Resource Sensing from Space

PROSPECTS FOR DEVELOPING COUNTRIES

NATIONAL ACADEMY OF SCIENCES

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RESOURCE SENSING FROM SPACE: Prospects for Developing Countries

Report of the Ad Hoc
Committee on Remote Sensing for Development
Board on Science and Technology
for International Development
Commission on International Relations
National Research Council

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1977

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Introduction

In mid-1974, the Office of Science and Technology of the Agency for International Development (AID) asked the Board on Science and Technology for International Development (BOSTID)* to examine the new technology of resource sensing from space for its potential value to developing countries, and, if warranted, to indicate steps that might be taken by means of technical cooperation to promote its transfer and diffusion abroad.

In more specific terms subsequently worked out, AID requested an assessment of the merits and effectiveness of the technology with particular reference to (1) its ability to meet information requirements of developing countries for resource surveying and environmental monitoring, and (2) its use as a tool in applications relevant to a country's development objectives. Further, it was expected the study would consider the probable character and effects of improved remote sensing systems that might become available within the next ten years, the institutional requirements that use of the technology by developing countries would evoke, and the various issues that would affect its dissemination and acceptance.

The request was made in the context of a continuing program of advisory studies performed by BOSTID, with AID sponsorship, of advances in science and technology that are important to the development effort. These studies generally are intended for a broad readership ranging from officials and specialists in AID and other bilateral and multilateral agencies engaged in technical cooperation, to policymakers, administrators, and technical personnel in developing countries who must weigh the applicability of unfamiliar technologies to their development problems.

Interest in remote sensing from space had been greatly heightened by the launching in July 1972 of the first Earth Resources Technology Satellite (ERTS 1, now renamed LANDSAT 1), and the ensuing diversity of assessments about the utility of LANDSAT data for various earth applications. Indeed, several major U.S. technical evaluations and reviews of LANDSAT performance were in progress at the time this study was proposed. One of

*The Board is a unit of the Commission on International Relations, National Research Council, which operates under the joint auspices of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

these was undertaken by the Committee on Remote Sensing Programs for Earth Resource Surveys (CORSPERS),* whom BOSTID invited to participate in overseeing the proposed study.

Work on the study was deferred for a year to allow these reviews to be completed and to give additional time for experience with LANDSAT data to be accumulated, especially in those developing countries beginning to make use of it. The Committee on Remote Sensing for Development was first convened in May 1975, and met again in January 1976. Informal working groups drawn from its membership, with the assistance of outside contributors, met at other times to address specific issues. The Committee consisted of 24 members, including 6 members from six countries other than the United States, all but one in the developing world. The members contributed a broad scale of experience ranging from the purely technical aspects of the technology, the disciplines and sectors in which it is finding application both here and abroad, to foreign policy and international organization.

It is fitting that the Committee make explicit the premises on which it proceeded and the boundaries it adopted to render its task manageable.

First, the Committee accepted the definition of remote sensing as applying primarily to the collection of data concerning the earth's surface from a satellite. It noted, wherever appropriate, the continuing importance of ground and aerial observation, but put the emphasis on the gains and new opportunities made possible by multispectral sensing from a platform in space.

Second, the Committee took as its point of departure the present LANDSAT system—a *given* whose cost had already been justified on grounds of U.S. domestic interest and whose further development and refinement as an innovative technology could be counted on as highly probable.

Third, in relating the technology to the resource information needs of developing countries, the Committee focused on those aspects which in the aggregate formed a broad common denominator. It did not attempt to tackle the larger and more complex question of developing country practices and capabilities in resource management. These, for the hundred or so nations that constitute the developing world, cover such a wide spectrum as to defy categorization or generalization.

Fourth, the Committee discussed several financial questions but eschewed any quantified valuation of the technology and its applications. Cost-benefit analysis is an uncertain art; its findings do not travel well. Cost-effectiveness figures may be more revealing, but as a rule are too particular to the specific problem, techniques, time, and place to which they apply to be cited for useful instruction. The calculation of benefit can be determined only by each

*A unit of the Commission on Natural Resources, National Research Council.

country in relation to its particular designs and circumstances, and to its intangible gains with respect to science education, indigenous research, and regional cooperation.

Fifth, the Committee felt that the matter of resource sensing from space could not usefully be examined in isolation from the important political problems it raises and which may significantly condition its future.

This last question—the international politics of remote sensing—proved to be a most difficult part of the Committee's assignment. To advise the Committee, a special group was formed, including both members and nonmembers of the Committee, and composed of Chairman Harlan Cleveland, William M. Capron and Abram Chayes of Harvard University, Richard N. Gardner of Columbia University, Bayless Manning of the Council on Foreign Relations, George Rathjens and Eugene Skolnikoff of the Massachusetts Institute of Technology, with the staff support of Julien Engel and Abraham M. Sirkin.

In the preparation of this report, the Committee and its staff obtained valuable information from many knowledgeable individuals in government and other agencies and in private organizations. The Committee wishes to acknowledge in particular the contributions of Charles L. Barnes, NASA; Seyom Brown, Brookings Institution; Alden P. Colvocoresses, U.S. Geological Survey; Jerald J. Cook, Environmental Research Institute of Michigan; Robert E. Durland, Bureau of the Census; Arnold W. Frutkin, NASA; Richard N. Gardner, Columbia University Law School; E. J. Greenblat, ECON, Inc.; Klaus P. Heiss, ECON, Inc.; David S. Landgrebe, Purdue University; Jules Lehman, NASA; S. Benedict Levin, Earth Satellite Corporation; Stuart McIntyre, Monterey Institute of Foreign Studies; Wilfred J. Mellors, European Space Agency; Richard Moke, NASA; James R. Morrison, NASA; Jacques Palgen, Earth Satellite Corporation; Archibald B. Park, General Electric Company; Priscilla Reining, American Association for the Advancement of Science; Charles J. Robinove, U.S. Geological Survey; Marvin Robinson, United Nations Secretariat, Outer Space Affairs Division; Thomas F. Rogers; Eugene B. Skolnikoff, Massachusetts Institute of Technology; William L. Smith, Environmental Research Institute of Michigan; Martin I. Stoller, Earth Satellite Corporation; William E. Stoney, Jr., NASA; Ronald Stowe, Department of State; Robert A. Summers, Energy Research and Development Administration; Paul G. Teleki, U.S. Geological Survey; Joseph A. Vitale, NASA; Richard S. Williams, Jr., U.S. Geological Survey; James V. Zimmerman, NASA; and George J. Zissis, Environmental Research Institute of Michigan.

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Foreword

By HARLAN CLEVELAND, Chairman
Committee on Remote Sensing for Development

This report conveys the findings and recommendations of a Committee named by the National Academy of Sciences to consider the relevance of present and future earth resource sensing satellites to resource planning in developing countries, and to suggest U.S. policies appropriate to the developmental and institutional issues to which this new family of technologies gives rise. It has been a privilege, and an enlightening experience, for me to serve as chairman of this Committee effort, representing the thinking of expert opinion drawn from seven countries.

The present technology consists of two orbiting platforms formerly called ERTS (Earth Resource Technology Satellite) and now renamed LANDSATs 1 and 2, each circling the globe 14 times a day and producing strips of "images." These images register energy reflected from the earth's surface in the visible and infrared portions of the electromagnetic spectrum and are transmitted to ground stations in a digital form that can be handled by computers. Virtually any area of the globe can be "sensed" up to 40 times a year, always at the same time of day (about 9:30 A.M.). The end products take the form of photolike images or computer tapes representing 3,000-square-kilometer "scenes" of the earth's surface. The present technology can distinguish, in four distinct spectral bands, earth features a little smaller than a football field (that is, the spatial "resolution" is 80 meters). Follow-on systems are planned to produce spatial resolutions of 40 and 30 meters and additional refinements of spectral definition. Much better resolution is already within the state of the art, but "a resource-surveying satellite does not need a spy satellite's fine vision. Users would be hopelessly swamped with data they couldn't process."*

The availability of imagery from LANDSATs 1 and 2, and the prospect of better imagery (finer resolutions, more frequent coverage, faster processing,

*G. Bylinsky, "ERTS Puts the Whole Earth Under a Microscope," *Fortune* 91:116 ff. (February 1975).

clearer modes of displaying information) from follow-on systems, present every developing country with a choice it never had to make before—whether to buy (or "read out" with its own equipment) the data about its resources these new satellites are "sensing," and combine them with other information from aircraft and ground observation; or, in the alternative, to forego this new increment to the power of information because it is too costly in trained people and money—and in the interdependence that active involvement with the technology does entail.

Our report tries to analyze what kinds of benefits may offset these costs. Three countries (Canada, Brazil, and Italy) already have their own ground stations; most others are purchasing images of their own sovereign slice of earth. But the experience with the use of remote sensing as an aid in resource management in developing countries is still so scant that most of our judgments have had to be based on evidence from practical applications in the United States. This evidence indicates present or potential usefulness of varying quality and importance in agricultural production (estimating crop acreage and yield, surveying soils), in the management of rangeland, forest, and water resources, in geologic survey and mineral resource management, in map making and population estimating, in land use planning, in health and environmental protection, in monitoring of marine resources, and in disaster warning and relief. Beyond these uses in local and national resource management, it seems likely that remote sensing imagery will be increasingly useful in transnational development planning (large river basins, deserts, forests, and shared marine areas) and in global efforts such as worldwide crop forecasting.

There is, we have learned, still a sizable gap between the technical experimenters and the resource managers even in the United States. In less developed lands, the gap between satellite imagery and information usable by planners and managers is much greater. Still, some experimental applications of remote sensing have been tried in developing countries and examples are cited in Chapter IV of our report; the presence of Committee members from Bolivia, Brazil, Egypt, Peru, and the Philippines was especially helpful to the Committee's understanding of this limited but suggestive experience.

It was not, of course, enough to analyze what could be done with imagery the existing technology can produce. We had to take into account—with the indispensable help of other units within the National Research Council*—the likely follow-on systems: the LANDSAT C Multispectral Scanner, scheduled for launch in the present decade; the Thematic Mapper with six or seven spectral bands of 30-meter resolution, planned for the early 1980s; and the potential of combined use of data coming from a variety of satellites and

*Notably the Committee on Remote Sensing Programs for Earth Resource Surveys (CORSPERS) and the Space Applications Board (SAB).

manned laboratories likely to be launched during the 1980s for missions bearing on the sensing of earth resources. The present state of planning and guesswork about future technologies is summarized in Chapter V of the report.

In less developed countries, the absorption of data from new sources into existing analytical and planning mechanisms is limited by the underdeveloped state of these very mechanisms. Shortages of trained people and a lack of familiarity with remote sensing among those who allocate funds, manage resources, control advanced education, and influence professional careers seem to be the main obstacles to realizing the benefits of remote sensing for economic and social development. Yet it is precisely to the developing Third World that remote sensing seems likely to make the biggest difference—that is, the significance of synoptic images may actually be more important in some fields (notably in planning land use, assessing agricultural troubles, and finding minerals) than in nations that are better mapped and more thoroughly explored. Chapter VI discusses both the short-term and long-term prospects for the effective use by developing countries of resource sensing data from space.

The leading role of the United States in experimenting with this new technology and our earlier role in writing the United Nations Outer Space Treaty (by which all signatories undertake to use space "for the benefit and in the interests of all mankind") oblige us to help enable the peoples whose resources we are daily "sensing" to take advantage of the images produced and openly offered for sale. Several agencies of the United States Government—notably the Agency for International Development, the National Aeronautics and Space Administration, and the Geological Survey—have special responsibilities to fulfill this obligation that flows from our use of the commons of outer space; what they can do is spelled out in Chapter VIII of our report.

We have considered, but did not find it possible to include in our report, the possible effect of remote sensing technology on the distribution of power, wealth, and income among and within the countries that use it. There is really no way to abstract the effects on social justice of this one tool for the exploitation of resources from all the other development tools.

As far as international equity is concerned, a developing nation clearly ought to have effective control of its own resources, and the more information it can get about these resources, the more effective its control will be.

However, in cases where resource exploitation redounds disproportionately to the benefit of outside investors (whether governmental or private), any new tool for better exploitation of those resources is likely to intensify the inequity. Information on economically valuable resources is obviously

most useful to those with the capital and know-how to use it—and historically they have often been large transnational enterprises (whether private or socialized does not affect the argument here). That situation is of course already in flux: governments of developing countries are learning fast the skills to extract larger royalty revenues, nationalize the resources which the outsiders have discovered, and band together for "collective self-reliance." In any event the antidote to international inequity is not to shun the means of growth, but to rearrange the controls and incentives affecting international trade, investment, and money in order to enlarge the share of the developing nations in the growth their resources make possible.

When it comes to equity within nations, the evidence is now overwhelming that economic growth does not necessarily lead to social equity. A study of 43 developing countries found that the poorest 60 percent of their people received only 26 percent of their national income—and the distribution of income in the mineral rich countries tended to be quite a lot worse than in the others. By any measure—nourishment, literacy, health care—there seem to be more poor people on earth (in good part because of sheer population growth) than before the succession of Development Decades was set in motion. The legacy of colonial rule is still part of the problem; but national independence and economic development have created their own elites and hierarchies with priorities other than a war on poverty.

The antidote to social injustice, however, is not to reject new tools for finding and measuring resources that are keys to development. It is, rather, to facilitate internal reforms designed to make the development process as a whole serve basic human needs—what the World Bank now calls "growth with redistribution."*

The most difficult part of our analysis turned out to be the international implications of remote sensing; the political dimension of this inherently global technology impressed itself upon us as inseparable from its technical evolution and as of particular interest to the developing countries. To advise

*Although this subject is beyond the scope of our report, it is important not to forget it in any consideration of new techniques for development. Much useful data are presented in Irma Adelman and Cynthia Taft Morris, *Economic Growth and Social Equity in Developing Countries*, Stanford, California, Stanford University Press, 1973; Hollis Chenery, *et al, Redistribution with Growth*, London, Oxford University Press, 1974; and John and Magda Cordell McHale, *Human Requirements, Supply Levels and Outer Bounds*, Princeton, N.J., Aspen Institute for Humanistic Studies, Program in International Affairs, 1975. Some policy implications are suggested in, among others, Irma Adelman, "Growth, Income Distribution and Equity-Oriented Development Strategies," *World Development* 3:67-76 (February-March 1975); and in *The Planetary Bargain: Proposals for a New International Economic Order to Meet Human Needs* Princeton, N.J., Aspen Institute for Humanistic Studies, Program in International Affairs, 1975, pp. 16-19. See comments by Professor Adelman on page 187 of this report.

the Committee in this area, we formed a special group, including both members and nonmembers of the Committee, whose names are listed elsewhere in this report.

To suggest what institutions should be built to contain, channel, and control new technologies is among the most demanding of interdisciplinary tasks. Sometimes, as in the Manhattan Project that produced the first atomic weapons, we do not even try until it is too late. Yet it is essential in fashioning complex systems to build the hardware and the human organization in parallel, not in series. In some cases—the World Weather Watch and INTELSAT are recent, though very different, examples—the institutional thinking has started soon after the perceptions of future technologies were reasonably clear. Much experience suggests that inventing and organizing effective international institutions takes at least as much time as is required to get from a proven scientific idea to a workable technological system.

In the case of remote sensing technology, we are dealing not with a single complex system—a deliverable nuclear explosion, an envelope of weather around the globe, a global network to handle familiar forms of communication—but with a new and rapidly expanding capability to contribute new and widely varied kinds of information to the whole of the development process, planned and unplanned. Images from remote sensors carried by space vehicles form part of a much larger arsenal of analysis that also includes observation from aircraft and innumerable facts and insights gathered on the earth's surface.

Because we are dealing with information, we are dealing with an element of power—in this case (if combined with capital and know-how), the power to develop resources, the power to meet people's requirements, the power to be self-reliant in an interdependent world. As of 1976, the United States of America has a quasi-monopoly of this new power, a situation not destined to last. What the American people through their government do about this made-in-America technology, how and when and with what conditions we share its capabilities with others, will very largely determine whether remote sensing becomes a source of international conflict or a major assist to meeting human needs through international development.

Our present monopoly of decision making about remote sensing from space seems bound to be eroded from two sides—by other industrialized nations' space programs, and by participatory damands from the nations whose territory we are sensing from space. The European Community, Japan, the Soviet Union, and India, among others, are considering experiments with earth sensing satellites, and a number of "sensed" countries are restive. Judging from bilateral discussions and by the debates in the UN Outer Space Committee and its Legal Subcommittee, these nations are variously worried that (a) the procurement of resource information by remote sensors is itself

an invasion of their national sovereignty, (b) the dissemination of such information to other countries and multinational companies may weaken their position in economic bargaining, and (c) remote sensing images may tell their neighbors something about terrain, security arrangements, or economic resources that they are not supposed to know.

These doubts and fears have not yet made remote sensing a major issue in "planetary bargaining." But one way or another, it seems inevitable and probably desirable that "consumers" along with other "producers" of remote sensing data will press to participate in decisions about the disposition of satellite imagery, the configuration of new sensors, and the management of reception and processing facilities on the ground. Our report recommends the formal recognition soon of the inherently international character of remote sensing technology. *The United States Government should declare soon that remote sensing systems constitute in effect an international public utility, destined for international governance.*

Chapter VII of our report discusses the varying modes of international organization that might prove to be appropriate to the case of remote sensing technology. For the system's ground segment, the apparent options are bilateral agreements with national ground stations, the establishment of regional stations, coordination through a specialized international agency (inside or outside the United Nations), or a unitary system owned and managed by an international body (inside or outside the United Nations). The space segment could continue to be owned and operated by the United States; it could be taken over by a consortium of those willing to invest in it (on the INTELSAT model); it could take the form of a multination arrangement in which several countries own remote sensing satellites but manage them as a single system (the World Weather Watch model); or it could be a fully international operating utility.

It may be premature to make a firm selection now among these options for several reasons:

- Other nations will remain reluctant to harness themselves to remote sensing technology as long as the United States has not given formal assurance of the system's continuity. Since the technology is still in an experimental phase and may take some years to become fully operational, the world is waiting for some clear indication from the United States that the system is to be a permanent part of the government's business. The Congress could clear up the ambiguity when it considers legislation to assign the system as a permanent function to some established, or specially created, agency of government.
- Thus far the United States alone has financed the R&D and operation of the space segment of the system. But once it is clearly a permanent part of

the international picture, some financial contributions could probably be secured in return for a real voice in decisions about management and about follow-on technologies. As new technologies go, remote sensing is remarkably inexpensive so far: total investment in the three LANDSATs (one yet to be launched) and the related U.S. ground systems will run only to $250 million, which would barely buy two modern destroyers or one nuclear-powered attack submarine. NASA's proposed budget for research and development in the area of resource sensing and environmental monitoring is $67.3 million for fiscal year 1977.

• Remote sensing technology is still in its infancy, and some important decisions yet to be taken need to be carefully considered to make sure they fit into a phased approach to internationalizing the system. One example will make the point: NASA is planning a communications relay satellite to pick up data from a variety of U.S. data-gathering satellites (meteorological, atmospheric, resource sensing, space research), and for purposes of economy and efficiency, to relay them to a single reception point in the United States. The data could then be retransmitted to users elsewhere in the United States and around the world. The costs and the technical problems that might be involved in speedy retransmission of resource sensing data to other countries are still unclear, and the likely consequence of this relay system for direct reception in other countries and regions (not to speak of their reaction to so centralized and American a system) is, at this point, unpredictable.

We have not recommended a U.S. position on the form of internationalization which might eventually fit both the technology and politics of global resource sensing from outer space. But it is important to make the following decisions soon:

• A public commitment now to the eventual establishment of an international regime. The U.S. should begin forthwith to develop its own proposal for such a regime, and conduct our own remote sensing affairs meanwhile so that they are compatible with later internationalization.

• A move (requiring Congressional action) to assure continuity of coverage and transmission to users of remote sensing data. A U.S. declaration of intent to proceed with further development of the technology would reinforce the presumption that remote sensing of earth resources is here to stay.

