarded due to the necessity for rectification and difficulty in data transfer to base maps, oblique images provide excellent mapping tools when a high degree of metric precision is not required, a metric base exists, or large area coverage is desired. This especially applies to some types of geological mapping and specifically fracture trace detection. Oblique images combined with low solar illumination levels prove particularly effective as survey mapping tools. Specifically, several areas shown on 1:5,000,000 scale maps of Africa have been experimentally updated using Gemini images with oblique angles as great as 60 degrees. Oblique angles of greater than 60 degrees from nadir are less satisfactory for scientific surveys because atmospheric turbulence and atmospheric scattering degrade image quality and further complicate basic metric measurement.

Opportunities for effective data collection using oblique rather than vertical photography affects earth resources satellite instrument-pointing requirements. It may not, for example, be possible to pass directly over specific areas with the frequency required for maximum data yield. The full value of oblique imaging for actually increasing data yield has yet to be fully defined.

A variety of films used on unmanned rocket and manned orbital space flights provides a base for evaluating the potential contributions of returned film capsules to selected earth survey problems. Both panchromatic and color films have been used on Mercury, Gemini, and Apollo missions. Color infrared film used during Gemini VII is poorly exposed and of marginal

value, although Apollo 9 data emphasizes its value in support of color coverage and specifically for agricultural and land use studies. Camera-carrying Aerobee rockets used black and white infrared film to limit the effects of haze and suggest such films are a useful supporting mapping tool for hydrologists.

Mercury, Gemini, and Apollo image data yield is significantly greater using color as opposed to panchromatic film, and probably black and white infrared film. Gemini and Apollo color photography emphasizes that color is increasingly critical for optimum multidiscipline data yield at resolutions poorer than 300 feet. Color increases the speed and accuracy of identifying and differentiating geological, hydrological, and oceanographic features and provides photo-analytical clues which ensure positive identification at low thresholds of image detail. Orbital photographs often reveal the "forest" instead of the "trees" and specifically that undetectable or apparently meaningless aerial photographic color variations may be integrated by the coarse-resolution space image "filter" for coherent analysis.

Multispectral terrain photography obtained from the Apollo 9 mission was intended for use in assessing the information quality of color film which might be recovered from orbit or data obtained from vidicon systems with appropriate filters. Using a 4-camera battery with simultaneous exposure, film loads included Ektachrome infrared aerial film with three emulsion layers covering 0.51 to 0.6 micron, 0.61 to 0.7 micron, and 0.7 to 0.91 micron bands. Vegetative reflectance in the near-infrared region of the spectrum was recorded. Panatomic X black and white aerial film

with a green filter covered the 0.48 to 0.62 micron region to maximize penetration of lakes and marine waters. With a red filter and Panatomic X film, the 0.59 to 0.72 micron band served for land use mapping. SO-246 black and white infrared aerographic film with a dark red filter covered the 0.7 to 0.9 micron region for studies of vegetative vigor and evidence of disease.

Following preliminary review of Apollo 9 data, color infrared orbital photography can be safely judged superior to color photographs for defining vegetative variations. For nearshore marine surveys, color infrared film records define the interface between vegetated backshore areas, beaches, and zones of sediment saturation.

TABLE I

Discipline	ERS Tasks	Compatibility with Early ERS Profile		
		Basic Mapping Mission	Sensor Mode	Apparent User Interest
AGRICULTURE	Land Use Survey	1	1	1
	Soil Survey	1	2	2
	Rangeland Survey	3	3	3
	Crop Identification	3	4	3
	Timber Inventory	3	3	2
	Forest Fire Detection	4	3	3
GEOGRAPHY	Mapping, 1:1,000,000 scale	1	1	1
	Mapping, 1:250,000 scale	1	1	1
	Mapping, 1:62,500 scale	2	3	3
	Mapping, 1:24,000 scale	2	4	3
	Urban Surveys	3	3	3
GEOLOGY & GEOPHYSICS	Geological Mapping, 1:1,000,000 scale	1	1	1
	Geological Mapping, 1:250,000 scale	1	1	1
	Magnetic Mapping	3	4	3
	Radiant Temperature Mapping	3	3	2
	Mineral/Petroleum Survey	2	1	1
	Volcanic Belt Reconnaissance	3	2	2
	Volcanic Eruption Damage Assessment	4	4	3
	Earthquake Belt Reconnaissance	3	2	2
	Earthquake Damage Assessment	4	4	3

TABLE I (Continued)

Discipline	ERS Tasks	Basic Mapping Mission	Sensor Mode	Apparent User Interest
HYDROLOGY	River Basin Mapping	1	1	1
	Water Pollution Survey	3	3	3
	Soil Moisture Survey	1	2	2
	Groundwater Survey	3	3	2
	Atmospheric Water Loss Survey	4	3	3
	Sedimentation Survey	3	3	2
	Erosion Survey	3	3	2
	Flood Mapping	2	4	2
MARINE	Ocean Mapping	1	1	2
	Commercial Fish Location (Support)	2	2	2
	Sea State Survey	4	3	1
	Nearshore Marine Surveys	1	1	1
	Coastal Engineering Survey	2	3	2
	Coastal Damage Assessment	3	4	3
	Navigational Hazard Survey	4	3	2
	Marine Pollutant Survey	3	3	3

Table I. Orbital Applications Priorities

Candidate applications include those suggested over the past five years by potential users and exclude those with purely scientific research objectives. Non-imaging tasks involving the interrogations of ground sensors such as river gauging, instruments,or buoys have also been eliminated.

A principal objective of early earth resources survey (ERS) missions includes establishment of a worldwide "cartographic" data base against which future surveys may be compared, and which would be contributory to multi-user applications. The priority key for basic mapping survey tasks follow: (1) Basic mapping requirement inferred; can supply more than 75 percent of applications data required by users. (2) Basic mapping requirement; can supply estimated 50 percent of applications data. (3) Basic mapping requirement; can supply estimated 25 percent of applications data. (4) No basic mapping; observational (monitoring) survey.

Three candidate ERS profiles appear likely: three V cameras for multispectral survey (Mode I); Mode I plus radiometer(s) (Mode II); and Mode II plus radar system (Mode III). Mode III is probably incompatible for an early ERS mission because of limiting power requirements, and Modes I and II are considered most feasible. Considering of the forementioned early ERS sensing modes, the following key is assigned: (1) Task can be successfully accomplished using Mode I. (2) Task can be successfully accomplished using Mode II or III. Sensor Modes II or II can remotely

contribute to solving the task. (4) Sensor modes' characteristics largely incompatible with task accomplishment.

Assessment of published literature and user contacts suggest user interest for early orbital application varies with potential ERS tasks, and the following key has been established: (1) Application has enthusiastic user support. (2) Application has continuing user interest. (3) Application of user interest, but little immediate opportunity for orbital success.