• A worldwide consultative effort, to cut both "consumers" and future "producers" of remote sensing data in on decisions about system management and follow-on technology. Some of the needed consultations might be handled as part of U.S. preparations for coming UN conferences–the two on water and desertification in 1977, and the UN Conference on Science and Technology for Development now scheduled for 1979.

A great deal of consultation, especially about detailed bilateral arrangements, is already engaged in by NASA; that agency has, indeed, long recognized an obligation to treat its global experimentation as an exercise in international cooperation. But the consultations here proposed would represent a different dimension and should be handled at a higher governmental level. Although we cannot now say just how this remarkable new technology should be organized to maximize its potential for human benefit and minimize its potential for international conflict, it represents the next major opportunity for American leadership in "world order politics." The declarations of intention we are proposing, and credibly open and vigorous consultations with those affected in other parts of the world, can do much more than just build consent for a viable system of financing and management. They are almost bound to improve the quality of our own national decision making for as long as we remain trustees of a new and beneficent global system.

I Summary and Recommendations

In this report the Committee discusses first the matter of resource information and its use in developing countries. It then describes, especially for the benefit of those unacquainted with it, the new technology of earth resource sensing from space. In two subsequent chapters the Committee summarizes the tested usability of the satellite data in various sectors of application and the improvements anticipated from future technological advances. The report then considers the prospects and problems of utilization of satellite data by developing countries, and proceeds to the international issues that need to be resolved to facilitate widespread availability and exploitation of the data. The report concludes with recommendations that address certain policy issues and technical cooperation initiatives that would foster the diffusion of the technology.

Below is a summary of the Committee's findings, in the sequence followed by the report.

Resource Information in Developing Countries

The primary base for the economic development of most developing nations lies in their natural resources. Yet these nations, on the whole, do not have thorough enough knowledge about the nature, quantity, and location of their resources to harness them effectively for the welfare and progress of their people.

Much of the developing world is still inadequately mapped. Many countries have yet to determine the extent and condition of their arable land, forests, rangeland, and water resources and to identify promising areas for mineral exploration. Vitally important, at a time of world food and energy shortages and of spreading environmental deterioration, is the need to monitor the changing condition of their natural domain—to forecast crop yields, to detect erosion of land and pollution of water, to recognize alterations in land use, to give early warning and assess damage of natural disasters, and to observe many other aspects of environmental change.

The nature, scope, volume, and detail of the resource information required will vary from one country to another. A nation's information needs will be

determined, among other factors, by its size, its development objectives, and the information already accumulated. Two factors set practical limits to the amount of resource information a nation can acquire and use: the costs of data acquisition, and the capacity of a country to assimilate the information and to utilize it productively.

Traditionally in all countries resource information has been acquired from different sources, gathered by a variety of means, and often maintained in separate agencies. For these and other reasons, national planners have rarely incorporated current and accurate resource information and environmental factors in their planning processes. The available national resource information has been more frequently integrated into planning for discrete development projects for which data requirements are generally more rigorous and sharply defined. Beyond the data wanted for national purposes is a growing demand for resource and environmental data required on a transnational scale to meet regional or global objectives such as crop yield forecasting, environmental monitoring, and river basin development.

For all these purposes the need exists for more comprehensive ways of looking at a nation's or region's resource base and for improved means, both technical and managerial, of making resource information count in development planning and resource management.

The Technology of Remote Sensing from Space

In the long evolution of techniques for resource information gathering, the first earth resource survey satellite, LANDSAT 1, launched by NASA in July 1972, represents a major technological advance. The new element is the combination of two recent technical innovations—the use of a space platform instead of aircraft, and the use of the multispectral sensor in place of the conventional photographic camera.

Moving in a near-polar orbit 920 kilometers above the earth, the satellite carries a Multispectral Scanner that senses, within four different wavelength bands, the relative intensities of light reflected from objects and features on the earth's surface, each of which has its distinctive band pattern or "spectral signature." These intensities are variously recorded in the selected bands—located in the visible and infrared portions of the electromagnetic spectrum—and are communicated by telemetry to earth receiving stations.

The satellite data are transformed by processing into two types of products—photo imagery, in film or print form, and computer tapes. From these data products trained photo-interpreters and computer analysts are able to extract information useful for a broad range of resource disciplines and management requirements. The digital tapes, which carry more data than are contained in a single photo product, can be used to generate a variety of such

products for human interpretation and can be further processed by computer to elicit detailed information about the spectral signatures of interest to resource managers.

Sensing from space platforms has three unique characteristics:

Synoptic View—LANDSAT "scenes" cover areas 185 by 185 kilometers in size, at a resolution of 80 meters. A single view of such a large area, under fixed solar illumination and from near vertical (orthographic) perspective, makes it particularly valuable for cartographic purposes and for recognizing indications of large-scale geologic features and vegetation patterns difficult to detect by other means.

Repetitive Coverage—The repeated coverage every 18 days (or every 9 days since the launch of LANDSAT 2 in January 1975) of each same part of the earth's surface provides an unequalled opportunity to monitor dynamic phenomena, such as changes in vegetation cover and hydrology, and to acquire multidate images needed for more exact identification of static resource features.

Uniformity—LANDSAT orbits are synchronous with the sun; each scene is scanned at approximately 9:30 A.M. local time throughout the world. The constant sun-angle and uniformly vertical perspective make possible image mosaics on a continental scale and the overlay of scenes taken on different dates to permit precise comparison.

LANDSAT reception stations and data distribution centers are now operating in the United States, Canada, Brazil, and Italy; one is under construction in Iran and several more are planned. Since each station can receive the satellite data for an area within a 3,000 kilometer radius of the receiver, no more than 20 properly placed stations could cover virtually all the inhabited land masses of the globe. Cloud-free LANDSAT images of one or more dates are now available for most of the land surface of the earth.

For some purposes LANDSAT data alone will suffice. For others, they will add an important new level to a multilevel system of data collection which includes sensing by aircraft and ground observation. Field investigations to determine "ground truth" are often essential for the interpretation of remote sensing data. Aircraft remain vitally necessary for the acquisition of data of higher spatial resolution and for flexibility in covering particular areas at particular times.

The LANDSAT Experience

Studies conducted principally in the United States show mixed results for the utility of present LANDSAT data in practical applications: highly useful

for some purposes, of little or no use for others. In many instances, however, where the data do not meet highly demanding user specifications in the United States, they may do so very well in developing countries, where user requirements are less stringent and where the resource data base is meager. The following summarizes the information available in 1976 on the capabilities and limitations of LANDSAT data in the major application sectors reviewed:

Agricultural Production:

Crop Acreage—95 percent accuracy of crop identification in large simple areas such as U.S. wheat fields; 75 to 80 percent in complex areas (small fields, intermingled crops) typical of developing countries. This is inadequate for acreage estimation but offers a base upon which an agricultural statistical sampling system can be designed.
Yield Forecasting—Does not by itself provide an acceptable substitute for existing U.S. methods, but gives promising results used in modeling procedures in combination with meteorological and other data.
Soil Survey—Findings encouraging for reconnaissance-level soil and land system surveys; with computer enhancement has been shown capable of detailed soil mapping at scales up to 1:24,000 in U.S. Midwest experiment.

Rangeland Management: Can provide useful inventory data but cannot identify all vegetation types. Monitoring of significant vegetational changes technically feasible with use of meteorological data and 9-day frequency of LANDSAT coverage.

Forest Management: Effective in improving sampling procedures for estimating timber volume, in monitoring of forest cutting of clear-cut type, and in mapping certain types of forest fire burns. Useful to developing countries for monitoring depletion of forests. Inadequate to meet U.S. statutory requirements for inventory of tree species.

Water Resources Management: Highly reliable in locating surface water. Useful in assessing major watershed characteristics that affect runoff. Effective in delineating large flooded areas. Can provide significant input to water consumption models at large irrigation projects. Identifies geologic features that indicate promising areas for groundwater exploration.

Geologic Survey and Mineral and Petroleum Exploration: Contributes to improved geologic mapping in the United States and enables developing countries to produce geologic maps for some areas for the first time. Unique capability to disclose large geologic anomalies which indicate possibility of mineralization. Saves costs by directing attention to areas where further exploration by air or on the ground may be rewarding.

Cartography: Useful in correcting and updating existing U.S. maps at scales of 1:250,000. With more than half of developing world not yet

mapped at scales larger than 1:1,000,000, provides data to map uncharted areas quickly and cheaply, update existing maps with acceptable accuracy, and indicate areas where higher resolution imagery from aircraft is required. Provides basis for an "automated" image mapping system of entire earth.

Land Use—Urban and Regional Planning: Because of spatial resolution, LANDSAT presently of limited value for most urban planning requirements. Useful for regional planners in providing frequent update on gross land use change among categories such as agriculture, wetlands, forests, built-up areas. Synoptic view of large areas particularly useful to developing countries.

Demography: Present LANDSAT data useful for studying certain urban growth patterns, but better spatial resolution needed for detail required in most U.S. Census operations. In developing countries, can identify village settlements and contribute to knowledge of population densities.

Environmental Protection: Inadequate spatial and temporal resolution for statutory monitoring of some aspects of water quality or certain wetlands disturbances in the United States. Ability to recognize discontinuities in water coloration can lead to detection of effluents carrying industrial and municipal wastes, water currents causing siltation, and oil slicks and oil seepage in coastal areas. Can monitor surface mining operations and land deterioration in arid areas such as the Sahel.

Marine Resources, Oceanography, and Coastal Engineering: Marginally useful in monitoring coastal waters to identify certain fish habitats and changing depths in navigation channels. Useful in monitoring shoreline changes, both erosional and depositional, of fairly large dimensions. Meteorological satellites generally more useful than LANDSAT for oceanographic and marine resource purposes.

Disaster Warning and Assessment: Frequency of coverage insufficient for warning in most types of disasters. Potential for damage assessment good for drought, forest fire, flood and crop disasters; uncertain for earthquakes and storms.

Human and Animal Health: May identify and map the types of vegetation that serve as reservoirs for disease-bearing insects and as habitats of carrier animals.

In most applications thus far, LANDSAT data have been used on an experimental basis; few resource data users have adapted their services for routine dependence on the new technology. There is still a gap between the technical experiments and the resource managers. This should be bridged by increased interaction between them and with planners and decision makers in resource management activities.

Some of the limitations noted in studies of present LANDSAT capabilities do not remain fixed. Significant new capabilities and new applications of remote sensing data are constantly being uncovered with increasingly sophisticated data processing and analytic techniques.

Technological Prospects

During the next decade the technology of space remote sensing is expected to undergo steady growth and continuing change. Limitations and weaknesses of the first generation technology are to be appreciably reduced with systems now on the drawing boards.

Before 1980, some advance will come with the launching of LANDSAT C to succeed LANDSATs 1 and 2. The LANDSAT C Multispectral Scanner will include a fifth, thermal sensing band, valuable for estimating soil moisture; the spacecraft will carry an additional sensing system composed of television type cameras with 40-meter resolution. The enhanced capabilities should be particularly helpful in some aspects of agriculture, in rangeland management, in land use inventory, and in cartography.

More substantial results are anticipated from the LANDSAT D satellite, proposed for orbiting in the early 1980s, which will carry a second-generation scanner, the Thematic Mapper, equipped with six or seven spectral bands of 30-meter resolution, a level that appears to meet many users' needs. The expected improved spatial and spectral resolution will be especially significant for agriculture and rangeland management—better crop identifications, detection of soil moisture and crop stress, and assessment of range feed conditions—as well as for identification of geologic strata and fracture systems, and recognition of numerous land use classifications.

Resources data analysis in the 1980s will be based increasingly on the combination of data streams from a variety of special purpose satellites—meteorological, oceanographic, hydrological—likely to be orbited in the coming decade. One experimental system, employing imaging radar, may be of special interest to countries beset with persistent cloud cover, which cannot be penetrated by LANDSAT sensors.

The multisource data, employed with plant growth, hydrological, and other dynamic models, should make possible the establishment of global and regional monitoring systems with important consequences for crop yield forecasting, water resource and rangeland management, and observation of ecological conditions.

Changes in ground systems will need to be made to keep pace with the expected advances in the space segment. To accommodate the larger data

volume from the Thematic Mapper alone, the capacity of future data reception and processing equipment will have to be significantly increased. Speed of data delivery to users will also be an important requirement.

Use of Remote Sensing in Developing Countries

The analysis of satellite data ranges from the relatively simple, such as photo interpretation of visual imagery for identification of simply structured areas and broad classifications, to the very complex, such as digital analysis of satellite data and computer enhancement of imagery of complex areas.

Many developing countries have begun to utilize LANDSAT film and print imagery and have participated in training programs and in research projects; a number have hired the services of external organizations. Several countries have or are planning their own reception stations, and a few are presently in a position to move to the more complex forms of data utilization. LANDSAT data have been put to practical use in geologic mapping, soils survey, mineral exploration, water resource management, project siting for transportation, detection of coastal pollution, and other applications.

The modular character of the technology permits countries to enter into its use gradually, beginning with simple equipment and a few trained people operating within existing technical services. The more flexible, versatile, and autonomous a country wishes to be in the use of space derived earth resources data, the heavier the investment it will need to make in equipment, trained personnel, and organizational and operational changes. For many nations, however, even comparatively low-cost use of the technology should provide many benefits in the coming years.

Shortage of trained personnel is the primary factor limiting the ability of developing countries to assimilate the technology. There is need for programs to inform policymakers, planners, and resource managers of the potentials of the technology; for short-term, in-depth training of scientists and resource specialists to enable them to analyze satellite data applicable to their resource sectors; and for longer-term academic training for those who will be involved with its technically more demanding aspects. To accommodate the larger number of people who will have to be trained in the next decade, educational institutions will need to modify their orientation and enlarge their capacities in this field.

A score of countries have begun to take steps to institutionalize remote sensing activity within their bureaucracies; some have created special units for the purpose. The spread around the globe of receiving stations, each encompassing large areas, provides the opportunity for creation of cooperative, regional centers where basic facilities can be concentrated for processing,

storing, distributing, and analyzing satellite data and for providing needed training and advisory services for nearby countries. Such centers would appear to hold the best prospect of bringing the capabilities of remote sensing within the range of users in many developing nations.

International Problems and Prospects

Resource sensing from space has generated a number of concerns which may affect its future progress and its international acceptability. Although apparently declining, these concerns, relating to sovereignty, security, and economic vulnerability, have led to proposals in the United Nations to require prior consent of a nation to the open dissemination of satellite data about its territory. An important continuing concern is the dependence that all countries now have on one nation—the United States—as the sole operator of a civilian earth resource satellite sensing system and the exclusive source of satellite data available worldwide. Because of this dependence and the fact that the United States has not committed itself to an operational remote sensing service, other countries, along with domestic users in the United States, retain doubts about the continuity of the program. The Committee recognizes the need for both further experimentation and assurances to users, and therefore recommends

> That the United States officially declare its intent to proceed for some finite period with further development of space segment technology of a resource sensing system, subject to no more than the usual uncertainties, and to make every effort during this experimental phase to provide continuity of sensing coverage and data transmission to stations and product users everywhere.

If the operation of a global remote sensing activity is to be politically acceptable, some type of international framework would seem to be required. The need for this is supported by several factors: the global character of the technology; its capacity to serve transnational objectives; the desirability of allaying national fears and concerns; the advantages of a cooperative, participatory approach as opposed to one characterized by either dependence or potential rivalry; and the increasing sense—both in the United States and in the international community—that activities in the common domain of humanity, such as the oceans and space, require some form of accountability to an international entity.

The problems of identifying, using, and managing the world's resources and of maintaining the earth's life-supporting environment call for collaborative action on an international scale. Resource sensing from space, organized and managed as a cooperative enterprise under international sanction, could bring into sharper focus both the complex resource challenges facing the

global community and the necessarily interdependent responses required to deal with them.

The Committee discussed various arrangements for dealing with the ground and space segments and concluded that movement toward multilateral arrangements for the ground stations and ancillary services appears more feasible and likely in the near term than toward control and management of the satellites. Two desirable moves toward achieving international cooperation with respect to the ground segment would be the strengthening of consultation among station owners, satellite owners, and data users, and the internationalization of ground facilities on a regional basis. The Committee recommends

> That an international mechanism be established to promote consultation on technical and managerial aspects of remote sensing among representatives of receiving stations, of satellite owning countries, and of countries substantially engaged as remote sensing users.

> That the United States, together with other nations and with international bodies concerned with resource and environmental sensing from space, work toward the internationalization on a regional basis, wherever possible, of receiving stations and of ancillary services (including processing, analysis, dissemination, training, and technical advisory services) as a desirable means of inducing cooperation and cost-sharing in the management and operation of a ground complex.*

The Committee examined four models of international arrangements for the space segment as illustrative of the range of options available to the world community. They included a continuation of U.S. ownership and management of the satellites under guidelines established by international agreement; a consortium of concerned nations similar to that which founded the INTELSAT system for the management of communications satellites; a combined space and ground system owned and operated by an international body such as the United Nations; and a system of nationally owned satellites coordinated by an international agency, as in the case of the World Weather Watch satellites coordinated by the World Meteorological Organization.

Without attempting to prejudge the character of an appropriate future international framework for a complete resource sensing system, the Committee thought it important that the U.S. Government take the necessary steps to declare and demonstrate its adherence to the concept of an international regime. The Committee therefore recommends

> That the U.S. Government make a public commitment now to the eventual establishment of an international regime for the space segment of a resource sensing system.

*See comments of Professor Rathjens, page 191.

That the U.S. Government begin now to develop its own proposal for a future regime.

That the U.S. Government, in regard to decisions affecting the future of this technology in the United States, set a course with the aim of facilitating its ultimate incorporation into an agreed international system.

A Development Assistance Program in Remote Sensing

The Committee is sufficiently persuaded of the promise of remote sensing for developing countries to conclude that a significant effort to help them assimilate the technology is justified. The task calls for a sustained commitment of all agencies, bilateral and multilateral, engaged in development assistance. But the United States has special reasons to take the lead in this regard:

- It has a proclaimed policy of sharing its science and technology with the poor countries to promote their development. As the innovator of global resource sensing from space and at present the sole source of satellite data, it has an exceptional opportunity to give practical expression to this policy by enabling interested countries to make effective use of the data.
- It is exceptionally well placed to assume this role for it has the preponderance of technical expertise and related resources.
- It needs to be responsive to the concerns that the technology has raised in some countries which fear they will be disadvantaged vis-à-vis outsiders more proficient in extracting meaning from the satellite data. The U.S. policy of open dissemination of data calls for a corollary effort to make the technology truly accessible—in terms of ability to use it—to all interested countries.

Thus far, the United States has engaged in a relatively modest assistance program, principally through the Agency for International Development (AID). This reflected the initial uncertainty as to the technical efficacy of satellite sensing. Now that a more positive, if still qualified, assessment of the capabilities of the technology is possible, the technical basis exists for a more confident commitment. The Committee therefore recommends

That the United States, through AID and through multilateral bodies where possible, engage itself in a sustained, long-term and systematic effort over the next decade to transfer to interested developing countries the capability to utilize the technology of remote sensing from space.*

*See comments of Professor Rathjens, page 191.

An AID program of technical cooperation in resource sensing from space, presently supported at a level of investment of well under $1 million per year, should be increased at least tenfold and should include the following elements:

Pilot country programs to help establish in a selected number of countries exemplifying a variety of conditions a broad indigenous capability to analyze and utilize remote sensing data.

Demonstration projects to show planners and resource managers how the technology works in individual resource sectors, and to translate the accumulating experience into methodological principles.

Research projects to address problems peculiar to the developing countries owing to tropical conditions, special data needs, and new application opportunities.

Information and training programs to help developing countries understand the capabilities and limitations of the technology, and acquire over time the pool of technically proficient personnel they will need.

Equipment information and procurement assistance to promote more knowledgeable acquisition practices and, where necessary, to facilitate through loans or grants acquisition of essential major equipment items.

Remote sensing data use in AID-sponsored projects to strengthen the Agency's internal project design and implementation capabilities and concurrently those of the recipient country.

Assistance to regional centers, in cooperation with other bilateral and multilateral development agencies, to help the centers get established and to enable them to perform their data dissemination, training and technical advisory services effectively.

Coordination initiative to ensure that the diverse assistance flows in remote sensing are complementary and reinforcing, and endow recipient countries with a permanent, institutionalized capability to apply the technology to their needs.

II Resource Information in Developing Countries

This chapter is intended to give the reader a brief overview of the information that countries generally need for the effective management of their resources. The matter is presented without consideration of any particular technology for data collection. It is designed to provide a setting for the discussion of resource sensing from space, but it is not meant to suggest that all these needs can be met by one technology alone.

The Need for Information

Many factors influence the course of a nation's development: its economic system, social structure, cultural legacy, political system, geographic setting, and its human and natural resource endowment. The natural resource endowment and its spatial distribution are particularly important in shaping both the potential and the direction of a nation's economic growth.

It can be argued that the natural resource base and its management are especially critical to the progress of a developing country. In industrial countries, economic life and employment now are centered in services, manufacture, distribution, and finance rather than in the exploitation of natural resources, even when they are an important component of the gross national product. Developing countries, on the other hand, typically are more dependent on their resource heritage (but not lastingly condemned by it, as the experiences of Japan and certain other resource poor countries have shown).

For this study, we will define the term *natural resources* to include whatever man finds of value in his physical environment: soil, water, vegetation, minerals, energy sources, and terrain. These resources are themselves interrelated; changes affecting one can have repercussions on others. They range from the clearly renewable to the practically nonrenewable, but none is ever unlimited. Because of their relative scarcities, their use and conservation entail rational planning.

As noted in a 1970 UN report, "the process of economic development consists largely of organizing the development and productive exploitation of

natural resources in the interests of the whole community."[1] To do so effectively a nation needs to know what resources it has and where they are, and it needs to have a fairly detailed grasp of its overall physical environment. For many developing countries, this knowledge base is limited, fragmentary, dispersed, and, on the whole, less than adequate for the purposes of sound national development. The capability to acquire, store, analyze, and use natural resource information for broadly developmental purposes still eludes many developing countries and indeed some developed countries. Most nations at present are seeking to acquire better resource information; to their advantage, this can now be gathered more efficiently with the aid of modern methods and technologies.

Categories of Resource Information

These are the principal resource sectors about which information is needed and, to a lesser or greater extent, systematically collected:

Water

Water is becoming a constraint to development in many parts of the globe. The needs for water for human consumption, irrigation, sanitation, power generation, mining, and industrial processing are all increasing in the face of a growing world population and rising living standards. Information on water resources is thus a central part of the resource data needs of most countries.

Although developing countries in general have more information about surface water than ground water, they usually need more data about both. Efficient water management may require a varied set of meteorological and hydrological data: the volume of runoff and the variability of stream flows; the geological, soil, and vegetation characteristics of watersheds, possibly including data on the extent and depth of high mountain snow; the area watered by irrigation; and the rate of agricultural use of water. Where floods are common, it is important to know the areal extent of flooding and to have early warning of potential flooding. Timely and precise indications of soil moisture are important for crop yield estimation and agricultural planning.

Soils

Small-scale soils maps (1:5,000,000) are now available for all continents and 1:1,000,000 scale mapping is quite common; but for national and local agricultural purposes, soil association maps of a much larger scale (at least

1:200,000 and even 1:100,000) are essential. For specialized studies of irrigable land, 1:10,000 or 1:25,000 scale maps may be needed. Relatively few soil maps at scales greater than 1:1,000,000 are available for the developing world.

Countries need to know the distribution, composition, characteristics, and genesis of the various soil types they possess. These data profiles enter into the determination of land capability or land use potential, a vital assessment for the rational and efficient use of land for agricultural or other purposes.

Crops and Vegetation

The estimation of crop acreage, both in general and for particular crops, recognition of crop stress, and timely and accurate prediction of crop yield are now matters of critical interest everywhere even though such data are particularly difficult to obtain in developing countries. Variation in crop production from year to year places considerable but varying demands on marketing and relief services. Any improvement in forecasting or measurement of crop production is thus immensely useful.

In forestry the needs for information relate to forest inventories, mapping of burned areas, monitoring of logging, and detection of pests and disease. With respect to rangeland the needs include inventories of range types, estimation of biomass, and monitoring of the condition of range forage. Lack of comprehensive, reliable, and timely collection of such data in most parts of the developing world is still a major problem and an obstacle to the increased production of protein foods.

Minerals

Minerals and fossil fuels—oil, coal, and gas—have been sought and located in many parts of the developing world. Large areas of the world, however, are still geologically unexplored. Although mineral resources are a vitally important asset and a major source of foreign exchange earnings, developing countries often do not have the detailed minerological information collected by foreign firms as part of their mineral extraction operations. Now, more assertive of their rights, developing countries want to have better knowledge not only about deposits already discovered and the extent of reserves, but about areas whose geology indicates the likely success of prospecting activity. Terrain studies, to identify landforms, faults, fractures, folds, major rock types and geophysical anomalies, are an important element in geological mapping and mineral exploration. This is a first step to the composition of a mineral survey and the identification of potential exploration sites. Geological mapping at a reconnaissance scale which is available for most areas needs follow-

up by detailed local mapping of selected areas. In some cases, study of ground water resources also requires special kinds of geological mapping.

Energy

In addition to searching for new fossil energy sources, in response to dwindling global supplies and recent sharp increases in oil prices, developing nations are also stepping up investigations of their renewable energy sources, particularly geothermal and hydroelectric, which depend importantly on geological and hydrological data.

Cartography

Although small-scale planimetric maps exist for most parts of the world, large sections of developing countries remain wholly lacking in thematic and topographic coverage or are inadequately recorded. For purposes of resource assessment and broad national and regional planning, medium- to large-scale maps for many areas are in great demand. With high population growth and the spread of development activities, decision makers at all levels require periodically updated cartographic information with detailed classifications. They need this information to guide their decisions on investments in agricultural expansion, opening of new lands, rural and urban development, siting of transportation networks and other large public works, as well as for routine management and conservation purposes. There is also a growing awareness of the need for land use maps that record current allocations of use and permit rational planning of future patterns of use.

Certain subjects on which data are collected are basically unchanging with time (static), whereas others are undergoing continuing transformation or change to a greater or lesser degree (dynamic). Excluding the changes brought on by natural catastrophes such as earthquakes and volcanic eruptions, or by large man-made works such as water impoundments, one may consider physical terrain, including geology and soil distribution, as an essentially static feature, and the need for updating of such terrain data as relatively infrequent.

On the other hand, the condition of soils, crops, forests, and rangelands, the behavior of water, and land use patterns are subject to continuing fluctuation and require monitoring of varying periodicity if information about them is to have substantial management value. For some purposes, as in flood warning, control, and damage assessment, it is critical that data be quickly acquired and analyzed and that the resulting information reach decision makers promptly.

Factors Affecting Information Needs

The nature, scope, volume, and timeliness of resource information that nations require vary from one country to another. There is no direct correlation between the level of economic development and the volume of resource information needs. In the case of relatively advanced countries with sizable and varied developmental activities, and capital and human resources to match, the scope of the information needed will be complex and the volume very substantial. However, information needs can be equally complex and substantial in countries that are less economically developed but are extensive in area. In the case of yet other countries, the practicalities of their development situation may call for much less information flow.

The factors that govern the nature, extent, and mix of the resource information that a country is likely to want to accumulate generally include the following:

- the size of the country, and the number and spatial distribution of its people
- the degree of diversity and complexity in the country's geography and culture, and the nature of its resource endowment
- the volume, quality, and availability of the resource information already accumulated
- the country's development objectives and strategy, and its investment priorities, factors which are generally tied to a perception of the country's resource base
- the degree of detail and specificity required in the data to be accumulated—whether it be the reconnaissance-level imagery (small-scale maps) of a whole country or large area, or detailed or semi-detailed maps of specific localities where current development efforts are concentrated
- the capacity of the country to assimilate the resource information acquired and to put it to operational use—a factor related to the nature of the country's present institutional structures, the effectiveness of managers, planners and decision makers, and the availability of scientific and technical expertise
- the assumed current or future utility of the collected data in terms of the costs of collecting them—their utility to be determined by their essentiality for an immediate undertaking or by their likely value if placed in a national resource data bank for long-range purposes—e.g., to help trace changes in the natural environment, to identify future developmental opportunities, and to sustain scientific investigation.

Development Objectives and Information Needs: Four Country Illustrations

The blend of factors noted above combined with the priorities that a nation's political leadership attaches to its development options provide a distinctive profile to a country's resource and environmental data collection needs. The following are brief illustrations of priority data requirements of four countries confronting different development problems:

Iran

Rainfall in Iran ranges from 50 millimeters a year in the arid plateau to 1250 millimeters in the mountain regions. With about half the population engaged in agriculture and four-fifths of the farmland dependent on irrigation, water management plays a vital role in Iran's development efforts. A substantial base of resource information is available, but much of it is related to past development projects in the areas of petroleum, minerals, transportation, dam construction, and land resettlement. Iranian central planners have these priority information needs:

- national geologic mapping for hydrology as well as for mineral exploration
- identification of land use and land capability for agriculture
- delineation and sampling of range and forest lands
- monitoring of irrigation levels for purposes of water resource management
- monitoring of crops and of range condition.

Tanzania

Much of Tanzania's economic development effort is directed toward agriculture and animal husbandry. In order to decentralize development decision making to make this effort more effective, Tanzania has put major responsibility in the hands of the country's 22 regions and their administrators. Principal resource data requirements in Tanzania are tied to immediate needs:

- land use and land capability (distribution of soils and vegetation types) to determine suitability for farming or range
- structural geology and groundwater, as linked to soils, vegetation, and topographic data, to help locate additional water sources, to increase the

efficiency of well digging and water impoundment schemes, and to help in the siting of new villages

- monitoring of land and range stress due to drought or overgrazing to permit rehabilitation of these resources.

All these are articulated needs, but such specific information is currently available for only one or two of the many regions.

Venezuela

Venezuela's topography and ecology are complex; its population is 75 to 80 percent urban. The country's development plans call for continued industrialization, further exploration of mineral and petroleum deposits, improved land use and quality of life in urbanized areas, colonization of frontier areas, greater emphasis on investment in agriculture, including expanded assistance to the rural poor and placement of more land under irrigation. To accomplish these objectives, Venezuela's data collection efforts emphasize:

- land use and urban change
- pollution assessment of beaches and coastal areas
- further mapping of geologic structures to aid in mineral exploration and siting of mine related construction projects
- classification of soils and vegetation in current and potential agricultural areas
- determination of crop acreage and changes in crop and range conditions
- monitoring of seasonal water coverage of lands being considered for new settlement, agricultural development, and improvement.

Zaire

Although Zaire is rich in mineral resources, the base of its export economy, three-quarters of its 23 million people are rural and depend for their livelihood on an underdeveloped agriculture that is largely characterized by shifting cultivation. The country's largest potential for economic development lies in minerals, hydroelectric power, agriculture, and forestry. To achieve this potential, Zaire's resource information needs for development planning include:

- medium- and large-scale photomaps with thematic overlay interpretations of geology, hydrology, soils, and vegetation to aid in mineral exploration and in siting of roads, railroads, and ports to move the products of mining, agriculture, and forestry to the towns and to port

- hydrologic information for water power development, for agricultural and rangeland improvement, and for management of river transport
- soil classification and land capability maps to help guide agricultural development
- classification and monitoring of grassland and savannahs to help increase domestic production of meat and dairy products currently imported
- identification of valuable hardwood species in the great forests for a program of lumber export and forest conservation.

Capabilities for data gathering for the resource sectors discussed earlier and for cartographic purposes, including facilities for map making, are now to be found in a good many developing countries, although with great variation in quality, in volume of output, and in distribution among sectors. Aircraft are utilized in some countries for resource survey purposes, but their use generally is confined to limited areas for specific projects. Few countries have up-to-date, nationwide photographic coverage, and fewer still would have it in infrared or color films with their expanded data range. For the most part, use of aircraft has been episodic, spotty, and well short of the important role that aircraft sensing can play in resource data collection. Part of the reason has been the unavailability in most countries of indigenous aircraft with advanced sensing instrumentation and the high cost of chartering aircraft coverage from private air survey firms.

The Role of Resource and Environmental Information

For governments and the external development agencies that assist them, resource inventory and environmental monitoring data serve several purposes: for national resource management and planning, for project feasibility and physical planning studies, and for environment related problem solving. These purposes may invoke different types of information in terms of coarseness or detail, large or small areal extent, archival or near real-time representation.

National Resource Management and Planning

Experience to date suggests that resource information generally enters but indirectly into the economic analysis and plan formulations of those countries that engage in central planning at the national level. Concerned traditionally with the allocation of financial resources, central planning authorities tend to base their calculations on broad economic, financial, and population variables. The particulars of resource information are attended to at lower levels under the aegis either of data collection agencies or of mapping

organizations such as a geological survey, cartographical unit, or soils survey, and generally come forth, in the dress of packaged project development schemes that are incorporated into the framework of a national plan.

The reasons for this are several. First, there has been generally a lack of coordination between physical planners, on the one hand, and economic planners, on the other. They have been trained in different academic disciplines and tend to apply their arts to different sets of problems at different stages in the planning process. Physical planners concern themselves with the occurrence, location, magnitude, and quality or suitability of resources for exploitation, whereas economic planners concentrate on the fiscal resource requirements and the revenue generating implications of such exploitation. The resource scientist, moreover, deals with observation and classification of vegetation or soil or geological systems, while the user of information in planning is interested in resource allocation issues. The two groups lack a common vocabulary and frame of reference.

Second, many economists are not yet aware of the significant advances in the quantity and quality of spatial and thematic resource information now available as a consequence of the use of new data collection technologies.

Third, economic plans have a five- to ten-year time frame and therefore concentrate on balancing flows of resources and commodities, rather than upon stocks.

No accounting framework has been constructed for natural resource balance sheets comparable to the national accounts framework. (It is only relatively recently that the national accounts framework has been extended to include people accounting in a set of integrated economic-demographic accounts.) Central planners at the national level under most political systems have not attempted to plan the use of space; this has remained the realm of area and project planners.

Resource management responsibilities normally are lodged in sectoral ministries and technical services, which gather data in pursuit of their assigned mission, often little coordinated on a day-to-day basis with the priorities of the development program. There are examples, for instance, of topographic mapping programs steadily turning out map sheets for sparsely populated segments of the country while the main centers of population remain poorly mapped.

In the larger and more advanced of the developing countries, with numerous ministries and specialized services, natural resource data may be gathered separately and individually by such agencies as a ministry of agriculture, which may or may not include services for soil science, botany, forestry, livestock, and for general agricultural research; a geological survey, sometimes including a hydrology service and a mines division; a weather service; and a general mapping service. A maritime country may have, in addition, a coastal

service and an oceanography and fisheries unit. A poorer country, whose apparent wealth may lie essentially in one or two commodities, is likely to have far fewer services while maintaining a ministry just for livestock.

A few countries have begun to recognize the value of an integrative approach to resource management and have established centralized (supraministerial) resource data collection, analysis, and planning services that incorporate the conventional data collecting units. But this innovation is still rare in both developing and industrialized countries; for most, the collection and use of resource data reflects the traditional sectoral compartmentalization.

Because central planners made no demand for it, and the parochial concerns of sectoral data collection agencies ran against it, there has been little incentive or effort to produce an easily accessible, comprehensive, and integrated representation of a nation's resource base as a decision making tool for national development. The arrival of a technology that can serve at once as a new mode of data collection, of data management, and of data display—the subject of this report—may in the long run induce significant change in planning practices.

Project Planning

The formulation and execution of a discrete development project generally impose the most stringent demands for natural resource and environmental information. This is especially true of projects subject to the criteria of international funding agencies. Projects may range widely in scale: a river basin development program supplying a vast irrigation grid; the use of hydrological resources for power and industrial development; the opening of new lands for cultivation and settlement; the construction of a transportation network; the exploitation of a mineral deposit; or a rural development scheme.

In the case of projects intended for a particular geographical area, the requirement may be for nested sets of data beginning with a generalized overview and moving to more place specific data covering the whole range of resources and environmental impact factors. Questions such as these have to be answered: What is the pattern of land use in the area? What is the terrain, soil type, and land capability? What are the geological features affecting the project? What are the best routes for transportation and other infrastructure to sites in the area? What are the vegetation, erosion, drainage, and cultural patterns? How will the project influence the surrounding area?

For many developing countries data collection oriented to specific project preparation has more immediate meaning than a generalized national survey. Data needs can be more easily defined for clearly identified short-term purposes; they can be confined to the space frame of the project and the time

dimension of the project program. A technical staff from different disciplines working together on a project is well placed to link one set of data with another. Integrated use of resource information can occur naturally in the design and execution of an area development project even in countries where such information remains fragmented at the national level.

International aid agencies that must base defensible decisions on well-documented studies of project feasibility, design, and execution have given an important stimulus to this approach. The World Bank, for instance, requires broad based data not only in the preparatory stages of projects but for supervision and evaluation. Preparation of AID sponsored projects must now include an environmental impact assessment akin to those required for domestic projects in the United States as well as a social impact statement.

Environmental Monitoring and Problem Solving

The need for continuity of data collection, and in some instances for great rapidity of data collection and analysis, have become more manifest in recent years with increased understanding of the impact that environmental factors have on the development process and on human welfare. The new world view of the interrelationship of environment and development—crystallized in Stockholm at the 1972 United Nations Conference on the Environment and made vivid by the consequences of the 1973-74 drought in the Sahel and elsewhere—has drawn attention to the vulnerability of wide areas to ecological deterioration and consequent massive loss in productivity.

In industrialized as well as in developing countries, there is now growing appreciation of the need for monitoring of natural systems—for example, forests, arid lands, mountain areas—both to anticipate natural and man-made disasters and to deal with their consequences. Some disasters are slow in the making, such as soil erosion, siltation, water logging, desertification; others are sudden, brief, and less predictable, such as earthquakes, floods, forest fires, and insect infestations. A global scientific effort—Earthwatch, under the auspices of the UN Environment Program—is now getting underway to gain better knowledge of some of these and other environmental processes; its pursuit will call for sustained and systematic data gathering in all parts of the world on a scale not heretofore attempted.

A committee of the National Academy of Sciences has recommended that, as part of the Earthwatch monitoring system, mapping be undertaken to detect change in certain land classifications in order to assess critical problems arising from agricultural and land use practices. The classifications recommended for such mapping include urban areas, desertification areas, deforestation and forestation areas, coastal zones, irrigated and nonirrigated

agricultural lands, lands prone to hazard, permafrost areas, upland wetlands, and surface mined areas.[2]

Integration of Resource and Environmental Information

Future resource planning and management at a national level will call increasingly for an integrated overview of different types of national data, gathered by different agencies, by different means, at different scales, and with respect to different resource sectors and environmental phenomena. This "horizontal" homogenization will to some extent be induced by organizational devices, such as a national office for resource surveys and planning, that are mandated to take a comprehensive approach to resource analysis and decision making.

There is also a "vertical" type of data integration for which need is becoming better recognized. Much valuable information on local resources and environmental processes is embodied in the largely unrecorded experience of people laboring in the provinces and villages—local administrators, technical workers, informed villagers. Much experimental information on soils, crops, vegetation, and water lies in the minds of cultivators and herdsmen. The resource data base to support development would be greatly enriched if the technical knowledge of the first and the ethnoscientific information of the second were to be joined with the systematic data gathered by the scientific investigator.