Considering these impacting factors, and using simple summation, a total of (5) or less suggests tasks of first priority. A comparable approach permits ordering of tasks within disciplines, and with respect to one another.

TABLE II

Suggested General Orbital Survey Activity	Resolution (Feet)		Tolerable Maximum Angle of Obliquity	Minimum Solar Illumination Angle
	Detailed Survey	Reconnaissance Survey		
AGRICULTURE/FORESTRY				
Soil Studies	(1)	< 50	45°	30°
Land Use Survey	50-100	100-300	45°	60°
Rangeland Survey	< 30	30-100	45°	60°
Fire Detection	N/D	300-400	70°	15°
Timber Inventory	< 50	100-300	N/D	60°
Timber Production Survey	(1)	N/D	N/D	60°
Crop Survey	(1)	(1)	N/D	N/D
GEOGRAPHY				
Mapping, 1:250,000 Scale	20-50	50-200	±5° +	30°
Mapping, 1:1,000,000 Scale	50-100	100-500	±5° +	30°
Industrial Studies	(1)	< 30	< 15° +	60°
Transportation Surveys	< 50(1)	50-100	< 15° +	60°
Urban Area/Dynamics Studies	< 20(1)	20-50	< 15° +	60°
Settlement (Regional) Planning	20-100	100-300	< 15° +	60°
GEOLOGY				
Geological Mapping, 1:1,000,000 Scale	100-300(2)	300-000	45°	20°
Geological Mapping, 1:250,000 Scale	50-100(2)	100-300	30°	20°
Mineral and Petroleum Surveys	50-100	100-300	30°	20°-60°
Heavy Metal (Coastal) Surveys	50-100	100-500	45°	60°
Earthquake Belt Studies	N/D	100-300	60°	N/D
Volcanic Belt Surveys	N/D	100-300	60°	N/D
Catastrophic Damage Assessment	< 20(1)	N/D	N/D	N/D

(1) Data probably best collected from aircraft N/D Not Determined (2) Assuming metric base is available

TABLE II (Continued)

Suggested General Orbital Survey Activity	Resolution (Feet)		Tolerable Maximum Angle of Obliquity	Minimum Solar Illumination Angle
	Detailed Survey	Reconnaissance Survey		
HYDROLOGY				
River Basin Mapping	100-200	300-400	30°	60°
Primary Streams	200-300	300-500	30°	60°
Tributaries	50-100	100-200	30°	60°
Water Pollution Survey	< 20(1)(3)	20-50(3)	N/D	N/D
Ground Water Discharge	20-100	100-300	60°	N/D
Soil Moisture Survey	50-100	100-200	N/D	N/D
Reservoir/River Sedimentation Survey	< 50	50-100	30°	30°
River Basin/Lake Bank Erosion	< 10(1)	10-50	N/D	30°
Flood Survey	20-50	50-100	N/D	30°
Fluvial Effluents	200-300	300-500	30°	20°-60°
MARINE SCIENCES				
Commercial Fisheries Survey (Environmental elements)	100-200	200-500	30°	60°
Coastal Engineering Planning	20-100	100-300	45-60°	60°
Navigational Hazard Studies (Reefs, Shoals, Bars)	100-200	200-400	30°	60°
Marine Pollutant Survey	N/D	100-200(3)	N/D	N/D
General Nearshore Marine Survey	200-300	300-500	45-60°	60°
Offshore Bar Growth	20-50	50-200	30°	60°
Nearshore Processes	50-100	100-500	60°	60°
Open Ocean Surveys	N/D	1000	N/D	N/D

(3) Multispectral techniques

REMOTE SENSOR STATUS AND RESOLUTIONS AVAILABLE

Status of Visible Region Sensor Development

Sensor development falls under the general categories of visible region, infrared, and microwave sensors. Some of the sensors tested in the Earth Resources Survey Program have been developed for meteorology (TIROS, NIMBUS) and terrestrial survey (GEMINI, APOLLO).

Various color, black and white, and multispectral cameras have been flown over many test sites from aircraft and spacecraft. The following tabulation lists these and other visible region sensors flown or planned including lasers,* multispectral imagers and imaging spectrometers. The practical resolutions shown are presumed for instruments in aircraft at 2000 meters altitude and spacecraft at 450 Km, with high resolution film for cameras.

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AIRBORNE

Sensor	Platform	Comments	Airplane or Spacecraft Spatial Resolution	
			Air	Space
ITEK 9 lens Multiband Camera	NASA MSC P3A	Satisfactory as airborne research camera to study various spectral bands for agriculture, geology, etc.	1m	100m

* Vehicle-borne laser scanners are "active" rather than passive (such as a camera or radiometer.)

Sensor	Platform	Comments	Spatial Resolution Air	Spatial Resolution Space
RC-8 Color Camera	NASA MSC RB-57 C-130, P3A	Satisfactory for broad band color and black and white photography from aircraft. 6" focal length and 9" x 9" film format could be used from space platform. Ocean photography should use multiband cameras with blue, blue-green, green, and red bands for better results.	1.5m	150m
6-70mm Hasselblad Multiband Cluster	NASA MSC C-130 RB-57	These multiband cameras are useful airborne research cameras for general terrestial purposes.	3m	500m
Scanning Image Spectroradiometer (SIS)	NASA MSC RB-57F	This narrow band imaging spectrometer is the first instrument designed for agronomists, geophysicists, oceanographers. Developed by TRW, it will undergo laboratory, field, and aircraft testing prior to space use. This airborne version will be aboard NASA MSC aircraft Sept. 1971.	10-20m	1000m 2000m
Zeiss Mapping Camera	NASA MSC RB-57F	9" x 9" format, 12" focal length; 37°x 37° fov. Geographers want this 12" focal length for spacecraft.	1m	100m
Laser Profiler	NASA P3A	Sea surface wave profiles tested to better than 6" accuracy from low altitude aircraft; valid surface truth from aircraft; space implementation not considered presently for this instrument. OK for certain types of ground profiling.	15cm	NA*

* Not applicable

Sensor	Platform	Comments	Spatial Resolution Air	Spatial Resolution Space
24 Channel Multi-spectral Imager	NASA MSC C-130	This 24-channel imager will be available in 1971 with visible region near infrared, and thermal infrared channels. It is similar to, but improved over, the imager flown on the U. of Michigan aircraft.	10m	5Km
		SPACEBORNE		
Advanced Vidicon Camera System (AVCS)	NIMBUS I, II ESSA I, III, V, VII	OK for Hydrography, Coast-line, gross terrain changes.	NA*	3Km
70mm Color Photography	GEMINI 3-12 APOLLO 4-12	Many examples of useful 70mm color photography for surface features. APOLLO IX multiband photography potentially useful for most geologic, geographic, ocean and agricultural purposes.	2m	10Km
Multispectral Photographic Facility (MSPF) S-190	SKYLAB A (1973 launch)	A contract has been awarded by NASA for this six band high resolution camera cover-ing blue-green, green, red, near infrared, color IR and broad band color.	NA*	100m
Filter Wedge Spectrometer	SKYLAB A (1973 launch)	Proposed infrared spectro-meter will determine spec-tral distribution of solar reflected energy from 0.4-2.4 microns and emitted energy from 6.3-17 microns.	NA*	NA*
Multispectral Image Plane Scanner (MSPS)	ERTS A (1972 launch)	This instrument is a four-band multispectral scanner.	NA*	75 m