It would be an error, however, to look upon resource and environmental data collection solely from the standpoint of individual country needs. Regional agencies, with a diversity of missions, engage in data collection and analysis to meet requirements for international cooperation in resource development and management. Large development projects—for flood control, irrigation, power generation—frequently embrace a group of countries. Furthermore, what one country does in the development of its resources, and what another fails to do with its resources in the face of ecological degradation, can have major consequences beyond country boundaries.

The recent concern over world food supply has underscored the need for greatly expanded international action to increase crop production and for systematic global survey and monitoring of agricultural and related resource factors. Such an effort would be but the latest of a long series of intergovernmental data collection programs, carried out for the most part under the auspices of United Nations specialized agencies, in such fields as hydrology, geology, meteorology, oceanography, biology, and the environment. In an increasingly complex world populated by more people who collectively want

more from the earth's resources, much more needs to be known about those resources and new local, regional, and global skills will be required to conserve and manage them.

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2. National Academy of Sciences, Commission on Natural Resources, *Early Action on the Global Environmental Monitoring System: Report of the International Environmental Programs Committee* (Washington, D.C., 1976), pp. 16-18.

III The Technology of Remote Sensing from Space

The Background

Major advances in the gathering of data about the earth's resources over large areas and from a considerable distance came first with the invention of the photographic camera and later of the airplane. Although aerial photography was developed and refined for military purposes in the course of two world wars, it began to be employed half a century ago to provide the visual data needed for a variety of peaceful pursuits, in agriculture, forestry, hydrology, geology, cartography, land use planning, and disaster assessment.

The contributions of the photographic camera and the airplane to the task of gathering data about the earth and its resources have by no means been exhausted, and they still have highly valuable functions to perform. However, in the face of the greatly increased need for detailed information about the earth's resources, both visual photography and aircraft platforms have their limitations.

For various important resource data objectives, especially those related to vegetation, water, geology, and mineral exploration, the dynamic range of conventional photographic film is too narrow to gauge other needed physical parameters, such as temperature, magnetism, moisture, or chlorophyll content. In recent years, therefore, airplanes have been outfitted with "sensors," such as radar, magnetometers, scintillation counters, infrared cameras, and multispectral scanners, to gather data to complement those obtained with conventional photographic film.

The airplane as a platform, for all its numerous advantages, is limited by the area it can cover in any one photographic scene, by the costs it accrues in covering very large areas, and by the degree of uniformity it offers either in its repetitive coverage of the same scene at different times or in its coverage of different scenes at the same sun time (that is, with the same sun angle).

With the coming of the space program, orbiting spacecraft were recognized as a potential means of overcoming these limitations and of providing advantageous platforms for data gathering cameras and sensors. The combination of new types of sensors with a space platform has proved to be more than a high

altitude extension of aerial photography. Remote sensing from space represents a major technological step forward in the gathering of data about the earth's resources.

The recording of observations of the earth's surface from an orbiting spacecraft began in 1960 with the first U.S. meteorological satellite, TIROS-1. Photographs taken by astronauts in the Gemini and Apollo flights increased recognition of the potential usefulness of photographs from space. The most significant experiments in earth resource sensing were initiated with the launching of the first Earth Resources Technology Satellite (LANDSAT 1) in July 1972 and the placement of sensor packages on three missions of the manned SKYLAB satellite in 1973 and 1974.

The experimental sensor packages on SKYLAB, which orbited the earth at 425 kilometers (235 miles) altitude, consisted of conventional photography, near-infrared photography, a 13-channel multispectral scanner, and microwave sensors. These provided data that will be useful in designing future resource sensing systems. Of particular interest was an Earth Terrain Camera (S190-B) that took photographs with an estimated ground resolution ranging from 17 to 30 meters (55 to 100 feet), using high definition black and white film and three types of color film. Each picture showed an area 109 kilometers (59 miles) square; about 10 percent of the United States, 5 percent of South America, and lesser portions of other regions were so covered. The resulting photographs, made available to interested scientists and resource specialists throughout the world, have given striking evidence of the effectiveness of high-resolution visual photography from space, particularly for cartography and land use inventory.

The LANDSAT Space Segment

Since 1975, two experimental LANDSAT spacecraft have been circling the globe sensing the earth's surface and transmitting to ground receiving stations the data acquired by the satellites' sensors (Figure 1). The U.S. National Aeronautics and Space Administration (NASA) placed LANDSAT 2 in orbit in January 1975 to assure continuity of data after the equipment on the first satellite ceased to acquire all the data desired and to supplement the coverage of LANDSAT 1 as long as the latter's sensors were still operating. Since the LANDSATs are the first U.S. spacecraft dedicated wholly to earth resource sensing, a brief description of their technical character and operation follows.*

*Technical detail in this chapter is derived largely from *Manual of Remote Sensing* of the American Society of Photogrammetry[1] and *ERTS Reference Manual* of the General Electric Space Division.[2]

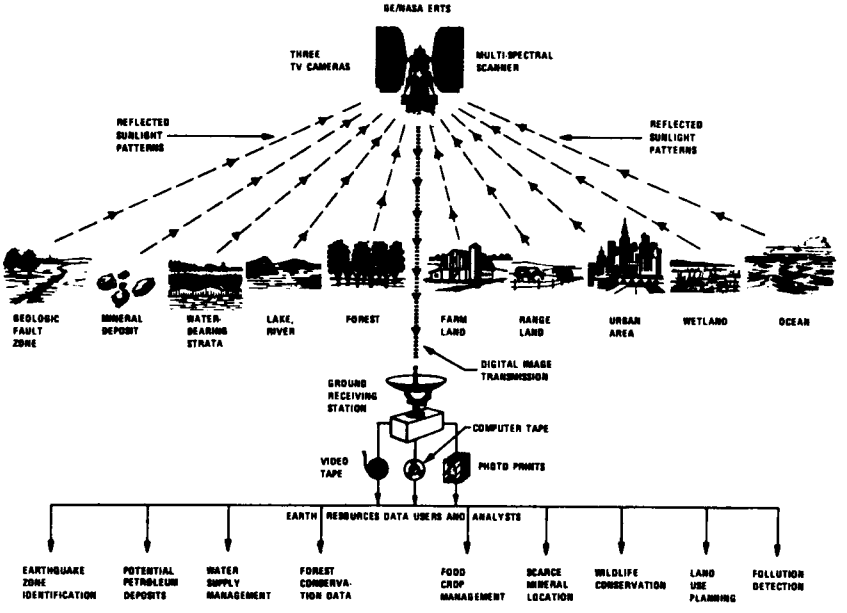

FIGURE 1 Typical ground features recorded via LANDSAT and the transmission of data for ultimate use by resource managers. Source: Louis F. Slee and Jesse Dean Perkinson, "Via Satellite," *Americas* 28(1):30(January, 1976). (Graphic Credit: General Electric Space Division).

The Platform and Orbit

The LANDSAT is a 950 kilogram (2,100 pound) spacecraft, 3 meters (10 feet) high and 4 meters (13 feet) wide when its two independent solar panels are extended (Figure 2). The solar arrays, connected to storage batteries, provide the power for the control, sensing, recording, and transmitting equipment aboard. The batteries are needed for the period when the satellite is on the dark side of the earth.

The satellite travels at an altitude of about 920 kilometers (575 miles) in a circular, near-polar orbit and crosses the equator at a 99 degree angle. It makes 14 orbits a day (103 minutes per orbit) and repeats its coverage of any specific point on the earth's surface at about 9:30 A.M. local time every 18 days (Figure 3). This uniformity of passage times in the sun-synchronous orbit results in the uniformity of the data and simplifies their interpretation.

The 14 strips of the earth's surface covered each day by LANDSAT are successively 2,800 kilometers apart at the equator. On each satellite pass, the strip viewed by the sensors is 185 kilometers (115 miles) wide. A day later the satellite passes over a point at the equator 170 kilometers west of that

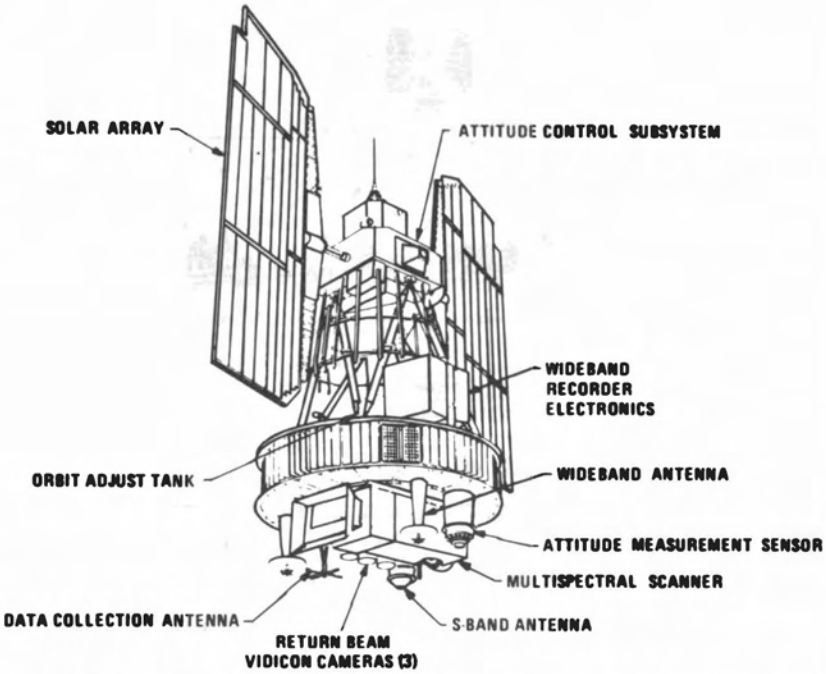

FIGURE 2 LANDSAT spacecraft configuration showing subsystems. Source: NASA/GSFC.[3]

same strip and senses a contiguous strip also 185 kilometers wide. This provides a 14 percent overlap at the equator so that at least 15 kilometers at the edge of each strip are always viewed twice on consecutive days in each 18-day cycle. The image overlap increases with latitude giving 19 percent overlap at 20 degrees and 34 percent at 40 degrees. An important advantage to areas enjoying overlap coverage is the double opportunity this provides in a 2-day period to obtain a cloud-free image.

The launch of LANDSAT 2 was timed to provide 9-day coverage as long as LANDSAT 1 continues to function.

The Sensors

The instrument package on LANDSATs 1 and 2 consists of two sensor systems–a Multispectral Scanner (MSS) and three Return Beam Vidicon (RBV) cameras–plus two Data Collection System (DCS) receivers and two video tape recorders.

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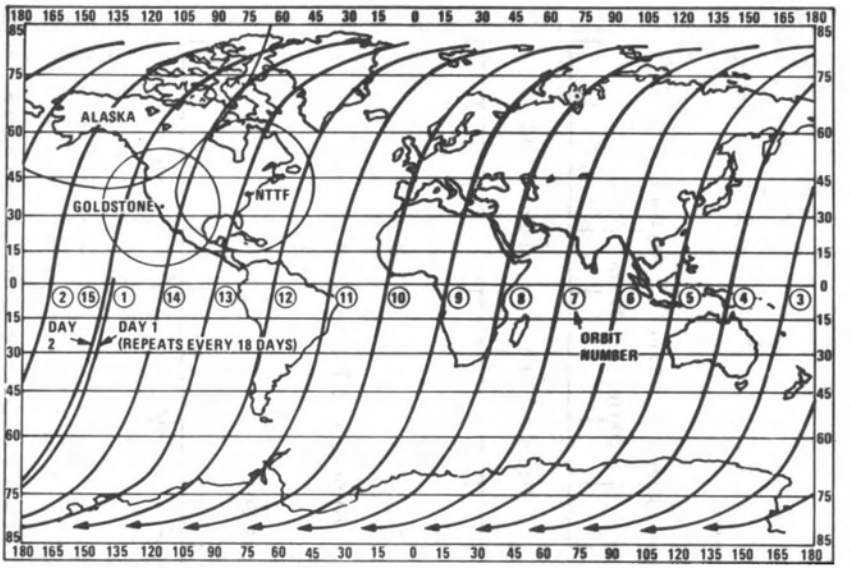

FIGURE 3 Typical daylight ground trace of LANDSAT satellite. Source: NASA/GSFC[4]

The MSS is a four-channel radiometer which scans the surface of the earth and registers the intensity of energy reflected by features and objects on the earth's surface. These are sensed by the MSS in each of four distinct wavelength bands of the electromagnetic spectrum.

All objects, inanimate or living, reflect, absorb, transmit, or radiate electromagnetic energy in the form of electromagnetic waves or radiation. The energy radiated or reflected may be characterized by its wavelength (the distance between the peak point of each wave) which ranges from smaller than an atom to hundreds of kilometers. The human eye is sensitive to radiation in only a small region (the visible region) of the electromagnetic spectrum. The main regions of the spectrum, in order of decreasing wavelength, are: radio (including microwave), infrared, visible, ultraviolet, X-ray, and gamma ray (Figure 4).

LANDSAT sensors are sensitive to radiation in the visible region and a part of the infrared regions, i.e., to electromagnetic waves with wavelengths on the order of one millionth of a meter or a micrometer (μm).

Every object, bombarded by the sun with radiation having a broad range of wavelengths, reflects or reradiates different proportions of each wavelength received. The physical properties of the object itself establish how much of the solar radiation of each wavelength is reflected and thereby determine the spectral distribution of the radiation reflected by the object. This reflected energy with its distinct spectral or wavelength distribution for each object

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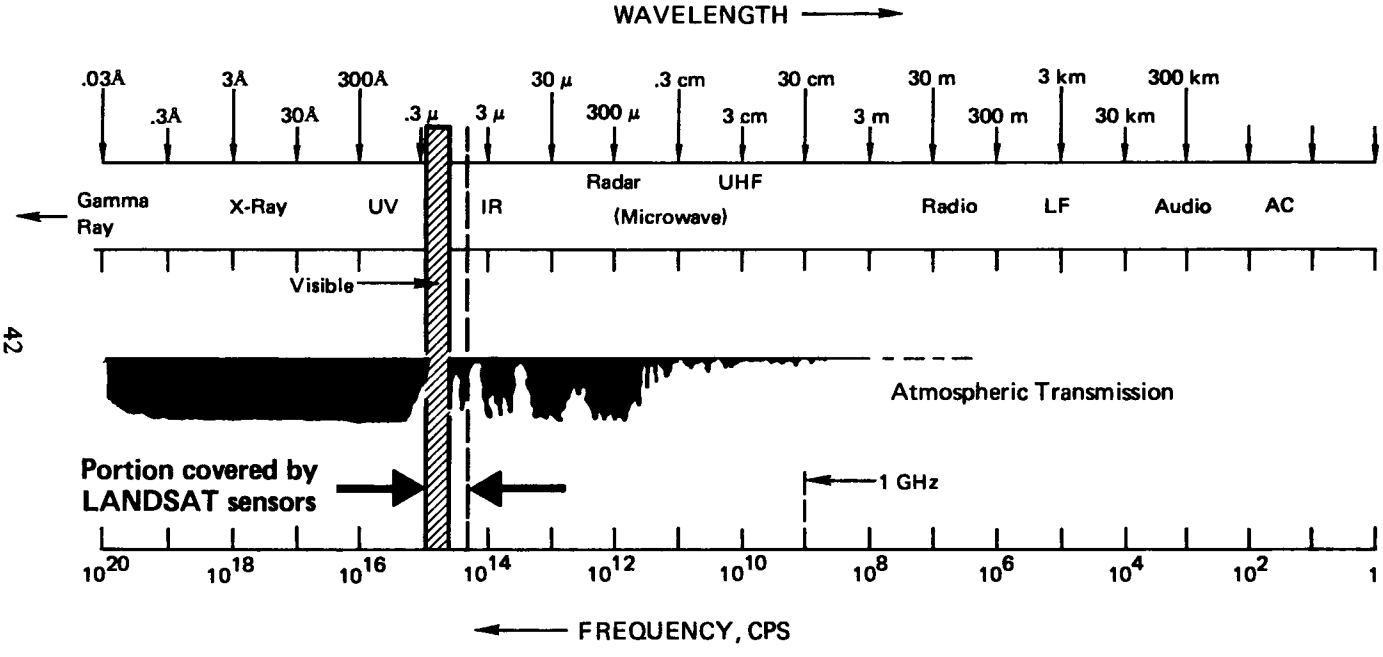

FIGURE 4 Electromagnetic spectrum. The bands in the sensors aboard LANDSATs 1 and 2 cover the visible (shaded area) and a part of the infrared (IR) portions of the electromagnetic spectrum.

(referred to as the spectral signature of the object) is selectively observed by the MSS in four small portions or bands of the electromagnetic spectrum. The use of multiple spectral bands increases the capability to identify or classify features on the ground.

The two LANDSAT sensors—the RBV and the MSS—use seven bands in the visible (0.4 to 0.7 μm) and near-infrared (0.7 to 1.1 μm) portions of the spectrum. (Near-infrared is the portion of the infrared region nearest the visible region.) The three bands in the RBV (Bands 1, 2 and 3) cover parts of the spectrum that are included also in the MSS (bands 4 through 7).

In both instruments, the sensing elements in each band respond differently to varied features on the earth's surface. The four bands in the MSS, and examples of the earth features to which they are particularly sensitive, are as follows:

Band 4 (0.5 to 0.6 μm), in the visible part of the spectrum, has the best capability of the four bands to penetrate water and to determine turbidity in water bodies, to distinguish green vegetation from other surface cover, and to identify geologic structures.

Band 5 (0.6 to 0.7 μm), also in the visible portion of the spectrum, is useful for defining cultural and topographic features and for classifying different types of green vegetation with full ground cover.

Band 6 (0.7 to 0.8 μm) spans the border between the visible and the near-infrared regions of the spectrum and is particularly suited to identify differences in land use and to sense the amount of green biomass in vegetation.

Band 7 (0.8 to 1.1 μm), in the near-infrared region, is effective for land-water boundary delineations and soil-crop contrasts.

Within each MSS band are six detectors whose function it is to receive the energy reflected from the ground features and relayed to the detectors via a scanning mechanism, and to convert this radiation into electrical signals that can be recorded on a magnetic tape on the spacecraft or telemetered back to earth.

The MSS scanning device, a mirror tilted at a 45 degree angle from the earth, rotates about 2.9 degrees, scanning the earth's surface from east to west within the 185-kilometer north-south strip viewed on each LANDSAT passage (Figure 5). Each sweep of the scanning mirror takes in reflected radiation signals from six parallel lines of landscape and feeds these lines of signals through a pair of fixed mirrors and a set of fiberoptic bundles to the detectors, the signals from one scanned geographic line directed to one of the six detectors in each of the four spectral bands. When the mirror returns for the next sweep, the satellite has advanced about 474 meters.

Each continuous line of signals acquired by the scanning mirror is divided into 3,200 separable signals, each of which is picked up by one of the optic fibers in the MSS and passed on to one detector in each of the spectral bands.

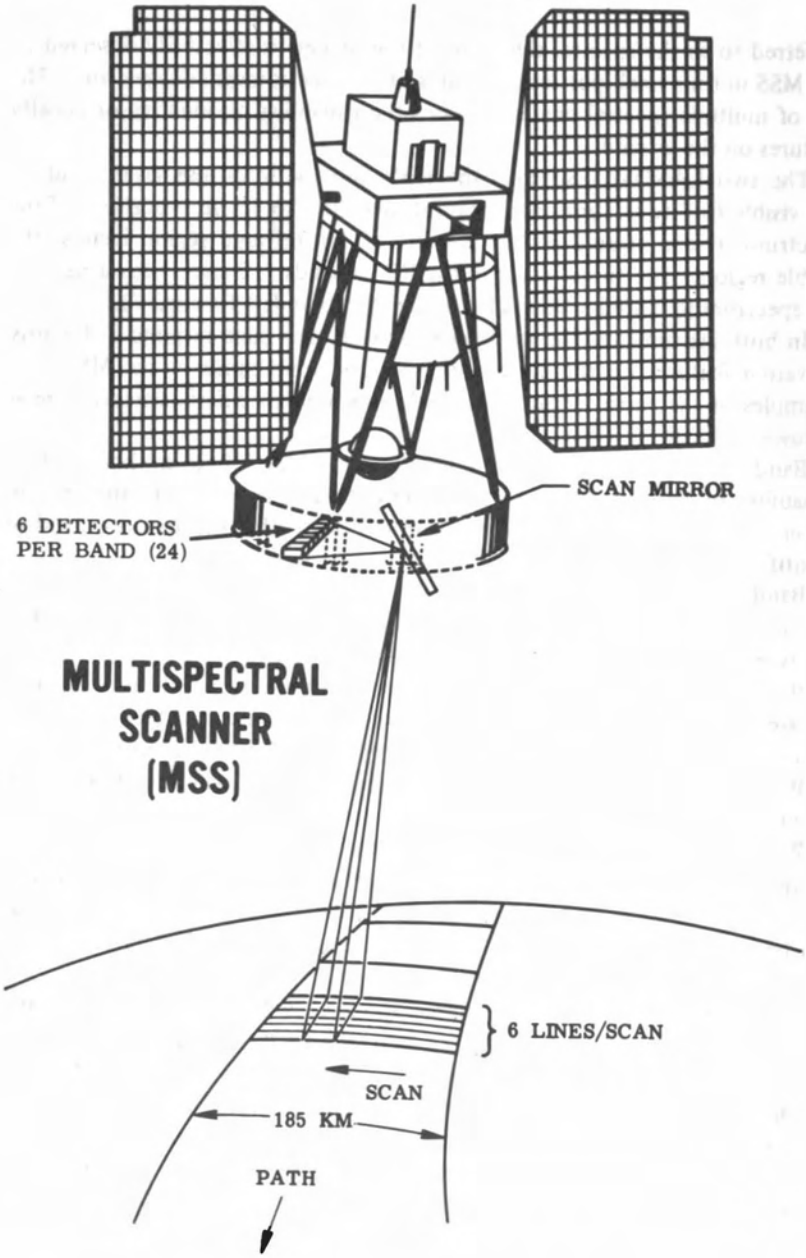

FIGURE 5 Multispectral scanner system pattern. Source: NASA/GSFC

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When the detector translates this single signal into an electrical signal for communication to the ground it is ultimately reproduced in the LANDSAT imagery product as one "picture element" or "pixel" representing an area about 80 meters (259 feet) square on the earth's surface. In other words, ground features or objects less than 80 meters square in size are not likely to be detected by the current LANDSAT sensors.

What distinguishes one radiation signal from another as it reaches each detector is its level of intensity. Each 80 by 80 meter area of the earth's surface has a variety of components with different wavelengths. Some pixels, such as those pertaining to oceans, forests, deserts, wheat fields, will have a high degree of uniformity. Others, in coastlines, suburbs, mixed croplands, for example, may be highly varied in composition. Depending on the nature of each 80 by 80 meter area and the wavelengths reflected by its various components, the level of intensity of the composite signal emanating from that area will be stronger or weaker as it reaches each detector. Because of the different sensitivities of the four MSS bands to the various wavelengths represented within each signal, the intensity level of that signal will be "sensed" and recorded differently in each of the four bands. The full range of intensities sensed by the MSS detectors on LANDSATs 1 and 2 can be transmitted to the ground in 64 distinct intensity levels.

It is the recording and analysis of these different levels of intensity and their identification with the features and areas they represent on the ground that provide the basis for remote sensing of earth resources.

The RBV cameras operate on a different principle. Three television cameras simultaneously photograph the same portion of the earth in three different spectral bands as follows:

Band 1 (green)	.46 to .60 μm
Band 2 (red)	.57 to .68 μm
Band 3 (near infrared)	.66 to .82 μm

When operating, the cameras photograph a 185 by 185 kilometer area every 25 seconds. Because the satellite moves only about 165 kilometers in 25 seconds, every 185 kilometer square scene has an 18.5 kilometers overlap with the next scene (Figure 6). Since each television picture has 4,125 lines and the camera scans rather slowly at 1,250 lines per second, it takes 3.3 seconds for each scene to be "read." Each line in the resulting image has 4,000 elements per line.

In the early orbits of LANDSAT 1, the RBV system generated data of excellent quality. However, as a result of a circuit failure on the first earth resources satellite within weeks after launch, its RBV system ceased to function and experimental development activity came to focus exclusively on the MSS. Although the RBV on LANDSAT 2 is in working order, it has been

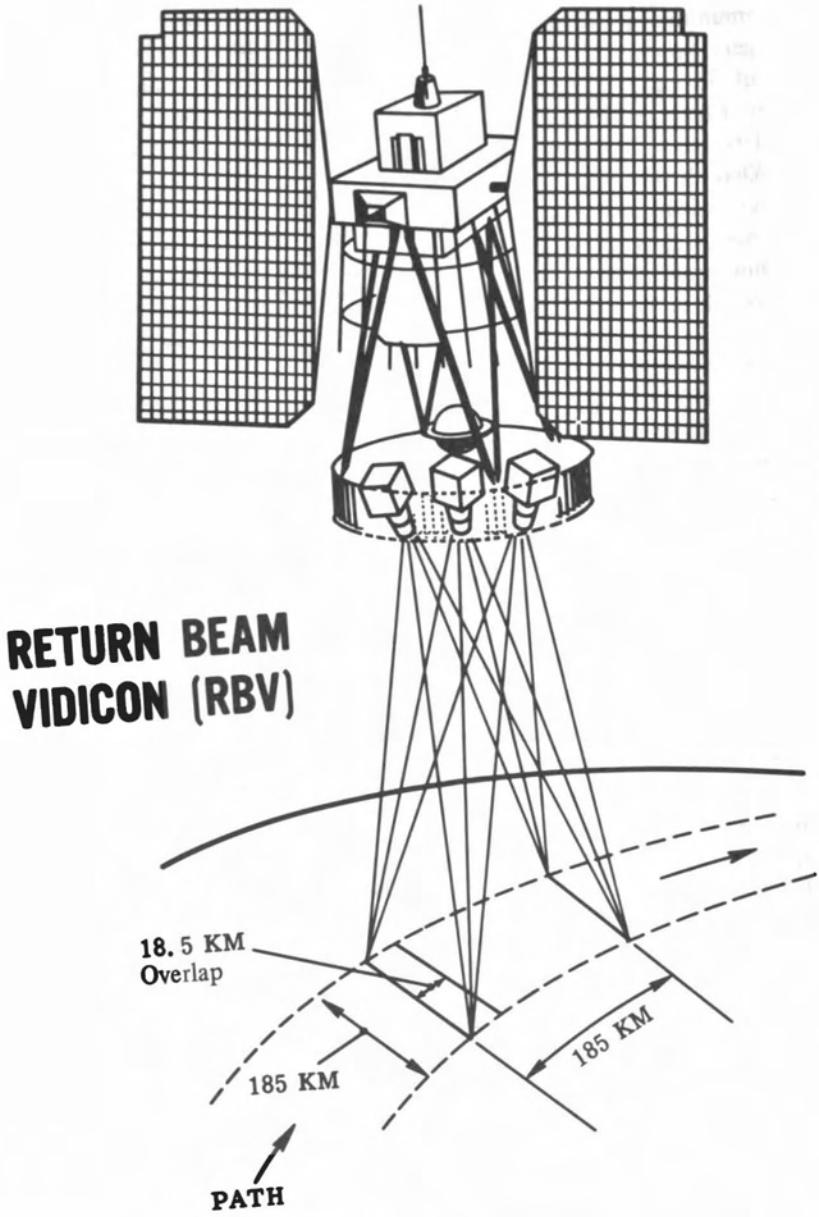

FIGURE 6 Return beam vidicon camera scan pattern. Source: NASA/GSFC

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operated primarily for equipment testing purposes and is being held in reserve for possible special or emergency use.

Data Collection System (DCS)

In addition to carrying sensors, the LANDSATs serve as communications satellites to relay hydrological, meteorological, seismographic, and other environmental data from remote and unmanned data collecting platforms on the ground to central receiving stations elsewhere. The function of these *in situ* ground platforms is to provide continuous readings of phenomena such as water level, stream flow, tide, rainfall, snow depth, temperature, volcanism (see Table 5 in Chapter V) in areas where direct and frequent human observation is difficult or uneconomic. The platforms can be situated in rarely frequented places on land and water and equipped with up to eight sensing devices. The coded data are transmitted in bursts to a passing satellite by command or on a random basis. The satellite records these data for "dumping" at a suitable station or relays them instantly to local user terminals.

Telemetry of Satellite Data

Two wideband video tape recorders (WVTR) were placed aboard each LANDSAT to collect and store the data acquired in areas beyond the range of receiving stations so that the data could be played back, or "dumped," when the satellite came within range of a receiving station. Until the establishment of the ground station in Italy, all LANDSAT data of the Eastern Hemisphere were recorded for later transmission, generally during night hours, to the three U.S. stations. Each WVTR has a 210-minute recording capacity and can handle either MSS or RBV data.

Technical problems have plagued three of the four recorders aboard the first two LANDSATs. No recorder was operating on LANDSAT 1 after June 1974, and only one is functioning now on LANDSAT 2. Users requesting LANDSAT coverage of any part of the world not yet served by a local reception station must await their turn for the recording of desired scenes on the remaining operating recorder.

A Telemetry, Tracking and Command Subsystem on board the satellite thus has four functions: To transmit satellite "housekeeping" information to the NASA operations control center in Maryland and to the NASA global network of tracking stations, and to receive commands from the NASA stations as needed to control the spacecraft; to transmit the data from the sensors on the satellite to ground stations wherever they may be; to dump the

data stored on the recorder to ground stations in the United States; and to relay the data picked up from DCS platforms to the tracking stations and local user terminals. The telecommunications bands, wavelengths, and data rates employed to accomplish these various links between the LANDSATs and ground communications are shown in Figure 7.

Qualities of Multispectral Sensing from Space

The special contribution of LANDSATs 1 and 2 to the gathering of data about the earth's resources is a combination of the advantages of the multispectral scanner over the photographic camera as a sensing instrument and the advantages of a regularly orbiting satellite over an airplane as a sensing platform.

The multispectral scanners have these qualities which differentiate them from conventional cameras:

- They make their sensed data available in digital form, permitting large volumes of data to be processed rapidly by computer to produce resource information desired for large areas in a relatively short time.
- The original data that they provide, unlike a film "original," can be communicated in digital form to numerous reception stations.

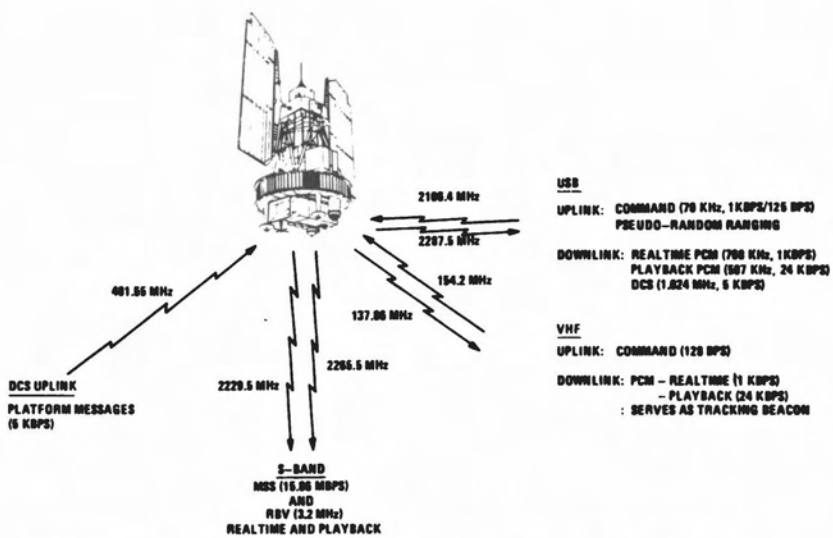

FIGURE 7 LANDSAT ground communication links. Source NASA/GSFC [5]

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- They enable spatial resolution and high radiometric and geometric fidelity to be preserved through numerous stages of digital processing.
- They can acquire important data in the infrared region of the spectrum that is beyond the range of camera systems.

The high resolution photographic camera is still superior to existing multispectral scanners in disclosing the identity, shape, and appearance of many small objects or features.

The unique characteristics of earth resource sensing from an orbiting space platform are these:

Synoptic View

From their high altitude vantage point, satellite sensors offer a synoptic view of a very large area (34,000 square kilometers or 13,000 square miles) in one scene. The capability to encompass such a large area from a narrow look angle with fixed solar illumination and in near orthographic (vertical) form has significance for several disciplines. It permits geologists, for example, to recognize large structural patterns that do not emerge clearly in mosaics of aerial photographs taken from different angles of view and at different illumination angles and intensities of sunlight. It enables the location and extent of an identified resource category to be observed over large areas.

Repetitive Coverage

The passage of a satellite routinely over the same scene every 18 days (or every 9 days when two satellites are in orbit) has two advantages. Repetitive coverage enables comparison of scenes of the same location at different dates and seasons; this is most valuable for monitoring change (vegetation, water, etc.) as well as for extracting more data from a scene by viewing it under different seasonal conditions. Since LANDSAT sensors do not penetrate clouds, repeated passes over the same scene also offer more opportunities to obtain an image with limited, or acceptable, cloud cover.

Uniformity Over Time

LANDSAT's overflight of each area at approximately the same hour of the day gives the repetitive coverage a valuable uniformity of illumination. This constancy of sun angle contributes an additional measure of accuracy in such monitoring functions as land erosion studies, wetland change studies, irrigation practice assessments, and monitoring of various agricultural production factors.

Uniformity Over Vast Areas

Since the uniformity of perspective and illumination that exists within each LANDSAT scene also holds true for its coverage of contiguous scenes in every direction, it is possible to compile mosaic images of unusual consistency and accuracy for vast areas. This permits recognition of large-scale geological structures and enables a reconnaisance level inventory to be made on a continental scale, in a very short time, of resources such as forests, surface water, forage or soil types.

The LANDSAT Ground Segment

LANDSAT earth resource data in the form of telemetry passes through four stages in its transformation into information: data reception, data processing, data storage and dissemination, and data interpretation and analysis.

Data Reception

Of the seven stations currently capable of receiving LANDSAT data, three are located in the United States (Fairbanks, Alaska; Goldstone, California; and NASA's Goddard Space Flight Center in Greenbelt, Maryland), and four are in Canada, Brazil, and Italy. NASA's Operations Control Center at Greenbelt controls the satellite and operates the programmer that turns the sensors and the recorder on and off. The operators of the stations outside the United States inform NASA when they wish the MSS turned on as LANDSAT passes within range of their stations. A station can receive telemetry from LANDSAT while the spacecraft is within its line of sight, or for an approximate radius of 3,000 kilometers. The surface area within each station's ambit—the so-called "footprint" of the current LANDSATs—is therefore about 28 million square kilometers (about 10.8 million square miles).

The number of scenes or frames from one satellite a station can receive in one day ranges from 44 at the equator up to 87 near the poles because of the increasing orbital overlap in the higher latitudes.

The satellite telemetry is acquired at a reception station by an antenna dish about 10 meters in diameter and is recorded on magnetic (video) tape. The three U.S. stations send their tapes to the NASA Data Processing Facility at Beltsville, Maryland. Stations outside the United States retain the tapes to do their own processing.

Data Processing

The video tape of LANDSAT telemetry undergoes a process of annotation, correction, and conversion into the particular form of data product–film, print, or tape–that will make it usable by the technician or analyst.

Annotation consists of attaching to the data product selected information about the source of the data–such as sensor, spectral band, time of exposure, date, orbit number, sun azimuth and elevation, receiving site–and its reference point on the ground. Some of these items are received from the satellite along with the data to which they refer.

Correction procedures are generally of three types:

- radiometric correction, relating to the functioning of the sensors, the recording of the data, and errors in processing
- geometric correction within each band and scene, relating to the position of the satellite with respect to the earth at the time of sensing, including scale changes due to satellite altitude variations, dynamic attitude and velocity variations, image skew arising from earth rotation during scanning, and other mechanical scanning errors
- registration corrections to adjust the images from the different bands of the same scene to one another so that valid composite images from the different bands can be produced.

The application of the annotations and some or all of the corrections to the original satellite data by means of special purpose computers is sometimes called "pre-processing."

The processing arrangements and the formats in which satellite data products have been made available are essentially the same at the processing centers currently operating in all four countries, although they differ in some details. A brief description of the standard data products available in the United States may therefore suffice.

The NASA Data Processing Facility produces only master copies of LANDSAT imagery–in both black-and-white and color composite forms–and computer compatible tapes (CCTs). This facility sends masters of its tapes and image products to the EROS (Earth Resources Observation Systems) Data Center, operated by the U.S. Geological Survey at Sioux Falls, South Dakota, for further processing and distribution.

From the original video tape of satellite telemetry, the processing computers produce four different black-and-white corrected images on film of each 185 by 185 kilometer scene, each image corresponding to the data registered on one of the four MSS bands. However, the 64 levels of intensity on the original tape are reduced in a black-and-white film to between 10 and

15 shades or levels of gray, which are about as many as the human eye can distinguish in that color. The gray levels for the same object in the four separate images often differ from one another. Vegetation, for example, is light in a Band 7 image and dark in Band 5. (For an illustration, see Figure 9, page 87.)

The black-and-white imagery is produced at EROS in several forms: 55.8 x 55.8 mm negative and positive transparencies of each spectral band at a scale of 1:3,369,000, and film and print enlargements 18.5 x 18.5 cm at 1:1,000,000; and print enlargements 37 x 37 cm at 1:500,000 or 74 x 74 cm at 1:250,000. The scale of 1:1,000,000 conforms to that of the standard Operational Navigation Charts (ONC). For parts of the world where the ONCs are the best available maps, this scale is especially useful since the ONCs can serve as base maps onto which LANDSAT data can be superimposed for purposes of geographic correlation.*

Another product is the "false color" composite image of LANDSAT scenes designed to take advantage of the fact that the human eye, unlike its limitations in respect to the gray scale, can distinguish many hundreds of color variations. If a primary color is applied to a transparency from one of the spectral bands and another primary color is applied to the transparency of another band of the same scene, the two transparencies can be registered as one composite color transparency or print. The color composite is a single image in which the original gray tone variations are expressed as different colors or variations in color tone. The third primary color can be applied to the transparency of a third spectral band and a color composite produced from three bands.[6]

The colors employed are not the same as the colors of the features seen by the human eye. Established usage is that natural green is presented as blue, red as green, and near-infrared as red. Vegetation, for instance, shows up in "false color" composites in variations of magenta, orange, and red. Studies have shown that color composites are better than single-band products at presenting the areal distribution of different surface categories, such as rock types.

In the standard processing of color composites, MSS Bands 4, 5, and 7 are combined, with yellow used for Band 4, magenta for Band 5, and cyan blue for Band 7. The color composites are available as film positives at a scale of

*A Canadian innovation is the rapid production of 70 mm "quick look" imagery as the initial data product. The "quick look" images have about half the spatial resolution of the NASA products but are available for examination at the receiving station on the day of their acquisition. The Canadian Center for Remote Sensing then processes higher resolution data on an "as needed" basis, amounting to about 20 to 30 percent of the total data received. NASA, on the other hand, processes all the data at the higher resolution and provides quick look data on an "as needed" basis. NASA expects, in late 1977, to make the higher resolution data available in about one week from acquisition. The Brazilian and the Italian stations also have a quick look capability.

1:1,000,000 and as glossy prints at scales of 1:1,000,000, both produced by NASA, and glossy prints at 1:500,000 and 1:250,000, produced at EROS.

To extract the full data value from the 64 distinct MSS intensity levels, the most effective product is the computer compatible tape (CCT). The original video tape data are first converted into intermediate High Density Digital Tapes (HDDTs) by one processing subsystem and then further converted by another subsystem into CCTs. These retain enough of the original telemetered data to preserve all the intensity levels in digital form. The CCTs can be fed into computers for digital analysis of the spectral properties of each pixel and for production of desired information in tabular form. The tapes can also be used to produce thematic maps emphasizing one or another selected ground feature. (See Table 3, page 80, and color plates, pages 84-86.)