* Not applicable

Sensor	Platform	Comments	Spatial Resolution Air	Spatial Resolution Space
Return Beam Vidicon (RBV)	ERTS A (1972 launch)	This three band TV camera system will fly on ERTS A. A green (475-575 mu) red (580-680 mu) and near infrared (690-830 mu) bands will be in use. These bands are designed for terrestrial targets.	NA*	100-150m

Status of Infrared Sensor Development for Earth Scanning

Various infrared radiometers have been flown on aircraft for thermal measurements of the ocean surface, and, increasingly, land surfaces. In addition, spaceborne infrared radiometers designed primarily for meteorology have been evaluated for temperature contouring (current boundaries) of the ocean surface and inland water areas. The most recent infrared radiometers on NIMBUS III and IV and ITOS I are being evaluated for possible operational use for sensing surface temperature conditions.

A summary list of infrared sensors follows:

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AIRBORNE

Sensor	Platform	Comments	Spatial Resolution Air	Spatial Resolution Space
Airborne Radiation Thermometers	NASA MSC C-130 NAVOCEANO C-121	Profiling of sea temperature from low altitude aircraft show accuracy to ± 1.5°C.	NA*	NA*

* Not applicable

Sensor	Platform	Comments	Spatial Resolution Air	Spatial Resolution Space
2 wave-length infrared radiometer	SIO Aircraft	3.5-4.5; 4.45-5 wave-length bands radiometer used by Scripps Institution of Oceanography to measure temperature and heat flow from sea surface. Highly accurate for SST but not directly adaptable for spacecraft. OK for lake, river and swamp sensing.	100m	NA*
RS-14 Dual Channel Imager	NASA MSC P3A aircraft (0.3-5.5) (8.0-14) (3 ft resolution from 1000')	2-channel infrared thermal imagery shows horizontal thermal distribution. Not under consideration for space implementation.	6m	NA*
Infrared Spectrometer, Infrared Radiometer	NASA MSC P3A	These instruments have a 0.4° x 0.4° field of view or 6 foot resolution from 1000 ft. No consideration is given for these instruments for space implementation.	12m	NA*
24-channel Multispectral Imager	NASA MSC C-130	This 24-channel imager will be available in 1971 with visible region near infrared, and thermal infrared channels. It is similar to, but improved over, the imager flown on the U. of Michigan aircraft.	15m	1 Km
		SPACEBORNE		
High Resolution Infrared Radiometer	NIMBUS III (3.4-4.2)	This radiometer was designed for meteorological use but evaluation showed that major thermal boundaries were possible to detect.	NA*	3 Km

* Not applicable

Sensor	Platform	Comments	Spatial Resolution Air	Spatial Resolution Space
High Resolution Infrared Radiometer	NIMBUS IV ITOS I	These radiometers in 6.7, 11.5, and 10-12 bands are being evaluated for surface temperature charting.	NA*	2 Km
Filter Wedge Spectrometer	SKYLAB A (1973 launch)	Proposed infrared spectrometer will determine spectral distribution of solar reflected energy from 0.4-2.4 microns and emitted energy from 6.3-17.	NA*	10 Km
10-channel Scanner	SKYLAB A (1973 launch)	Contract let for blue, green, red, near infrared and thermal infrared 10-channel scanner.	NA*	NA*
Multispectral Point Scanner (MSPS) (Thermal Channel)	ERTS B (1973 launch)	Thermal channel to be added to ERTS A MSPS for later (1973) ERTS Satellite.	NA*	500-900m

Status of Microwave Sensors

Considerable research in laboratories, pier and tower measurements, and airborne microwave radiometry is underway to measure terrain and ocean surface roughness, and wind fields, sea and lake temperatures and the effects of foam, precipitation, and salinity on radiometric measurements over water.

Several microwave systems are scheduled for the SKYLAB A earth orbiting laboratory for a 1973 launch and the NIMBUS F satellite planned for a 1973 launch.

The following list shows the status of passive and active microwave systems in the NASA ERS Program.

* Not applicable

AIRBORNE

Sensor	Platform	Status	Spatial Resolution Air	Spatial Resolution Space
L, X and K band Passive Microwave Radiometer	Argus Tower	NRL demonstrated a correlation between brightness temperature and wind speeds for L, X and K bands. Ground truth for A/C program.	20-100m	NA* at this time
Multifrequency Microwave Radiometer (1.4;10.2;22.2; 22.3;32.4 GHz)	NASA MSC P3A	Over water missions flown in various wind and sea conditions. Data processing very slow. May be useful for agriculture, savannahs and lakes.	100m	NA*
Passive Microwave Imager (37GHz)	NASA AMES Convair 990	A profiler has flown over the Arctic Ice pack as prelude to development of an imager for NIMBUS F. May be used for dry-land profiling.	10m	NA*
13.3GHz Scatterometer (active radar)	NASA MSC C-130	Airborne flights have shown oil-slick detection and surface contour sensing capabilities.	5m	?
Four-Frequency Radar System (P.L.C and X bands)	NRL C-121	Presently the most reliable platform for the collection of radar back-scattering characteristics of the earth's surface. Also used for ice mapping and pollution studies.	3m	NA*
16.5GHz slide looking airborne radar (SLAR)	NASA MSC P3A	Fine for mapping (geodesy, etc.)	2m	?

* Not applicable

Sensor	Platform	Status	Spatial Resolution Air	Spatial Resolution Space
K Band SLAR	Westinghouse Aircraft	High quality imagery over land. Targets show sea weed, debris lines, etc. Not proposed for space at present.	1m	NA*
X Band SLAR	Goodyear Aircraft	High quality imagery over land.	1/2-1m	NA*
		SPACEBORNE		
10GHz Radiometer Scatterometer (RADSCAT)	SKYLAB A (1973 launch)	Contract with General Electric for this instrument for 1973 SKYLAB. Alternate passive and active signals to be evaluated over various sea roughness and sea temperature conditions. Possible terrain applications.	NA*	150m
10GHz Radar Altimeter	SKYLAB A (1973 launch)	Altimeter to contribute to fundamental research in satellite altimetry for sea level, sea slope, and geodetic applications.	10m vertical	10m
19.3 GHz Radiometer Imager	NIMBUS E	Designed to measure water vapor in the air column, but will have some capability to observe the earth's surface.	NA*	NA*