Data Storage and Dissemination

In the United States the function of cataloguing, storing, reproducing, and distributing the film and tape products of remote sensing from satellites and aircraft is performed by the EROS Data Center, which services requests—foreign as well as domestic—for space and aerial remote sensing and photographic output of U.S. federal agencies.*

To facilitate cataloguing and as a service to potential users, NASA prepares strips of 16 mm microfilm containing miniature replicas of the new data products available for each sensor band every month. While not good enough for most practical uses, these films do show the degree of cloud cover in each scene and therefore the extent of its usability. Strips may be obtained from the EROS Data Center as reels or microfiche or examined at various "browse facilities" throughout the United States. NASA also publishes two monthly data catalogues—one for U.S. and one for non-U.S. coverage—which contain the geographic coordinates, identification numbers, cloud cover data, and various other items of information about the scenes that are on the "browse" microfilm for the month.† NASA has also prepared cumulative catalogues of satellite coverage of U.S. and other areas.‡ One or more cloud free images are available for between 80 and 90 percent of the land surface of the earth.

*By the end of 1977, NASA will confine its LANDSAT data processing to the production of annotated and corrected HDDTs. The function of producing master imagery and CCTs and copies for consumers will be transferred to the EROS Data Center.

†These catalogues are available from the National Technical Information Service, Springfield, Virginia, 22161.

‡Index maps of the world, designed to show the number of relatively cloud-free images that exist for each scene, are available in two collections: (1) The USGS has published 7 maps at a scale of 1:18,000,000 as *Index to LANDSAT Coverage*[8] with percentage of cloud cover, produced up to July 1974; (2) the World Bank has issued a *LANDSAT Index Atlas of the Less Developed Countries of the World*[9] valid through May 1975, noting the date of each image and the degree of cloud cover, and enabling the user to identify the particular image desired. Other index maps have been prepared by private firms, including oil companies, but these index maps are not publicly available.

As of January 1976, the archives of the EROS Data Center included 600,000 frames of LANDSAT imagery, 40,000 frames of SKYLAB and other satellite data, 4 million frames of Interior Department aerial mapping photography, and nearly 2 million frames from NASA's research aircraft program. Total demand for these products has grown from 165,000 frames in 1973 to more than 400,000 in 1975.[7] The pricing policy is determined by the costs of reproducing the data product. As of January 1977 the Center's schedule of prices was as follows: $200 per scene for CCTs; $8 per 18.5 cm black-and-white paper print of a scene from one band; $12 per 18.5 cm color composite paper print; $10 or $15 for film products of the same size, and higher prices for 37 cm and 74 cm products. More than half of the dollar value of sales has come from LANDSAT data. In dollar value, private industry has been the heaviest purchaser (30 percent), followed by federal government agencies (24 percent), academic and educational institutions (16 percent), and foreign customers (12 percent).

Distribution of LANDSAT data by stations outside the United States is governed by the bilateral agreements between NASA and foreign station owning agencies. A station is expected to supply data it receives on an open and nondiscriminatory basis at a fair and reasonable charge based on actual cost.

Data Interpretation and Analysis

The final step in the process of transforming the remote sensing raw data into information that is intelligible to, and usable by, resource managers is the interpretation and analysis of the imagery or digital data. (Figure 8 summarizes the flow of the data from reception to the analysis stage.)

Various methods of extracting information from remote sensing data can be used. Arranged in rough order of increasing cost and sophistication, they are: (1) manual interpretation of standard photographic products using very simple, inexpensive instruments; (2) manual interpretation aided by photographic enhancement and employing more costly optical equipment; (3) manual interpretation of special digitally enhanced photographic products using the equipment of step 2; and (4) digital analysis of the computer compatible tapes in a process of man-machine interaction to produce the desired computer output, which in turn is subject to further human interpretation and analysis.

The simplest of these procedures—manual interpretation of standard photographic images—calls on skills of photo-interpretation familiar to geologists, geographers, foresters and other resource scientists. The interpretation

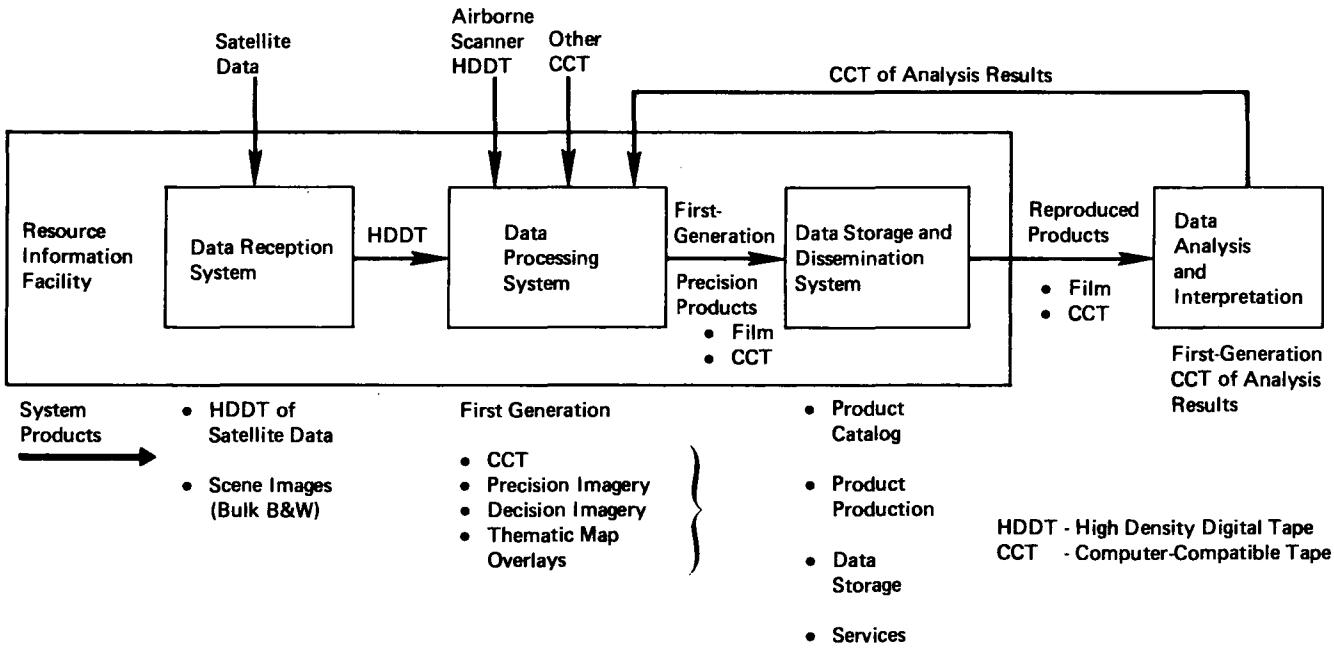

FIGURE 8 Basic elements of the ground segment of an earth resource sensing system. Source: Adapted from U.N. publication[11]

will usually be aided by photographic enlargement, or diazo processing* and use of light tables and simple projectors available at prices of a few hundred dollars apiece. The more experienced the analyst as resource scientist and interpreter, and the more familiar he is with the area under study, the better the interpretation is likely to be.

If the resource scientist has access to a modestly equipped color photographic laboratory of the sort found in many government departments and universities in developing countries, additional enhancements which are well known to photographers may be employed to assist the interpreter. Such enhancements may be used also with special equipment, such as zoom transfer scopes, color additive viewers, and microdensitometers. These cost in the range of $5-8,000, $10-15,000, and $8-30,000, respectively, and may be more or less valuable depending on their intended use. The zoom transfer scope enables data from enhanced images to be transferred to resource maps at different scales. Using a color additive viewer, an investigator can view individual spectral bands of a scene through separate color filters, at different intensities. Specific surface characteristics can thus be emphasized and communicated more effectively to the data user. Densitometers measure the color densities of a composite color reproduction or of each layer of color by insertion of appropriate filters, and may be used to quantify some aspects of image analysis.

The photographic procedures used in this level of analysis include techniques for bringing out boundaries or edges of surface features; for superimposing incongruent registration of several images, taken on different dates, of a single scene; and for assigning different colors to specific image density ranges or "slices" so that the various densities can be more sharply differentiated. These are all forms of "image enhancement," the process of departing from the fidelity of an image in order to enhance those features that are of special interest to the investigator, planner or resource manager. Where base maps of the appropriate scale exist, LANDSAT film overlays can be superimposed to relate the satellite data to the geographic features they represent.

*Diazo techniques can be used in the laboratory or in the field to provide the investigator a flexibility with color products unattainable in the standard false-color product obtained from the EROS Data Center. The technique, simple, relatively inexpensive, and readily usable by anyone familiar with blueprint reproduction, allows conversion of black-and-white film into color with a minimum of photoprocessing materials. A photosensitive emulsion reacts with ammonia vapor to produce a vivid color on ammonia-sensitive film, which is then exposed through the black-and-white MSS transparencies. Three MSS band film products and diazo transparent bases in the appropriate colors are all that are required to produce standard false color transparencies in which the gray shades are reproduced as color tones. Diazo permits experimentation with a variety of colors to enhance specific features. These products can be made in sunlight or in ammonia blueprint copying machines using ultra-violet light.[10]

In some cases, LANDSAT images have themselves provided the first base maps to be made of previously unmapped areas.

The third step may use all the preceding methods, but in addition calls for special digital enhancement of photographic products. At present, these products are produced by several commercial houses, universities and government research laboratories in the United States. Except for the very largest of institutions, users may have to obtain these products primarily from commercial sources for some time. Single LANDSAT scene enhancements—color band ratioed images* and several forms of color edge-enhanced images—have been widely purchased by major resource companies in the United States (mining, petroleum, timber) at a scale of 1:250,000 and at a cost (in October 1976) of some $800-1,000 per scene. The investment is apparently warranted where major exploration costs are involved, and may be warranted also as part of a basic inventory project in developing countries.

Finally, there is the most complex, and initially most expensive procedure—digital analysis of computer compatible tapes. The results of this digital analysis appear in a variety of visual forms: statistical tables, graphs, digital maps, histograms, map overlays, annotated imagery, or thematic maps in which the landscape objects or features of interest are enhanced and often appropriately colored to define their location and extent.

Major universities and government departments in the United States, Japan, France, Germany and other developed countries now have the technical means to perform such analysis and to generate some or all of these products. In addition, a number of firms, mainly in the United States, offer these services and products on a commercial basis. U.S. federal and state agencies and many private companies purchase such products and services despite their cost ($2,000-8,000 per LANDSAT scene, depending on the type of product desired) because they may be needed only for small areas, or sufficiently infrequently that the service is cost-effective. As competition increases, and better computers for image processing are employed, these costs will come down.

The investment in digital processing equipment may range from $300,000 to over $1,000,000 depending on the computers and peripheral display and color recording devices obtained. The purchase of such equipment is a major investment decision for a developing country; careful exploration of potential costs and benefits on a country-by-country or regional basis is required.

In the early days of LANDSAT 1, the bulk of the demand in the United States was for film and image products. As users have become more aware of

*Band ratioing is the technique of using the ratio between the different signal intensities sensed by individual spectral bands to provide an additional factor in spectral analysis. This ratio between bands tends to minimize atmospheric interference effects. Differing weights can be given to each band to accentuate differences between reflecting surfaces.

the cost/value trade-off for digital enhancements and classifications, there has been a clear increase in the demand for CCTs. The fact that the original LANDSAT data are received in digital form promotes the use of computer methods for study of the spectral bands. Digital processing preserves, and permits an investigator to exploit, the total information content of the original satellite data, unlike the film and print output which loses information detail with each successive processing of the same scene.

A new mechanism for facilitating the display and manipulation of digital data is the interactive data analysis terminal (IDAT). The terminals accept CCTs and as independent units can be located anywhere. With help of an IDAT and a brief course of instruction an analyst or resource manager can take a tape of a LANDSAT scene and perform a variety of functions to transform the data into usable information. He can compile statistical data, initiate automatic classification of discernible ground features, display processed data in which he is interested and, with the proper ancillary equipment, make copies of the display in permanent form.

An IDAT permits the selection of colors to enhance specific signatures, themes or patterns. The operator works from a television monitor and assigns colors to patterns chosen as "training areas" or "training sets" delineated by an adjustable cursor. The computer can be directed to extend the same colors to similar spectral signatures elsewhere in the same scene, and even to adjacent scenes or to the same scene sensed on different days or in different seasons for purposes of comparison. A computer count of the number of pixels included in all the similar signatures will give quantitative measurements of the feature—whether it be crop area, rangeland condition, forest, water body, land use category, or geologic structure. These data can then be displayed on the IDAT screen as thematic maps, histograms, or other types of graphic presentations. The current cost of minimal IDAT systems is $250,000 to $500,000, depending on the peripherals included.

Multistage Data Collection

To be fully effective, satellite sensing must be complemented for many purposes by data from aircraft and from observations on the ground. Such multistage sampling yields progressively more detailed information for correspondingly smaller units of the area under study. The more detailed subsamples make it possible to extrapolate findings to an entire LANDSAT scene and thereby to produce an inventory of chosen features.

The special roles of aircraft sensing and ground observations in a full system of remote sensing may be briefly described.

Aircraft Sensing

Aerial photography missions can be flown over a specified area to collect data of an intermediate level between satellite sensing and ground observation. If acquired concurrently with a LANDSAT overpass, or reasonably soon thereafter, the data may be used as "ground truth" with which to calibrate the data of the space sensors.

In addition, for purposes not met by satellite sensing, aerial photography or sensing is frequently the sole alternative. Aircraft provide excellent platforms for photographic cameras, magnetometers, radar, scintillation counters, and infrared instruments, particularly for data collecting missions not requiring repetitive monitoring of wide areas under uniform conditions. New aerial sensors are continually being developed for mineral and petroleum exploration, mapping, geophysical study and applications relating to forestry, agriculture, ecology, and water resources.

Low altitude (up to 9 kilometers or 29,500 feet) aircraft are used currently in range management, fish spotting, water quality studies, and acquisition of photos for mapping and charting. Medium altitude (9-15 kilometers or 29,500-49,000 feet) aircraft, equipped with side looking radar, radar scatterometers, infrared and multispectral cameras, and various metric and multiband photographic equipment, are of special value for photoreconnaissance, urban planning, agricultural monitoring and environmental quality applications. High altitude (over 15 kilometers or 49,000 feet) planes with high resolution and wide angle cameras, multiband cameras, and various infrared cameras and scanners are used in horizon scanning and broad area, high resolution mapping. High altitude, high resolution photography proved to be extremely valuable in assessing the damage of the Guatemala earthquake in 1976.

Aircraft systems can provide MSS hard copy, film and tape for on-ground analysis; some are equipped for onboard analysis or data editing. The aircraft's special advantage lies in the flexibility it offers in the selection of the best line of flight, altitude, and time of day for one-time studies or for observing specific events.

Various sensor payloads have also been used from free or tethered balloons. However, pendulum effects, rotation, and wind influence make balloons unattractive for studies where platform stability is important.

Ground Observations

Ground observations are essential components of any remote sensing program. Whether an investigation is based on spaceborne or on airborne sensing products, the resulting data may be meaningless without "ground truth" field work–the examination, sampling, or measurement of features of the earth's

surface to correlate what is seen on the remote sensing data products with what actually exists on the ground. The need for such a correlation exists with respect to both static and dynamic elements of the earth's surface.

Requirements for some broad categories of information can be met by study of satellite data with virtually no ground observation. If hydrologists wish to know the surface area of a country's lakes and reservoirs, spectral analysis of the satellite data alone can yield the answer. A minimum of ground observation data make it possible, for instance, to differentiate summer crops from winter crops in LANDSAT images.

In general, however, without ground measurements and observations appropriate to the remote sensing task, the accuracy of the information gleaned from the space imagery or digital data, and the geodetic control of the data, may well fall below acceptable standards and be of marginal or of no use to the resource manager. If the objective, for instance, is to identify, separate, and map twelve categories of green vegetation, five categories of water, or nine different soil mapping classification units, the ground observation component becomes exceedingly important.

For some monitoring purposes, such as estimation of wheat acreage or forest clear-cutting, the need for continued validation of the space data by ground observation can be progressively reduced with succeeding passes as the data signatures become familiar with experience.

The extent and nature of the ground study in a remote sensing program depend not only on the program's objectives but on the types of sensors used and the methods of data analysis to be employed. To assure efficiency and accuracy in a study, investigators must carefully select the optimum timing of measurements, sample location, instrumentation, and the properties to be observed or measured.

For some purposes, especially in regard to dynamic conditions such as soil moisture, ground truth data must be obtained at about the time of the satellite pass. The sites chosen for ground sampling should be representative of the features or conditions being sought in the study and be readily identifiable in the imagery.

For many applications of remote sensing, the field check can be accomplished with nothing more than the human eye. Instrumentation may be required, however, for certain tasks: standard sampling and laboratory equipment for field studies of soil and water, infrared radiometers to ascertain temperatures, and various types of spectrophotometers or spectroradiometers to measure spectral reflectance of objects near the ground for correlation with the reflectance of such objects in the mass as registered on the satellite sensors.

One type of ground observation useful for analysis of satellite or aircraft data is to note and record atmospheric conditions at the time of the over-

flight; reflectance and transmission of electromagnetic energy will be affected by these conditions and, if information on them is available, a correction factor can be introduced in the analysis of the data.

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IV Experience with Landsats 1 and 2

Since the launch of the first LANDSAT in July 1972, images from its multispectral sensors (and of the companion LANDSAT launched in January 1975) have been subjected to intensive study and experimentation by many hundreds of scientists and technicians in a broad range of disciplines. Included in this community of remote sensing researchers is a specially designated group of principal investigators, located in the United States and 52 other countries, whose research project proposals were selected by NASA for formal sponsorship as a means of inducing systematic examination of LANDSAT's potential. Their reports and the findings of many other experimenters provide the basis for evaluations of the content of the satellite data and of its utility for a wide array of applications.

The now voluminous output of scientific and technical literature on remote sensing application experiments addresses primarily techniques of processing, analysis, and interpretation, and a modicum of quasi-operational experience, in such areas as agriculture, rangelands, forestry, water resources, geology, cartography, land use, demography, environmental protection, oceanography, disaster warning, human and animal health.

The results of many of these experiments have also been reported at a series of major symposia and have undergone critical evaluation in several review studies.* These largely are the source for the summary accounts that follow. The accounts describe, with respect to each of the application sectors just listed, the current assessment of what LANDSAT† multispectral data can be made to reveal, the extent to which they respond to data requirements in

*Of the many published reports, three of the most significant are (1) *Remote Sensing for Resource and Environmental Surveys: A Progress Review*, by the Committee on Remote Sensing Programs for Earth Resource Surveys, National Research Council;[1] (2) *Earth Resources Survey Benefit-Cost Study*, by Earth Satellite Corporation and Booz-Allen Applied Research Corporation;[2] and (3) *Practical Applications of Space Systems*, by the Space Applications Board, National Research Council.[3]

†Although meteorological and other satellites increasingly contribute to environmental monitoring, their capabilities are generally known and will not be detailed here. This chapter concentrates on experience with the new LANDSAT satellites that are designed specifically to yield earth resource data.

the United States, and the uses they may have, or have been shown to have (with some case illustrations*), in the varied milieux of the developing world.

Agricultural Production

The intense and worldwide preoccupation with the question of food supply has naturally focused strong attention on the contribution of space remote sensing to better management of agricultural systems and better and more timely information on output of key agricultural commodities.

Investigations of the application of satellite sensing to U.S. agriculture have dealt principally with the inventory of crop acreage, forecasting of crop yield, soil survey, design and operation of irrigation projects, and assessment of flood damage. The latter two areas are covered in the subsequent section on water resource management.