* Not applicable

SUPPORTING INSTITUTIONS NEEDED IN DEVELOPING COUNTRIES

Before listing ERS institutions, facilities and personnel required for developing countries, it should be noted that many developing countries lack:

1. Radio tracking and telemetry facilities
2. Communication satellite links
3. Wideband land line or micro-wave links
4. Advanced teletype
5. Analog to digital data analysis and management systems, including suitable computers
6. A local "Bureau of Standards" where electronic/electrical, agricultural, agronomical and photographic base lines are established.
7. Trained photogrammetricians and facilities, such as: stereo-viewers; image analyzers; image converters; digital storage or analysis modes; color photoprocessing and standards laboratories; and film cutting and cassetting benches.
8. Photo interpreters and pattern recognition experts
9. Modern weather forecasting facilities, including automatic picture transmission (APT)
10. Well-staffed government or university departments of agronomy, hydrology, geology, cartography, civil engineering, and ecology and environment.
11. Aircraft and camera and instrument maintenance and servicing facilities.
12. Direct person-to-person links with U.S. personnel and facilities for obtaining ERS data on a quick "turn-around" basis.
13. An adequate network of ground truth correlation sensors, such as seismic and atmospheric sensors, ground, moisture and chemistry, detectors, coastal-zone buoys, river gauges, etc.
14. Geographically well-established grids of railroads or roads or other points, as bench-marks for ERS or other remote sensors.

It is not possible, nor is it necessarily desirable to establish all of the above in a developing country, before a remote sensing program is initiated. However, the following are considered minimum manpower/facilities goals for a remote sensing endeavor in a developing country:

1. An established link with U.S. ERS data management centers;

2. An APT ITOS/NOAA satellite link;

3. Telefax, teletype and weather facsimile links;

4. An office of remote sensing evaluation staffed with a photogrammetrist and photo image interpreter and liaison with the country's agricultural, hydrological and geological experts. The office should be equipped with image display devices, a photo reader and dissector, a grammetric/topographic converter and a complete set of topographical maps.

5. If aircraft usage is planned, an operations office should be established for logistics scheduling, etc.

6. A ground-truth sensor network should be established

Thus, the flow of ERS data to developing countries from developed countries should be scaled to the formers' capabilities to assimilate the data of various kinds. The capabilities will gradually be expanded through education, training, and laboratory experience.

For the developing countries the following ERS-usage steps might be appropriate:

1. Selection of one or more scientists or engineers who can relate color photography of the country to surface conditions. This group should have some stature and be able to develop strong rapport with the governmental departments concerned.

2. The group should have access to APT and meteorological data.

3. An ERS instruction package should be prepared by U.S. agencies for use by the group. The ephermeris of ERTS and other spacecraft with times and nature of specific coverage of a given area or country should be included in the package.

4. Three or four basic training centers for teaching the essentials of ERS photointerpretation should be established on a regional basis, e.g., N. Africa, E. Africa, Central America, etc. Techniques of data management, computer analysis and storage, etc., might be part of the curriculum.

Cost Factors

It is impossible to estimate the cost of technologies related to remote sensing, that would have any meaning in the context of this paper.

The following sums up the situation:

1. Airplane coverage is easiest to estimate, although costs vary widely from one country to the next, for reasons of logistics, etc.

   To scan 10,000 square miles of Ethiopia from 5000 feet, with 5 foot resolution, should cost about $20,000, assuming clear weather during the scan, with a King Air 2-engine turboprop. This includes development of 2000 photographs and cursory analysis. Thus, the cost is about $2/square mile.

   To scan the same area in Chad, might cost about $35,000, since the base of the aircraft would have to be at least 500 miles from the scene.

2. ERTS and Skylab apportioned time for a subject country is impossible to estimate and NASA cannot supply a cost/hr. of the spacecraft.

   It is suggested that this question be left in abeyance until a basis can be established.

3. An ERS instruction package should cost about $12,000 to develop, print and distribute.

4. Four regional centers, in, say, Africa, with data links, apparatus, and 4 U.S. or other experts in residence, should cost about $110,000 per year to operate and $150,000 to establish: including

   -- building modification, and air-conditioning ($15,000);

   -- photo developer, reader, scanner, image analyzers (about $60,000); and

-- communication links, CDC 600 computer, etc. ($75,000)

5. An APT station could be built for about $1,000, depending on local electronic expertise and resources.

PHASE IV

APPLICATION OF REMOTE SENSING TECHNOLOGY

The tasks of this phase were to review remote sensing procedures as applied in the U.S. for solving specific problems, in a cost-effective manner, and to determine how the U.S. experiences can be adapted to developing country applications.

Remote sensing, defined literally, is the detection and acquisition of data from a "subject" (i.e., object) without the mechanism of a physical or electrical coupling.

Aerial photography has been the "classical" remote sensing technique, used extensively in the U.S. and elsewhere for agriculture, geography, forestry, geology and geophysical exploration, water balance (i.e., hydrology), mapping and surveying (e.g., urban planning, road location, dams, etc.), and coastal zone activities.

Aircraft based photography is still the prime and most widely used technique although spacecraft photography, historically from Gemini and Apollo spacecraft and, in the future, from Skylab and other spacecraft will permit much more extensive terrain coverage and may also, because of the unique altitude and picture repetitiveness, yield information difficult or impossible to achieve from even high flying aircraft.

While sophisticated photography, (near I.R., color, multispectral, new high resolution films, etc.) will provide the mainstay of remote sensing for the foreseeable future, an increasingly important primary, or, supporting, role will be played by electromagnetic imaging and sequential strip sensing (video, radar, passive microwave, I.R., etc).

Some examples follow, where photography and the above have been applied to specific development problems in the U.S. These sensing examples, while often ancillary to ground-based measurements, were able to stand on their own merits and were done where conventional techniques proved too expensive because of poor terrain accessibility, lack of local ground facilities, time constraints, etc.

Representative Examples:

a. Agriculture

Airborne scanner data were obtained on 6 May 1966, and 30 June 1966 over an agricultural area near Lafayette, Indiana, using the University of Michigan multispectral scanner. The purpose was to recognize and map winter wheat and measure its acreage.

Representative fields were selected from the data to be used as training sets from which to extract crop signatures. A single signature was adequate for some of the runs while others required two signatures and for one run, four signatures were needed to cover the range of wheat conditions represented.

During the set-up procedure, no significant false detections were observed, and therefore, no background signatures were used. Processing was based on the decision that the data were sufficiently similar to the signatures selected.

The data were processed at real-time rates using analog recognition circuitry. The output was recorded on 70 mm film to provide maps showing the locations and sizes of all fields detected.

The strip maps were analyzed to determine the success of the automatic recognition of winter wheat, as a crop type, for two different stages of the wheat life cycle, and for two different altitudes. Recognition percentages were obtained and causes of non-detection and false detection of wheat were determined from ground-truth data and interpretation of aerial photography.

A comparison between the May and June recognition results using the 3,500 ft. data revealed that in May, 84% of the total acreage of winter wheat was detected using only a single signature, whereas in June two wheat signatures were required to detect 87%. The area covered by the 10,000 ft. data was larger than that covered by the 3,500 ft. data; consequently, a greater number of conditions of wheat were represented. Processing results of the high altitude data indicated that four signatures were requied to detect 72% of the total winter wheat in the scene.

The geometric boundaries of a wheat field (basis for calculating 100% detection) do not necessarily contain wheat exclusively, or wheat of uniform spectral characteristics. Fractional portions of wheat fields having lower ground cover and thus different signatures, than that found in the training-set field were not detected in the May data. For the June data, lodged wheat, immature green wheat, dead-ripe wheat, and harvested wheat were also, quite correctly, not recognized. However, because these

processing techniques are capable of discriminating subtle differences in the spectral radiance of wheat which are indicative of crop productivity, recognition results using a larger number of signatures have provided more accurate information for estimating wheat yields.

The University of Michigan has developed various techniques applicable to the remote sensing problem for agriculture. These techniques apply the tools of pattern recognition to the determination of the minimum number of spectral characteristics which will allow target detection against specified backgrounds. To provide input for these techniques, analytical models have been constructed for determining the radiance reflected from an agricultural scene.

b. Geography

Geographical analyses from remote sensing data, particularly photographs, permit various scientific data of the earth's surface to be brought into proper regional and country-wide perspective, thus yielding a sound inventory of cultural* and physical assets and features.

For example, a Gemini 4 photo (S65-34776) taken with a 70mm Hasselblad Model C showed about 10,000 square miles of the western end of the Gulf Coastal Plain of the United States between Laredo and Uvalde, Texas. Located south of the Balcones Escarpment, this area includes the upper part of a gently falling coastal plain, an undulated surface of Tertiary (especially Eocene) deposits.

Clouds partly cover the land in the west along the Rio Grande. Several streams and creeks are cut in the plain, having formed shallow, broad valleys. This is mainly the drainage basin of the Nueces River,

* Towns, roads, potential road beds.

which receives tributaries from the west and the south.

The water divide is not very obvious or easy to establish. A more conspicuous feature is the reddish soil formation of the Duval series that crosses through the center of the picture in a large belt from south to north between the light-gray soils of the Maverick series in the west and the brown-colored soils of the Victoria series in the east. The terrain conditions of the Nueces Valley floor are different (drier and supporting less vegetation) in the area of the Duval soils. The color photography brings out these soil differences much better than the black and white.

The land has a semihumid climate with from 20 to 25 in. of precipitation. It is known as brushland because of its subtropical vegetation of small trees (mesquite), thorny shrubs, cactus, weeds, and short grass, called mesquite-chaparral. The valley floors have different water conditions and denser vegetation, including different trees such as pecan, elm, oak, etc. This green vegetation in combination with the wet soil, sometimes even swampy ground as in the lower Nueces Valley, makes the dendritic drainage pattern very evident in the photograph.

Ranching of cattle, goats, and sheep is the main use of this brush country. But the same region has also another name, the "winter garden," where all kinds of vegetables and fruits are produced. If the land can be irrigated, excellent harvests in late winter and spring can be expected. The irrigation water comes mainly from wells but also from stream reservoirs. The orientation of the field patterns around a town differs from place to place, and shows that Texas has no single standard type of land survey.

c. Silviculture (Forestry)

The only feasible way of obtaining detailed resource information over large forested areas is by means of sampling--even when remote sensor data is used. Aerial photography has been employed in increasing the efficiency of forest sampling for many years. Substantial increases in sampling efficiency have been attained by means of generally available resource photography. However, good as these methods are, there has been a slowly developing desire to obtain current estimates more frequently and at the same time with greater reliability over a variety of parameters. With the advent of high altitude aircraft and spacecraft has come an increased interest in the potential application of small scale imagery to forest inventories. One limitation in the use of such imagery in forest surveys is the difficulty of identifying specific sampling locations that are small enough in size to be measurable on the ground.

However, in 1968, the Forest Service, U.S. Department of Agriculture, Berkeley, California became involved in developing new multi-stage sampling theories, using the additional information available at each stage, in conjunction with timber mortality surveys and on one national forest management plan inventory. From these studies, it became apparent that some combination of small scale and large scale imagery would be useful in several kinds of forest inventories from intensive management plan inventories to extensive forest surveys. What finally evolved was a new multi-stage sampling technique with arbitrary probabilities of selection at each stage. The sampling probabilities at each successive stage are formulated from the additional information obtainable by virture of the increasingly finer resolution of remote sensor data at

each stage. Finally, at the last stage, measurements are obtained on the ground.

The method has been proven to be unbiased and the estimates are independent of the quality of the imagery. The sampling errors on the other hand, are directly dependent on the accuracy of the predictions from the remote sensor data. Perfect correlation between the predictions and their corresponding measurements in a sample would result in a sampling error of zero, regardless of sample size. Therefore, better remote sensors, and better methods for extracting reliable data about forest resources from the imagery has the direct payoff of increasing the efficiency of sample surveys when using this method.

The general sampling technique has been applied successfully on several varied kinds of inventories. Most recently, it was applied to a five stage timber inventory in Louisana and Georgia using Apollo 9 space photography to define the primary sample units. This inventory was highly successful, operationally,as well as statistically.

d. Geophysical Exploration and Geology

Many geological features and their subsequent geophysical interpretation and practical applications (seismic fault location, useful minerals, sediments, etc.) require a considerable sophistication in remote sensing exploration, as well as elegance in data interpretation by highly trained personnel.

Airborne geophysical searches and geological terrain feature scanning is "big business" and a well established one, in the U.S., Canada, and Mexico; this technique depends upon magnetic anomaly

measurement, color and multispectral photography and, increasingly, microwave, I.R. scanning and spectral gamma radiation analysis. Active (i.e. - radar) techniques are also important.

An increasingly powerful technique is the analysis of infrared emission spectra, using airborne infrared spectrometers.

For example, a joint endeavor by Lockheed Missiles and Space Company, Stanford University and NASA, Manned Spacecraft Center, obtained useful geological data from several airplane flights over Texas and Senora Pass (California) which yielded the following geological results:

(1) Padre Island at Brownsville, Texas is a quartz beach sand i.e., not carbonate or feldspar. The data are comparable either from 2000 ft. or 10,000 ft. above the target.

(2) The "granite" (Topaz Pk quartz monzonite porphyry) and "andesite" volcanics (Relief peak andesites of the Mehrten formation) at Senora Pass are,

(a) differentiable

(b) their contacts can be mapped in flight to ± 20 feet.

(c) identifiable as high silicic quartz-bearing rocks, and as more mafic, quartz-free rocks, despite the obvious difference in crystallinity, texture, form, etc.