Crop Acreage

Accuracy of crop identification with present LANDSAT data has run to 90 percent or higher in studies of areas where there are large, homogeneous, rectilinear fields with few competing crops, such as irrigated rice in California and bare autumn ground being readied for wheat in Kansas, Oklahoma, and Texas. The accuracy of LANDSAT data for crop identification in certain U.S. wheat-growing areas is being studied in the current LACIE experiment.† Relatively few areas in other parts of the world, however, are structured as simply as wheat fields in the United States. In the developing countries cropland frequently is interspersed with noncropland, fields are small and irregularly shaped, numerous crops have similar spectral responses. In such complex environments, a single LANDSAT image may not provide enough data to be useful for purposes of crop identification.

*Illustrations of LANDSAT applications in developing countries, provided by Committee members or drawn from other sources, are presented at the conclusion of most of the sectoral accounts in this chapter.

†NASA, the U.S. Department of Agriculture (USDA) and the National Oceanic and Atmospheric Administration (NOAA) are currently engaged in a major study to determine the degree of accuracy in crop identification, acreage, and yield that can be achieved by LANDSAT remote sensing. The project–the Large Area Crop Inventory Experiment (LACIE)–began with monitoring of wheat plantings, yields, and crop conditions in the Great Plains area, checked against ground truth and conventional data collection carried out by USDA personnel. If the results are satisfactory in the United States, the experiment will continue in respect to wheat in other countries and then may be extended to other crops such as rice and soybeans.

Improved identification can be obtained by merging imagery of several different dates; this has produced accuracies with computers reaching 95 percent or better in simple areas and 75 to 80 percent in more complex areas.[4,5,6] Further improvements in accuracy can be anticipated as additional data are accumulated for each sample area, such as improved crop calendars conforming to natural phenological boundaries, information on soils and crop composition, and greater knowledge of local agronomic practices. The application of statistical sampling techniques, such as are already in use by the Statistical Reporting Service of the U.S. Department of Agriculture, in combination with LANDSAT imagery, will provide yet additional accuracies in estimation of crop acreage over large areas.[7,8]

For developing countries, the LANDSAT experience with crop identification in the United States to date has these implications:

- The small irregular fields and the practice of intermingling crops typical of many developing countries will make it difficult to identify and measure the acreage of selected crops at current resolution levels.
- Problems occur in the use of satellite data for the wet tropics because the same crop can be at many stages of growth throughout the year. In addition, current sensors cannot penetrate the seasonal cloud cover.
- These limitations notwithstanding, if developing countries with inadequate crop acreage information can obtain crop acreage estimates of 75 to 80 percent accuracy from earth resource satellites, they will for the first time have a base upon which to design an agricultural statistical sampling system.

Yield Forecasting

Identifying crops and measuring acreage are only one step in the process of forecasting crop production. The other is forecasting yields. So far, U.S. studies indicate that for wheat yield forecasting, LANDSAT data *alone* are not likely, in most instances, to substitute for existing methods. However, in association with the LACIE crop acreage estimation, parallel studies have been carried out on wheat yield estimation using a combination of wheat plant stress models and ground and satellite meteorological observations.* The preliminary results are promising. In the latest phase of the investigation meteorological data have been used with LANDSAT observations of crop condition to further improve the yield estimating procedure.

*An agrometeorological model thus obtained is a numerical description of the way a crop interacts at various stages of growth with its environment (atmosphere and soil) in absorbing and using solar energy, and in absorbing water from the soil and transpiring it to the atmosphere. For completeness, the model also includes the moisture and energy flows of portions of crop fields which are unvegetated.

Current results with the MSS data with respect to wheat lead to cautious optimism for the application of improved yield forecasting and acreage estimation to the developing countries, with judgment still reserved on the capability of existing LANDSAT and meteorological satellites to provide improved acreage and yield estimates for other crops.*

Soil Survey

Studies to determine whether LANDSAT data could provide useful soil and land system surveys have been encouraging. Variations in soil characteristics can be identified in computer enhanced LANDSAT imagery. Delineation of these patterns, confirmed by ground observation, can yield soil association maps which provide a good indication of probable soil characteristics.

Cooperative studies between soil scientists of the USDA Soil Conservation Service and scientists in universities have shown in Indiana and Missouri that digital processing of LANDSAT data provides sufficient information for detailed mapping of soils at scales of 1:15,840 and 1:20,000, and, in some cases, permits identification of specific series and types of soil.[10] Spectral maps produced from LANDSAT data have given important separations or differences between soils not discernible in conventional black-and-white photographs. With a spectral map of a county prior to field sampling and measurements, a soil surveyor can determine quickly locations and areal extent of soils with significant differences. Such information can greatly reduce the number of observations and time required in the field.

LANDSAT data and imagery have been used effectively to provide a base for the preparation of semidetailed soils maps at scales ranging from 1:50,000 to 1:250,000. Based on the demonstrated capability of the present LANDSATs, it should be possible to provide many of the developing nations with detailed or semidetailed soils maps that would be impossible to obtain in the foreseeable future by conventional methods. The areas where this cannot be done are those where dense tropical vegetation prevents any observation of

*The LACIE experiment seeks to test the technical feasibility of deriving—from satellite, meteorological, and historical data—wheat production forecasts that are close to exacting USDA standards. To provide timely and useful forecasts of global yield of major world crops, however, it may not be necessary to reach these standards. A plan for a Global Agricultural Information System, based on data from LANDSAT and other satellites and on acceptable agro-meteorological models for each major crop, as well as on other data inputs, is under consideration by the UN Food and Agriculture Organization and has been presented to the U.S. Congress Office of Technology Assessment. According to its author, the program could give satisfactory worldwide production forecasts for wheat two years after its initiation, for corn and soybeans after three years, and for rice after four years.[9]

the soil, although some information can be gained by mapping vegetation types which have an affinity for particular kinds of soil.

The capability to overlay the LANDSAT multispectral data onto topographic maps and/or other two-dimensional data opens new possibilities for producing land use capability maps and soil productivity ratings. A good land use capability map can help a developing country select areas for possible priority agricultural development.

Significant use of LANDSAT imagery is foreseen for land and soil reconnaissance level surveys in the developing world. In a project now underway in Tanzania, digitally enhanced LANDSAT imagery, in conjunction with substantial small-area soil and plant community ground observations, and drawing on research personnel in the field and light aircraft observations, has been used to provide a basic land system evaluation of the Arusha district at a scale of 1:250,000.[11]

The soil survey staff of the UN Food and Agriculture Organization is now utilizing LANDSAT data in a worldwide study of soil limitations for agricultural production.

In summary, LANDSAT data, when complemented by existing and supporting information, could improve the technical basis for management decisions in agriculture in these respects:

- Better planning to meet food and agricultural needs as a result of improved crop acreage estimation in those countries that have sizeable areas of large-scale, simple structure farming
- Improved crop yield estimation through collateral use of meteorological satellite and other data in a yield estimating procedure
- Improved agricultural planning based on better knowledge of soil capability and water availability.

As part of a national water study of *Mexico*, soils maps at a scale of 1:1,000,000, intended to show the location and extent of the country's potentially arable soil resources, have been prepared largely with the aid of LANDSAT data. Two sets of LANDSAT color transparencies for most of the country—one taken in the autumn wet season and the other in the February-March dry season—provided the basis for the mapping project, which covered present land use as well as soil capability. The study of present land use covering the whole country (197 million hectares) took two years and cost $200,000 (0.1 cents per hectare). One significant finding was that 6.3 million hectares were in a state of advanced erosion. The study of soil capability covered 45 million hectares and was completed in one year. Thematic maps were extracted from the satellite data to indicate potential for cultivated crops and range, soil depths, wetness, slope, erosion hazard, and irrigation prospects. The maps now offer the Mexican Government a guide to the soils that are considered good or fair for development and that deserve more detailed study. For instance, it seemed

clear from the maps that some areas used for rice might be better for other crops and that the soils of the Gulf Coast area would be more suitable for rice production.[12,13]

Rangeland Management

Investigations in the U.S. to determine the value of remote sensing from satellites for rangeland management have focused on three concerns: inventory of range vegetation types, evaulation of range feed, and monitoring of rangeland improvement and change.

Since most of the land used for range in the United States is arid to semiarid, not all range types show up clearly to satellite sensors. That is because the density of plants is low, the plant composition is variable, and the percentage of ground cover is often not more than 50 percent. Despite these problems, the LANDSATs have produced useful rangeland inventory data in the United States and could assist U.S. rangeland resource managers in deciding where to allot time and funds for more detailed inventory.[14,15]

The present sensor resolution is adequate only for identification of broad categories of grassland types, the locations of which are generally known in the United States. In developing countries, however, where the disposition of these broad categories is not widely known or mapped, LANDSAT data could make a useful contribution to both regional and local rangeland management, as in the Tanzania example described below.

Rangeland monitoring studies are conducted to gather information needed to improve productivity. They seek data on range conditions, trends, readiness for grazing, and patterns of grazing use.

Dynamic sensing from LANDSAT of the annual grasses which cover most of the foothill terrain in California has traced the greening of the landscape with the onset of the rainy season each fall and winter and also the progressive browning with the onset of the dry season in the spring and summer. Such information may help recognize potential fire hazard, project the anticipated weight gain of livestock, and determine the extent to which drought and grazing have reduced available forage.[16]

In one study rangeland features such as meadows, springs, moist sites, islands of browse, ponded water, and small reservoirs—as small as 1 1/2 acres in size—were detected by using LANDSAT data and manual analysis techniques. These features in rangeland environments are sensitive "areas" that need to be monitored in order to permit assessment of the associated grazing, wildlife, and recreational potential of the broader area. In addition, through the analysis of multidate LANDSAT imagery during the spring and with the help of limited amounts of aerial photography and direct on-site observation,

image analysts could observe changes in both the forage and water resources of the overall rangeland area. This information can contribute to better planning of resource use.[17]

Quantitative estimates of the condition of range feed, based on LANDSAT data, have not yet been attempted. But several experiments in the United States and Australia have shown that for some semiarid pastures it is possible, through "band ratioing," to derive estimates of green biomass.[18]

Although results in U.S. rangeland studies thus far have been mixed, enough has been learned to indicate that with a nine-day frequency of satellite coverage, with use of data from meteorological satellites and with efficient delivery of the information to the users, an effective, high-quality system of range condition reporting, trend monitoring, and forecasting is technically feasible with present LANDSAT data.

Besides identifying existing or potential rangeland areas that require more detailed aerial or ground observation, a system of rangeland monitoring from space can help to guide a number of important decisions in developing countries:

- timing of turnout and removal of livestock in grazing areas
- preparation of plans to prevent overgrazing and to open up new areas for grazing
- timely measures to reduce fire hazards
- additional investment in range improvements by draining, irrigating, seeding, or fertilizing.

A study in the Arusha region of *Tanzania* employed LANDSAT data successfully in delineating boundaries for 550 distinct landscape units in a 32,000 square mile area on the basis of landform and vegetation characteristics. Fourteen grassland types of varying suitability for forage—three herbaceous, eight shrub/scrub, and three savannah—were recognized in the LANDSAT data. These delineations, fortified with detailed sampling information provided by aerial photography and on-site inspections, have identified promising areas for range, agricultural, and ground water development.[19]

Forest Management

The survey and management of forests in the United States is accomplished by a complex and thorough system of aerial photography at different altitudes. Because of the very detailed types of information needed to meet statutory requirements, and the mixture of tree species typically found in U.S. forests, LANDSAT data, particularly for inventory purposes, are proving to be inadequate.

However, the research findings of various investigators indicate that LANDSAT data could contribute to forest management and help to reduce forest inventory costs. The data have proved useful with respect to:

- sampling procedures for estimating volume of timber
- monitoring of forest cutting of clear-cut type
- mapping of forest fire burns, especially the "crown fire" type common in the western part of North America.

Quasi-operational studies in Northern California found that LANDSAT data, with the aid of multistage sampling, were able to provide timely and cost-effective inventories of gross timber volume and an economical inventory of total timber resources, including the factors of growth rate and timber stand condition. Manual and automatic techniques of data analysis used in the same studies detected changes in the resource base over time, assisting location and area estimation of harvesting activities, post-fire mapping and fire damage assessment.[20]

A Canadian project using LANDSAT imagery to map forest burns in Saskatchewan detected 42 burns across the northern part of the province. The LANDSAT imagery was produced far more quickly and accurately than would have been possible for photographic imagery obtained from conventional helicopter or aircraft platforms.[21]

In most of the developing world, data on forest resources are crude and incomplete at best. There are no comprehensive systems of forest inventory by aerial photography of the type found in the United States and in other technologically advanced countries. But data requirements may also be substantially less stringent. In such a setting, LANDSAT data may be of significant benefit in providing basic information on the extent and location of forest resources and the changes occurring in the woodlands.

Developing countries are increasingly aware of the need to manage their forest resources not only to meet their timber and energy needs but also to preserve the ecological balance and to prevent erosion, siltation of dams, and pollution of coastal waters. Mapping of forest vegetation, estimation of timber volume, and measurement of the rate of depletion—to which satellite data can make important contributions—are essential steps in the planning of control measures.

In *Brazil*, LANDSAT imagery has been used to monitor a program for controlled development of large areas of the Amazonian forest for various purposes, especially cattle grazing. Landowners, with the help of government subsidies, are permitted to cut down trees up to a third of their land holdings. Routine and systematic use of LANDSAT imagery has proved to be the only economic way of enforcing the terms of the government-assistance contracts and of monitoring and controlling the volume of tree-cutting.

The salient characteristics of simply structured and complexly structured agricultural, rangeland, and forest areas and the feasibility of using remote sensing techniques to derive information of such areas needed by resource managers are indicated in Tables 1 and 2.

TABLE 1 Characteristics of Vegetation Resources

SIMPLY STRUCTURED AREAS	COMPLEXLY STRUCTURED AREAS
Agricultural Characteristics	*Agricultural Characteristics*
Agricultural fields large, regularly shaped, little interspersed with non-croplands	Agricultural fields small, irregularly shaped, largely interspersed with non-croplands
Few competing crops	Many competing crops
All fields of a given crop type planted on about the same date and hence developing in essentially the same seasonal pattern	Fields of a given crop type planted on many different dates and hence developing in many different seasonal patterns
Forest & Range Characteristics	*Forest & Range Characteristics*
Blocks of forest and rangeland large and only moderately interspersed	Blocks of forest and rangeland small and greatly interspersed
Terrain flat to gently rolling; few differences due to slope and aspect	Terrain moderately steep to very steep; many differences due to slope and aspect
Small elevational range; hence few species and nearly uniform seasonal development throughout the entire area	Large elevational range; hence many species and widely varied seasonal development throughout the area

Water Resources Management

Remote sensing by satellites, including meteorological satellites, SKYLAB, and LANDSAT, has already been proven a useful tool for acquiring valuable hydrologic information for water resources management. Such information on all three major components of the hydrosphere—namely, atmospheric water, surface water, and subsurface water—has practical value for the planning, design, and operation of water resources projects for various purposes.

Atmospheric Water

Meteorological and atmospheric satellites have demonstrated the capability of delineating cloud cover, cloud type, and cloud persistence, air temperature,

TABLE 2 Feasibility of Using Remote Sensing Techniques to Derive Information Needed by Those Who Seek to Develop and Manage the Vegetation Resources

Agricultural / Rangeland / Forestland Vegetation	Feasibility*	
	In a *Simply* Structured Area	In a *Complexly* Structured Area
1. Crop, forage or timber type	++	+
2. Crop, forage or timber vigor	+	+
3. Identity of damaging agents	+	–
4. Yield per unit area	+	+
5. Area occupied by each crop, forage or timber type and condition class	++	+
6. Available soil moisture	– +**	–
7. Available soil nutrients, by type	– –	– –

*To achieve the feasibilities noted, satellite sensing in some cases may require higher resolutions than are available in LANDSATs 1 and 2. These feasibilities, however, may reasonably be anticipated from future generation technology now being contemplated (see Chapter V). The ratings in this table do apply now in all instances to aerial photography.
++ = Usually can be determined readily by remote sensing, after some preliminary field calibration. May require both multiband and multidate sensing, however.
+ = Can be determined often enough by remote sensing to be useful for this aspect of vegetation analysis; however, may require extensive use of multiband, multidate, multistage and multi-enhancement techniques.
– = Determinable on occasion by remote sensing, but not consistently or often enough for remote sensing to be useful for this aspect of vegetation analysis.
– – = Not determinable by remote sensing, even though this type of information is much needed by the managers of vegetation resources.
**With the aid of meteorological satellite data and bookkeeping procedures.

solar radiation, and moisture flux in the atmosphere. Knowledge of these factors helps in making the precipitation and evaporation estimates needed in planning and operating irrigation and water supply projects.

Surface Water

LANDSAT data have been found to be particularly reliable in locating surface water. One multispectral channel (Band 7) shows the contrast between water and other surfaces on the ground so clearly that water bodies

larger than 10 acres can be identified with 99 percent accuracy.[22] With the help of computer programs, it is now possible to compile maps showing surface water areas larger than 6.2 acres for most countries of the world.[23]

For areas lacking adequate drainage maps, LANDSAT in many cases can provide data on stream networks to within a few percent of those displayed on topographic maps. In some cases LANDSAT alone cannot provide acceptable data, but in conjunction with topographic maps showing basin boundaries it can give relevant information on land use and vegetation for water resources management with better quality, less cost, and more frequency than can be obtained from other sources. Whether a stream is in continuous or intermittent flow, frequently an important question, may be determined more readily by analyzing the repetitive coverage of LANDSAT than by arranging multiple flights of aircraft.

LANDSAT imagery can be used to assess major watershed characteristics that affect runoff. In a 1973 experiment significant correlations were obtained between integrated basin reflectance values from LANDSAT and actual watershed conditions and runoff amounts in areas of dormant vegetation and dry conditions in Oklahoma.[24] This suggests that it would be feasible, in semiarid to arid watersheds in developing countries, to develop much needed information for runoff prediction based on data from LANDSAT and available meteorological satellites. Recent studies in Colombia and Venezuela have indicated the value of data from synchronous meteorological satellites for improved runoff prediction and efficient, economical siting of hydrometeorological stations.[25,26]

Many studies in the United States as well as in several other countries have demonstrated the effective use of LANDSAT data for delineating flood areas, at least in large drainage systems where the floods lasted long enough to be observed on an 18-day cycle operated by LANDSAT or where trace of their past presence can be noted.[27] For example, flooded cropland in the Indus Basin in Pakistan was distinguished easily by the satellite data from flooded semiarid areas and arid desert.[28]

In many parts of the world, water availability stems from snowmelt. LANDSAT 1 has shown a capability of measuring snowline and extent of snow within 5 percent of the accuracy obtained by aircraft measurement or other means.[29] The average of snow cover, multiplied by its depth and density, represents the storage of water that may be available for water supply, hydropower generation, navigation, and irrigation, or that could be released suddenly to cause floods downstream.

LANDSAT has been able to provide reconnaissance-level data needed for the design and operation of large-scale irrigation projects and for the design of a major impoundment structure.[30] Studies based on LANDSAT data have produced significant results as input to water-demand and groundwater-flow

models in Kern County, California. These studies of a desert region have identified crop areas to within 1 percent of the aircraft census with acceptable levels of crop identification. LANDSAT data are now regularly used as an important factor in the water supply/demand assessment for that region.[31]

Subsurface Water

Geologic information relating to groundwater may be derived from data obtained by multispectral sensors.