(d) the data were repeatable on successive flights at 2000 ft. and 9000 ft. above the ground, while at 150-200 knots airspeed.

e. Water Balance and Hydrology

The determination of sub-surface water is one of the most demanding tasks for remote sensing. Such water has a very subtle "signature", at best, and visible ground surface features (vegetation, discoloring, etc.) are often lacking.

Yet the search for and discovery of such water is an urgent task both for the U.S. and developing countries. Although water remote sensing methodologies are less important or applicable for the U.S., certain regions in the Southwest and West Texas are relatively inaccessible to drilling parties and other ground-based exploration means. For such regions remote sensing can be economically rational especially if a sudden development arises (e.g. - a major mineral discovery demanding mining machinery, ore crushers, flotation vats, etc. - all water users).

Microwave radiometric techniques show considerable promise and have been applied for the detection of wet sands (sub-surface), "sink holes," etc. I.R. scanning is -- and will continue to be -- however, the promise sensing mode; black and white and color, or multi-spectral, photography have limited use for sub-surface water detection, but have proven to be a powerful tool for drainage line, stream gradient, stream and lake shore erosion, and savannah evaluation; occasionally springs have been located and mountain melted snow drainage and runoff have been clearly assessed from aircraft and space photographs.

f. Mapping and Surveying

General and grammetric photography really "shines" in these applications; indeed aerial surveying and mapping for dam, road, breakwater

and town construction was begun during the U.S. Civil War when army camps' layouts were photographed; by 1914 the German Army had an aerial survey battalion.

Over 100,000 new maps are produced annually, in the U.S. and elsewhere, many of them derived from aerial surveys, using photogrammetric cameras and techniques which approach the accuracy of ground surveys.

The Department of Housing and Urban Development and other Federal agencies as well as local state and private organizations make extensive use of aerial surveying and mapping, for "new town" layout, road building, locating sewer and water lines, and high tension electrical transmission line routing.

Space photography from Gemini and Apollo 7 and 9 showed the potential of this technique for wide area coverage, with image quality and precision approaching that of aerial photos.

For example, a picture of western Texas, taken from Gemini 4, showed directly, or by inference:

(a) a railroad,

(b) roads and highways,

(c) a road by-pass, and

(d) field boundaries

Similar information was revealed from a Gemini 5 photo of the El Paso and Tuarez area.

The two areas above resemble many of the less populated and productive areas of the world.

g. Coastal Zone Activities

Much of the U.S. and many developing countries have extensive

ocean or lake frontage. Besides such obvious features as silting, shoals, fish-breeding beds, dune formation, it will also be important to search for another important feature of shorelines: both lake and ocean fresh and brackish water springs.

As a typical promising methodology applied in the U.S. the following experiment by the Colorado School of Mines is described.

In 1968 and 1969 airborne infrared scanner imagery was collected over the Mono Lake, California, during four different missions to investigate the ability of a non-classified, airborne thermal infrared scanner to detect, delineate and evaluate shoreline fresh water springs. The Mono Lake test site was admirably suited for this investigation because its saline water is analogous to a marine environment, yet it is free from complicating effects of tides, currents and surf. Numerous fresh water springs flow into and under the lake.

Thermal anomalies apparent on infrared imagery arise from a temperature contrast of target and background, in the case of this study, from the temperature difference between fresh spring water and saline lake water. Shoreline springs and seepage can be detected in this manner. Some of the smaller springs that were detected were (a) less than 1 gpm (gallon per minute) with a temperature difference between spring and lake of 26° C, (b) 2 gpm and 8.5° C and (c) 120 gpm and 1° C. Under optimum conditions, springs can be detected when there is no difference in temperature between the fresh water (at its point of discharge) and the open salt water.

Cold sublacustrine fresh water springs were not normally apparent on the imagery because of extensive mixing with salt water. Such springs

did appear on some imagery, however, but only because nearby shoreline springs had created a surface sheet of cold fresh water which the upwelling current of (mostly) salt water disrupted, producing a warm anomaly.

Fresh water discharge patterns were delineated on infrared imagery. Temperature data, originally in the form of film density, were reduced to absolute temperatures and plotted to yield an isothermal map. Correlative use of a radiometer produced isothermal maps with temperature values within 0.5° C of ground control measurements. In the reduction process of film density to temperature, an incremental densitometer provided a rapid, adequate means of quantifying density.

From isothermal maps derived from the infrared imagery, the anomaly associated with a fresh water discharge was quantified. The area between successive isotherms was measured and this area multiplied by the difference between its average temperature and the temperature of the open salt water, the anomaly then being expressed in deg m^2. The size of a spring's temperature anomaly was found to be a function of spring discharge, spring water temperature, open salt water temperature and air temperature. Measured anomalies were correlated with (ground measured) spring discharge, and the effects of the other variables were empirically determined. Air temperature was the single most important variable. When the empirically derived corrections were applied to some twenty spring anomalies, their calculated discharges compared with actual measured discharges with an average error of 14% and negligible bias.

The optimum time to detect shoreline springs is when the anomaly on infrared imagery produced by the fresh water is greatest. In the case of Mono Lake, this optimum time is during pre-dawn hours in the early autumn and late spring.

The foregoing sample remote sensing applications and technologies were chosen as being representative of U.S. applications as they may pertain to lesser developed country (LDC) situations.

It is clear that no one U.S.-derived technology, applicable in the U.S., is readily transmittable or transferable to LDC problems. The economic, social, political and educational conditions, while varying widely from one LDC to the next, are, all of them, different enough from those extant in the U.S., to require special, modified methodologies.

For example: If a detailed geologic and grammetric scan of a remote U.S. region is desired, resources can be brought to bear promptly. We illustrate:

-- any one of several geophysical airplane-equipped companies, mostly based in Texas and Oklahoma, can be given specifications and task definition, placed under contract within several days, and appear over the scene within hours;

-- pertinent NASA space photos of the region can be ordered, obtained from files, or, better, personally sent for, within several days;

-- Federal, State or other charts, surveys or maps can be purchased and scanned within days;

-- if the site is quite inaccessible (rare, in the U.S.) helicopters or STOL aircraft can land ground crew (geologists, etc.) and equipment (seismometers, explosives, etc.) within hours, upon the site; and

-- the data from all the above can be quickly collated, correlated, interpreted and translated into action programs.

Such endeavors may be temporally or managerially, difficult to achieve in an LDC, when, as in the above case, a wide variety of sophisticated technology and activities is needed.

Nonetheless geological, mineralogical and geophysical surveys are being conducted. When capital, equipment and managers are mobilized, usually with economic motivation, then airborne mineral searches do move fast (although rarely as fast as the U.S. because of logistics, etc.) and useful minerals and other resources are found:

e.g. -- bauxite in Jamaica, the Guianas;

-- copper in Brazil, Chile, Ecuador, the Congo, Botswana;

-- nickel in the New Hebrides;

-- tungsten in Tanzania, Kenya;

-- tin in S.W. Brazil, Malawi; and

-- oil in many countries.

Aerial searches were an important factor in most of the above discoveries, although consulting geologists to the companies involved used space data on occasion (e.g., Occidental Petroleum Company used Apollo 9 photos for Libyan desert analysis).

U.S. airborne remote sensing technology is thus being adapted to the economic development needs of developing countries in many instances This will be extended during the next decade as the quest for natural resources intensifies, and as the governmental and private infrastructures are expanded and strengthened in these countries to more effectively utilize this technology. This process can be accelerated by the education and training of LDC scientists and engineers in the techniques and beneficial applications of remote sensing in context with their country's needs and by strengthening communications between the technical community and government officials responsible for agriculture, hydrology, energy, natural resources, transportation, health, and land use planning.

By providing earth technology satellite and Skylab data to the developing countries, the U.S. can broaden awareness of the utility of remote sensor imagery in contributing to the solution of important economic development problems. The flow of photography and imagery to developing countries should be regulated, however, according to the capabilities of the countries themselves to assimilate this material and to apply the information produced to their priority needs. Thus, over the long term, the effective utilization of remote sensing technology in developing countries will depend upon the degree of success in stimulating awareness of its potential, educating and training scientists and engineers in its application, and convincing governmental and industrial officials of its benefits. A first step in a long term effort toward expanding remote sensing applications was described in the preceding section, Phase III.

GAME COUNTING AND EVALUATION BY

PHOTOGRAPHY

NOTE: This paper was prepared for illustrative purposes only. Its inclusion in this report implies no commitment by the Agency for International Development or other U.S. Government agency.

GAME COUNTING AND EVALUATION BY PHOTOGRAPHY

1. Problem: To photograph and count and identify game in a typical 50 square mile, relatively primitive, tropical area, 4/year (2 in dry, 2 in wet season).

   Tasks:
   a. To select the most technically feasible and economical aircraft/camera system

   b. To summarize the estimated cost of several systems

2. Background

A systematic airplane surveillance scheme, which would yield precise animal count data, is subject to the following constraints and conditions:

Natural

- wind weator
- clouds
- precipitation
- sun intensity and position
- dust
- vegetation type and distribution
- water vapor
- terrain contract
- turbulence
- terrain contours

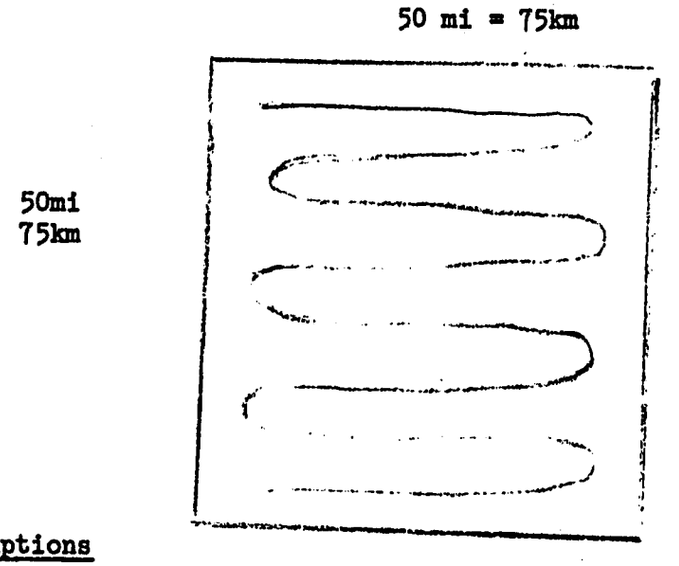
System Controllable Conditions and Features

- navigation (e.g. - references)
- plane altitude
- plane attitude
- camera system (optics, exposure, film)
- speed
- laboratory development
- laboratory analysis
- type of aircraft
- type of camera mounting and location in plane

Miscellaneous Semi - Controllable

- plane vibration
- ambient temperature (artificial, limited control possible)
- project duration
- plane noise (influence on game)

3. Project description



A. Assumptions

a. aircraft to make overflights in reasonable time, at reasonable cost
b. 2 foot ground resolution
c. minimum noise disturbance
d. animals do not move significantly during scan
e. nearby based aircraft to be used. (Ferry costs at least double the basic cost of such a project)
f. a local black and white color developing lab available
g. a local photogrammetric lab (or machinery)
h. negligible aircraft drift
i. local aircraft modification facilities available
j. camera to be "hard mounted" and pointing vertically
k. image motion compensation not desired
l. aircraft waiting time and other "down" time to be no more than 150% of flying time
m. a photo interpreter is available (if not, add to cost $200/day and transportation)
n. several short test flights are taken to obtain contrast ratios, pilot familiarity, etc.

B. Flight pattern

a. all photographs to be of grammetrical quality
b. 20% overlap
c. regular "strip" flying, with matrix identification
d. visual reference markers to be used; radio aids necessary in bad weather

5. Visual flight rules only, 500 feet below clouds, even with radio aids
6. operating altitude: 5000 feet (± 200 ft.), depending on local air traffic regulations

C. Optics

a. 90 degree field of view
b. cartographic quality, 10-15 lines/mm
c. 9 inch film, pan, super pan and/or color
d. single lens, (interchangeable filters, interchangeable lenses)
e. remote control desirable
f. intervalometer control desirable
g. standard, 6 inch f.l. (150mm) mapping camera, giving scale of 1:10,000, at 5000 ft.

The following considerations are also applicable:

a. 81 inch (9x9) images yield about 850 ft. sector/1" of film x81
b. 1 exposure, at 2 foot resolution, would yield a footprint of:

$$\frac{850 \times 850 \times 81}{5380 \times 5280} \sim \frac{2 \text{ miles per}}{\text{exposure}}$$

c. The total area is 50x50 = 2500 square miles
d. 1250 pictures produce coverage at zero overlap; 1500 pictures needed at 2% overlap
e. High speed (ASA 800), high-contrast, and high resolution film (pan xxx).
f. Cost of camera: $3000
1/300 sec exposure time is possible assuming average (i.e., 9a.m.) light conditions
g. at plane speed of 150 mph, at 5000 feet no lens panning or film movement compensation is needed

Table 1. Aircraft Comparisons and Specifications

	Light (Piper PA 18, Cessna 150)	Medium twin (Cessna 401)	Light twin jet (e.g.,Lear jet)
Still air cruising speed (mph)	100 - 150	180 - 220	500
Optimum service ceiling	5,000'	8,000'	30,000'
Range (miles)	500	900	1,200
Cost $/hr.*flight (includes pilot)	$30	$100	$700
Cost $/hr.*standby	$20	$ 70	$400
Cost of camera installation modification	$200	$300	$1,000
Hours required to perform one mission @ 50 scans per mission	17	12	6 (turn around time included)
Flight cost per mission	$510	$1,200	$4,200
Standby cost	$255	$ 600	$2,100
Total cost	$765	$1,800	$6,300

* Adjusted for assumed local conditions.

Summary of Comparisons

Cost per mission, assuming 50% extra standby time, no maintenance time, still air and visual flight rules.

Then:

light single = $765
light twin = $1800
light set = $6300

Note:

The above assumes the same camera for the twin props, and an equivalent camera for jet.

However: To use the full altitude and speed capacity of a jet, a professional grammetric survey camera, with image motion compensation should be used. Multi-spectral cameras are better, but film processing problems may rule this out. Then, at 2 foot resolution, with automatic aperture film compensation and latest film, a 50 mile foot-print area is available (at 30,000 - 35,000 ft.), which, at 500 mph. and a 10 mile by 5 mile footprint means 5 scans/mission, 1/10 of that postulated in Table 1. Therefore, jet cost/mission at 0.6 hrs/mission (assuming 5 scans is $600 plus 50% standby equals $900.

This makes a strong case for the borrowing of a metric camera of suitable quality, and therefore, the use of a jet.

Including modification costs, a final summary of cost/mission is, amortizing modification costs for 4 flights:

Single prop - $815
Twin - $1875
Twin jet - $1150

The jet also has the following advantages:

- less affected by cross winds, micro-turbulence
- less vibration microphonics
- higher navigational accuracy, assuming radio beacon aids
- quicker area coverage, and therefore less double counting of animals
- jet noise at plus 30,000 feet seems to have negligible effect on animals

Jet questions: Service? Larger airports in tropical countries have service capabilities; at least 2 private twins fly in per week during winter.

Rainy season flying conditions?
this is a major drawback; jet could fly below clouds, but must have 1,000 foot separation. at 500 ph and at, say 3,000 foot altitude, a special image compensation camera would be needed.

Availability? There are various twin engine aircraft in most countries at any one time. The question of commercial rental for only 4 missions, must be determined. It would be uneconomical to ferry a jet from Europe or the U.S. for such a limited mission. Estimated cost at 15 hrs. ferry time, plus standby 3 hrs. plus incidental fees is:

$10,500 + $1,200 + $1,500 = $13,200

Item: The twin prop is not necessary or desirable, except for heavy loads (e.g., extra observers) and safety margin.

Item: A helicopter is out of question for the following reasons:

- high noise level
- high vibration level
- limited space and load capabilities
- high cost per hour; Bell 47 G-4A, costs $200/hr., at 80 mph flying speed and service altitude of 4,000 ft. max.
- poor cross-wind navigation

Photo interpretation and analysis

- cost as stated before
- the availability of a trained interpreter may be most severe limitation

Everything points to making use of an existing local geophysical or agricultural aerial survey organization.

APPENDIX I

SMITHSONIAN/AGENCY FOR INTERNATIONAL DEVELOPMENT

SYMPOSIUM ON POTENTIAL APPLICATION OF REMOTE SENSING

TO ECONOMIC DEVELOPMENT IN DEVELOPING COUNTRIES

NOTE: Copies of the Proceedings of this Symposium can be obtained from the National Technical Information Service, Springfield, Virginia 22151

POTENTIAL APPLICATION OF REMOTE SENSING TO ECONOMIC DEVELOPMENT IN DEVELOPING COUNTRIES

AID sponsored a two-day symposium on November 19 and 20, 1970 as part of its effort to evaluate the role of remote sensing in resource development and environmental planning. Participants included U.S. experts in remote sensing applications, resource data analysis and dissemination, resource assessment and management, and resource economics. It was anticipated that subsequent symposia would involve specialists from the developing countries. Topics considered in invited papers and the following discussions included a review of past experiences with resource surveys in developing countries; new techniques of remote sensing which might be applied to future surveys; special requirements of particular countries in the area of resource development and management; technological, financial, and institutional barriers to effective application of remote sensing; sensing; the need for and utility of improved means of data storage and retrieval techniques; and identification of those techniques, systems, and programs with greatest potential for the developing countries.

BACKGROUND

In order to understand the importance of remote sensing for developing countries, it is first necessary to determine (a) the type, quality, quantity and timeliness of data required; (b) the most efficient means of collecting, analyzing, storing, and disseminating the data; and (c) the institutions, manpower, facilities, and mechanisms which make it possible to translate resource data into effective decision-making. In the absence of such a broad overview, there is a tendency to emphasize data collection and

technology which may lead to less than optimum allocation of resources by AID and the developing countries.

AID is relatively unique among Government agencies as it has an operational interest in development of a wide variety of earth resource data; it is basically user-oriented; and it has no particular institutional biases concerning the means employed in collecting data.

This symposium in which remote sensing was considered within the broad context of earth resource data requirements of developing countries served the following purposes:

1. It helped to balance the strong emphasis on sensing technology by directing more attention to questions concerning the types of data that will be most useful and how best to collect, analyze, store and disseminate such data given a variety of techniques and systems.
2. It helped to establish better communication among those who know they need data, those who don't know they need it, those who are expert in collection, analysis and storage, and those who are concerned with dissemination and utilization.
3. Insights and experiences from the meeting provided an input to the planning of the International Workshop on Remote Sensing (held at the University of Michigan in May 1971).

LOGISTICS

Administrative support was provided by the Smithsonian Institution on contract with AID. This included conference space and supplies, arrangements for travel of out-of-town participants whose travel will be

paid by AID, preparation of a summary report on the symposium, and dissemination of papers and the summary report.

PARTICIPANTS

The participants included invited experts from the fields of agriculture, forestry, minerals, economics, water resources, demography, remote sensing technology and information handling. These specialists made presentations based on prepared papers and participated in the discussion of the presentations. In addition invitations were extended to selected AID and other U.S. Government officials whose responsibilities included support and management of programs involving earth resource data.

AGENDA ITEMS

The following items were covered in the course of the symposium. Various participants were asked to present papers on each item. Group discussion followed each item. Following the seventh item was a wrap-up discussion and solicitation of recommendations concerning AID activities in remote sensing.

Item 1.

What are the economic considerations in assessing the role of remote sensing in country development?

Item 2.

To what extent has information obtained in surveys of earth resources been used by developing countries? To what extent have developing countries used information collected through remote sensing?

Item 3.

What type, quality and quantity of earth resource data has been and will be required by developing countries?

Item 4.

How will the new technology be useful to developing countries in fulfilling the need to monitor environmental parameters?

Item 5.

From the perspective of the developing countries, how will the new technology enhance capabilities to collect, analyze, store and disseminate earth resource data?

Item 6,

From the perspective of the developing countries, what type of U.S. research and development activities should be emphasized?

A. Data acquisition systems?
B. Data analysis?
C. Data storage and dissemination?

Item 7.

What kinds of institutions are required in developing countries to exploit the technology in the acquisition, analysis, storage and dissemination of earth resource data? What are the kinds of costs involved? What kinds of manpower are necessary and how can training requirements best be fulfilled?

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