LANDSAT data can offer information on surface lithology, fracture patterns, and vegetation and geomorphic indicators of shallow aquifers. Such information, properly interpreted, can serve as an exploration base and strategy for groundwater prospecting.[32,33] Recent studies have shown that the information is useful in siting shallow wells and thus may provide a cost-effective tool for improving groundwater exploration in semiarid lands.[34] LANDSAT imagery has led to the identification of alluvial fans which may contain very large groundwater reservoirs. An alluvial fan about half as big as the state of Iowa has been identified in LANDSAT imagery of Western Brazil.[35]

In summary, earth resources satellite data, when properly processed, interpreted, and used jointly with collateral data from other sources, can provide useful hydrologic and other physical information for improving water resource management in these respects:

- Improved regulation of reservoirs for efficient hydropower generation, flood control, and water supply on the basis of better snowmelt and runoff prediction
- Improved planning of regional water distribution based on better monitoring of surface water amount and soil moisture
- Better decisions regarding irrigation management for crops through improved knowledge of water consumption and supplies
- More efficient and economic siting of potential shallow wells to tap groundwater supplies through proper interpretation of geologic information obtained by satellites.

Two series of LANDSAT images taken 5 weeks apart made an important contribution to a multi-stage study of the annual flooding of the Lower Magdalena-Cauca River Basin in northern *Colombia*. The sequential images made possible a classification of the river marginal lakes according to their role in tempering the water wave and their potential for serving as reservoir basins. The LANDSAT imagery was particularly successful in identifying the lakes that dried up in the 5-week interval. The LANDSAT data, together with aerial photographs and side-looking airborne radar (SLAR)

images, yielded information needed by governmental planners to determine the most practical means to reclaim land in the lower part of the inundated area.[36]

Geologic Survey and Mineral and Petroleum Exploration

The geologic applications of space derived data fall into two general categories, one concerned with essentially static phenomena such as the distribution, character, and structure of rock bodies, and the other concerned with dynamic phenomena such as those associated with earthquakes and shoreline processes.

In observation of static phenomena, one of the most valuable attributes of satellite data derives simply from the great distance from which the earth is viewed, and the consequent large area covered by a single observation or photograph. A few LANDSAT frames can cover whole mountain ranges, and a few hundred frames can cover entire continents. As a result LANDSAT images provide a view of the geologic fabric of continents which is compatible with the scale of modern theories of global or plate tectonics. Structural elements, perhaps irregular or even discontinuous within the confines of a smaller area, may be revealed as lineaments of regional or even semi-continental extent, and prominent rock units may be traceable far beyond the site of initial recognition. Geologists can follow such features across an entire fold belt without trying to piece together a multitude of photographs which differ in scale, exposure, light angle and quality of print. These features, which may be of greater or lesser importance geologically, often can be observed in arid or well-exposed terrains by simple visual inspection of unenhanced imagery; in low lying, vegetation covered terrains, however, detection is likely to be difficult or impossible, even with image enhancement.

Observations from space of static phenomena have two practical applications: improved geologic mapping and more efficient resource exploration. Good geologic maps are essential for the proper siting of major construction projects, including railroads, highways, dams, and power plants. Even in the United States, satellite data have been able to contribute to the accuracy and completeness of existing geologic maps and to identify faults hitherto unperceived.[37]

A contribution of the U.S. Geological Survey to the 35 nation Circum-Pacific Map Project demonstrated the value of LANDSAT data for evaluating the accuracy of existing geologic maps and for augmenting map detail.[38]

In some developing countries, national or regional geologic maps have been produced with the help of LANDSAT imagery far more quickly and efficiently than could have been accomplished by usual means and now provide a

good basis for locational planning of development projects. For site location decisions, however, satellite data on the geology, topography, and hydrology of a region must be complemented by more detailed data obtained by conventional methods—aerial photography and ground observation studies.

The application of remote sensing to geology, especially to mineral exploration, reaches back over several decades, beginning with the development of aerial photography, continuing with airborne adaptations of magnetic, gravimetric, and radiometric instruments, and culminating with the placing of various sensors on orbital satellites. All techniques remain in current use and some, such as the airborne magnetometer, have unique qualifications for specific purposes. The information received from space-based instruments will rarely in itself lead directly to location of a mineral resource.* It does, however, provide a large extra dimension to the thinking of the regional or exploration geologist.

LANDSAT has made it possible, for instance, to obtain synoptic and virtually distortion free images of high-relief mountain provinces in the Himalayas, the Alps, and the Andean Cordillera.[41,42] Such images help increase understanding of mineral genesis.

Location of major geologic elements generally will serve as a guide to selection of smaller targets worthy of closer study as possible resource areas, particularly if the interpretation is done by a trained observer familiar with the region. These smaller target areas can be further limited by image enhancement and/or computer analysis of multispectral data, with consequent reduction in the amount of costly and time consuming ground search. Further sophistication can be added by use of data acquired during different times of the year, to take advantage of details revealed by seasonal differences in vegetation or soil moisture. In general, however, a large percentage of the potential information on static phenomena can be obtained from a single, cloud-free pass over the area.

By eliminating areas where further effort in mineral exploration is likely to be unrewarding, satellite data can identify the areas where more detailed study by aircraft and field work might be profitable. Several findings of minerals in various parts of the world have been facilitated by analysis of LANDSAT scenes.

The second broad area of applications relates to dynamic phenomena. The particular value of space-based measurement lies in repetitive observation which makes possible the detection of short-period changes, such as those in a stream course following a major flood, or along a coastline after a major

*Mineralization at the surface may, of course, register on the sensors. Certain oxides of iron, often indicators of the possible occurrence of other metal ores, can be specifically identified with computer processing.[39,40]

storm. LANDSAT images, for example, have enabled Bangladesh scientists to identify and measure the accretion of new land to islands in the Bay of Bengal, opening the way for a government program to plant trees and stabilize the new land for agricultural purposes. Studies in Iceland showed that with the aid of LANDSAT some of the surface effects of intense geothermal or volcanic activity can be mapped.

In brief, experience with satellite-derived data, both in the United States and in other countries, indicates that developing nations can make use of such data for geological purposes in the following ways:

- Develop geologic maps of areas not previously covered and evaluate existing geologic maps to determine their accuracy and completeness
- Identify large- and medium-scale structural and geologic features, and correlate them over separate areas that may be widely spaced from one another
- Provide preliminary planning bases for siting of transportation, communications, irrigation, energy and industrial projects
- Select potential geological resource areas worthy of more detailed examination by aircraft and by ground observation
- Provide a base for specialized studies, such as of stream geochemistry
- Provide an opportunity to monitor, through use of repetitive coverage, altered or transient geologic features, such as changed stream courses and sand dunes.

On the basis of a rock-type classification map produced by digital computer processing of LANDSAT data, 30 prospect-target sites were chosen in a *Pakistan* area near known copper deposits. Out of the 19 sites visited, 5 yielded evidence of surface mineralization, indicating the possibility of an enriched zone of copper at depth.[43]

A plan to make a new geological map of *Egypt* at a scale of 1:1,000,000 in ten years at a cost of $2.4 million using black-and-white aerial photographs was altered when LANDSAT imagery proved to be more satisfactory. The latter offered roughly three times more geological detail and could accomplish the task more quickly and at less cost. In three years, maps covering about half the country have been completed and the task is expected to be finished in two more years.

Cartography

The LANDSAT multispectral scanner has shown capabilities for cartographic mapping greatly exceeding original expectations. MSS imagery has several characteristics that enable it to contribute significantly to small-scale cartography in the United States and to become probably the most efficient

current means of portraying the face of the land.[44] These characteristics include:

- uniformity of view over a wide area
- near orthogonal (vertical) angle
- geometric and radiometric fidelity
- superior definition of certain natural features
- capacity to be turned into a finished map product very near to the "real time" of the acquisition of the data.

LANDSAT imagery is helping to correct and update certain features of existing U.S. maps at scales of 1:250,000 or smaller at, or near, national map accuracy standards.[45] With multispectral imagery it is possible to make 1:250,000 photo map overprints to fit with previous black-line data of conventional maps. The fresh information in the overprint has made it possible to observe such developments as urban sprawl and modifications to transportation networks. Using LANDSAT imagery and new mosaicing techniques, the U.S. Geological Survey has produced a new map of Florida which is the first color mosaic in map form that maintains uniformly high image quality.

A new type of small-scale map has been made possible by the unique capacity of LANDSAT Band 7 to delineate land-water boundaries. This band can define water bodies as small as 200 meters in diameter with high reliability and can identify streams 20 to 50 meters wide if they are not overhung by trees. The capability is especially important for updating charts of estuaries in coastal areas and for outlining interior lakes.[46,47]

Sensors on current LANDSATs are able to penetrate clear water surfaces to a depth of about 10 meters. In the Caribbean, LANDSAT 1 data made possible the charting of shallow underwater features that were previously unknown.[48]

Cartographers have found that the LANDSAT scanners can produce, with virtually no distortion, a generally continuous image on a defined map projection. Thus the LANDSAT series, with their uniform repetitive coverage, may provide the basis for an "automated" image-mapping system of the entire earth.[49]

For developing countries, the value of LANDSAT for cartographic purposes promises to be very high. More than half the geographic areas of Asia, Africa, and Latin America have not yet been mapped at scales larger than 1:1,000,000 and many of the base maps for the other areas are outdated. With LANDSAT data, uncharted areas can now be quickly and cheaply mapped, existing maps can be updated with acceptable accuracy, and decisions can easily be made regarding areas where higher resolution imagery from aircraft is required. Several South American countries are currently using LANDSAT imagery to revise their small-scale and intermediate-scale maps.[50]

Developing countries also have need for frequent updating of charts with respect to geographic features subject to change. For example, the temporal and spectral characteristics of LANDSAT are of exceptional value in defining land-water boundaries in countries with large deltas (Egypt, Bangladesh, Iran) or with shallow, interior drainage-basin lakes (Iran).

As already noted, the multispectral data can be processed to yield thematic maps providing a variety of classifications of resource data.

> *Bolivia*, with sizeable parts of its territory still inadequately mapped, is now using LANDSAT imagery to help fill the gap. A map at the scale of 1:1,000,000 of the entire country has already been updated and published. A more detailed map at 1:500,000 of the Coipasa area, meeting U.S. National Map Accuracy Standards, has also been published. LANDSAT data made possible the first geomorphological map of the country and contributed corrections to a recently published tectonic map. Maps now being produced at a scale of 1:250,000 will serve as a basis for an inventory of Bolivia's natural resources including soil, forests, and promising areas for mineral and petroleum exploration. With LANDSAT data, a task that was expected to take eight years, will now be accomplished in two.[51]

Land Use—Urban and Regional Planning

LANDSAT imagery has proven useful for regional planning purposes and the monitoring of land conversion along the urban fringe. However, urban planners, concerned with the disposition and relationships of small spatial units characteristic of the cityspace, generally require very high resolution imagery of the sort obtainable at present only from aerial photography.

State and regional planners, on the other hand, are interested in frequent updating of broader scale changes in the nature of land cover—such as the extent to which agricultural land is giving way to housing or the pace at which forest land is being depleted.

The level of accuracy obtained in the United States from LANDSAT 1 in distinguishing among major categories such as forests, water, and urban areas has been generally an adequate 90 percent or better. Except for urban and built-up areas, more detailed categories (which distinguish, for example, between deciduous and evergreen trees) have been generally identified at an accuracy of 80 to 85 percent.[52] In some studies, imagery taken at different seasons has been digitally merged and has led to greater accuracy in identification.[53]

For present land use purposes, satellite data cannot be substituted completely for aerial photography. They can, however, be a useful complement to photographic studies from aircraft platforms. For regional planning in particular, a satellite "scene" can serve as a reconnaissance base on which planners

can pinpoint areas of stress or of rapid change for which more detailed information is required and can be obtained by aerial photography.

It is anticipated that earth resource satellites will play an expanding role in providing periodic updates to data bases originally derived from standard mapping techniques. For the first time planners have a land use data acquisition system which can be continually revised at a level of accuracy commensurate with the accuracy of statistical updates developed for population and economic data between the decennial censuses. The computer processing of LANDSAT tapes permits incorporation of such data in data banks, whose use is rapidly increasing, and in which social, economic, and resource information from a variety of sources is retrievable in relation to specific localities.

Resource planners in several state governments in the United States are beginning to use LANDSAT data in large-area transportation, recreation, and environmental planning.[54,55]

Developing countries increasingly need land use inventory data to keep pace with change. Were the data to be acquired by conventional means, required investment in aircraft coverage and photo interpretation would cost more than most countries can afford and would require more trained staff than is generally available. Satellite data therefore could become vital to land resource planning in those nations where rapid population growth and spreading human settlements lead to significant change in man-land relationships.

Comparative analysis of two sets of LANDSAT scenes covering the state of Orissa in *India* has yielded a substantial volume of land-use information of direct value to the state's resource managers and agricultural planners. The earlier imagery—8 scenes taken in the dry season in 1973—were studied primarily to locate areas of present and potential two-crop rice cultivation, but also to identify as many land-use categories as possible. Indian soil technicians, foresters, and geologists, trained by a World Bank team in interpreting satellite imagery by field survey methods, succeeded in recognizing about half of the 30 categories sought. Twelve new LANDSAT scenes were taken while the trained "ground-truth" group was in the field at the end of the monsoon in 1975 to locate relatively pure "training sites" for each category with the aid of jeeps, helicopters, and planes. The "supervised" classification of the new imagery performed in the United States identified 23 categories (see Table 3). The two sets of LANDSAT scenes highlighted the differences between dry and wet season agricultural patterns and identified promising areas for conversion to irrigated two-crop production. The LANDSAT data also indicated areas suitable for dams or barrages, showed the extent of forest cutting in the highlands and coastal regions, provided a new base for checking the accuracy of crop acreage estimates done by conventional means, and showed the changing course of the Mahanadi River and its tributaries from the time of the last topographic mapping two or three decades earlier as well as major changes in sandbars, spits, and islands along the coast.

See color plates and accompanying text pages 83-85.

TABLE 3 "Supervised" Categories of Land Cover Defined and Demarcated from Wet Season Coverage of Three Districts in the State of Orissa, India, by LANDSAT November 18-21, 1975*

		Balasore		*Bolangir*		*Cuttack*	
	Cover or Vegetation Type	*Km²*	*%*	*Km²*	*%*	*Km²*	*%*
Water:	Unclassified/Cliff or cloud shadows	14.13	.3	48.28	.6	30.32	.3
	Ocean, deep lakes/Coastal currents	64.69	1.1	53.28	.6	115.49	1.1
	Rivers/Lakes	.18	–	1.80	–	51.57	.5
	Shallow turbid water	89.21	1.6	70.81	.8	417.87	4.1
	Swamps/Marshland	63.58	1.1	33.59	.4	213.59	2.1
Small Grains:	Pulses/Upland rice/Dry farming	877.38	15.6	1,606.23	18.3	2,553.19	25.0
	Single crop rice area	2,709.35	48.0	2,607.81	29.8	2,797.16	27.4
	Double crop rice area/& Other crops	104.92	1.9	231.04	2.6	226.15	2.2
	Double crop rice area	444.46	7.9	1,277.44	14.6	845.30	8.3
Other Crops:	Fallow land/Unknown vegetation	38.09	.7	162.38	1.9	76.92	.8
	Grassland	188.01	3.3	181.50	2.1	347.70	3.4
	Riverine shrubs/Reeds/Sugarcane	211.34	3.7	458.15	5.2	218.91	2.1
	Palms/Horticulture, mixed farming	45.48	.8	62.36	.7	342.23	3.4
Forests:	Highland mixed forest/Diptocarps	190.96	3.4	651.35	7.4	468.37	4.6
	Lowland mixed forest/Mangroves	228.97	4.1	849.08	9.7	597.31	5.9
	Hill and ridge shadows	55.17	1.0	217.83	2.5	103.30	1.0
	Conifer-casurina pine/Bushland	57.61	1.0	135.24	1.5	243.93	2.4
Other:	Sand/Saltflats	20.29	.4	48.12	.5	295.15	2.9
	Mudflats/Silt deposits	213.28	3.8	44.82	.5	215.82	2.1
	Urban/Industrial	21.95	.4	15.02	.2	43.07	.4

*Preliminary comparisons of area count of picture elements (pixels) corresponding to each District indicate an accuracy ranging between 2.9 percent and 5.8 percent of official Government of India area figures (Ministry of Information and Broadcasting, Bureau of Statistics and Economics, Orissa). The accuracy of area measurements of land use categories is still being checked in the field. Source: World Bank

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Demography

In the United States, demographic applications of LANDSAT data have been studied under the general heading of land use investigations. To the extent that urban classification categories can be identified, a population density can be assigned to each category on the basis of careful ground sampling. The U.S. Bureau of the Census is working with digital data from LANDSATs to test the validity of this application. Present LANDSAT data are useful for identifying new urban areas and drawing urban/rural boundaries. It is generally assumed that better spatial resolution will be needed for reliable classification of urban categories.

In many developing countries, the problem in demographic census is not only to gauge increments to urban growth but to determine the number, location, and population density of old and new villages. Since most village settlements cover more than one acre (the approximate size of the individual pixel that registers on a LANDSAT sensor), satellite data may provide a better base for estimating rural population in countries where compact villages are common than any enumerating system thus far employed. In countries in which rural population is more dispersed, LANDSAT data can provide information on patterns of land use from which it may be possible to infer population density with some accuracy. Studies to develop appropriate sampling techniques have been undertaken in several countries in Asia and Africa. Preliminary results appear to be promising.[5 6]

In AID-financed studies in Bolivia and Kenya, the U.S. Census Bureau is seeking to determine in what ways LANDSAT imagery may be applied in demographic census and sample survey operations and in population estimates based on village measurements and land use interpretations. The study in Bolivia was in progress before, during, and after a nationwide census undertaken by the national government. The timely coincidence of the study and the census makes it possible to test the value of LANDSAT data for precensus preparatory work and postcensus checking for accuracy.

Environmental Protection

Studies have been conducted to determine the possible value of LANDSAT data for environmental monitoring. For certain purposes, such as detection of water pollution and wetlands disturbances, the sensitivity, spatial resolution, and frequency of observation of the current LANDSAT system were found to be inadequate to meet many U.S. requirements. More satisfactory results presumably would follow improvement in any or all of these factors.

However, the LANDSAT capabilities to recognize discontinuities of coloration in water and to distinguish differences in land cover over large areas

have proven of value in identifying certain types of pollution or environmental degradation. Coloration differences seen in LANDSAT imagery have led to detection of oil slicks and oil seepage in coastal areas, effluents carrying industrial or municipal wastes, and water currents causing siltation. The effects of tin mining in shallow water along the coasts of Malaysia have been mapped with the help of LANDSAT data, which are also being used in a UN study of the environmental effects on land of strip mining of tin in that country.[57]

LANDSAT imagery is being used experimentally to monitor strip-mined areas in the Appalachian region and in Idaho, to observe land deterioration in arid areas such as the Sahel, and as noted in other parts of this chapter, to measure the extent of damage of forest fires and floods.[58,59]

In studies of sand seas, scientists have relied heavily on LANDSAT data to establish a basis for classifying and monitoring environmental changes in the principal desert areas of the globe.[60,61]

In *Gambia*, LANDSAT imagery showed clearly that the currents from the Gambia River, carrying effluents from the city of Banjul, for some portion of the year swing past the beach frontage for which a tourist development project was planned with financing from the World Bank. New planning studies have had to take this factor into account. LANDSAT scenes disclosed offshore pollution problems also at two coastal tourist development sites in *Turkey*.

Marine Resources, Oceanography, and Coastal Engineering

Data from various meteorological satellites (ITOS and NIMBUS) have been applied more extensively to marine and coastal investigations than have data from LANDSATs 1 and 2, which lack infrared sensors in the bands that are particularly useful in oceanographic work. By sensing sea surface temperatures synoptically over large areas of the oceans and long stretches of near-shore waters, the meteorological satellites have provided new information or confirmed theory on the distribution of water masses, on worldwide water circulation patterns, on coastal current structure, and on zones of converging or diverging water masses where temperature gradients are steep. These interface zones are known to have important concentrations of fish.

Data from these satellites are also useful in determining sea state and areas of wave generation—information that can be important for early warning of potential flooding and wave damage in shore areas. Sun glitter patterns are useful in delimiting slicks and eddies that may be associated with currents and the spread of pollutants.

(text continues on page 88)

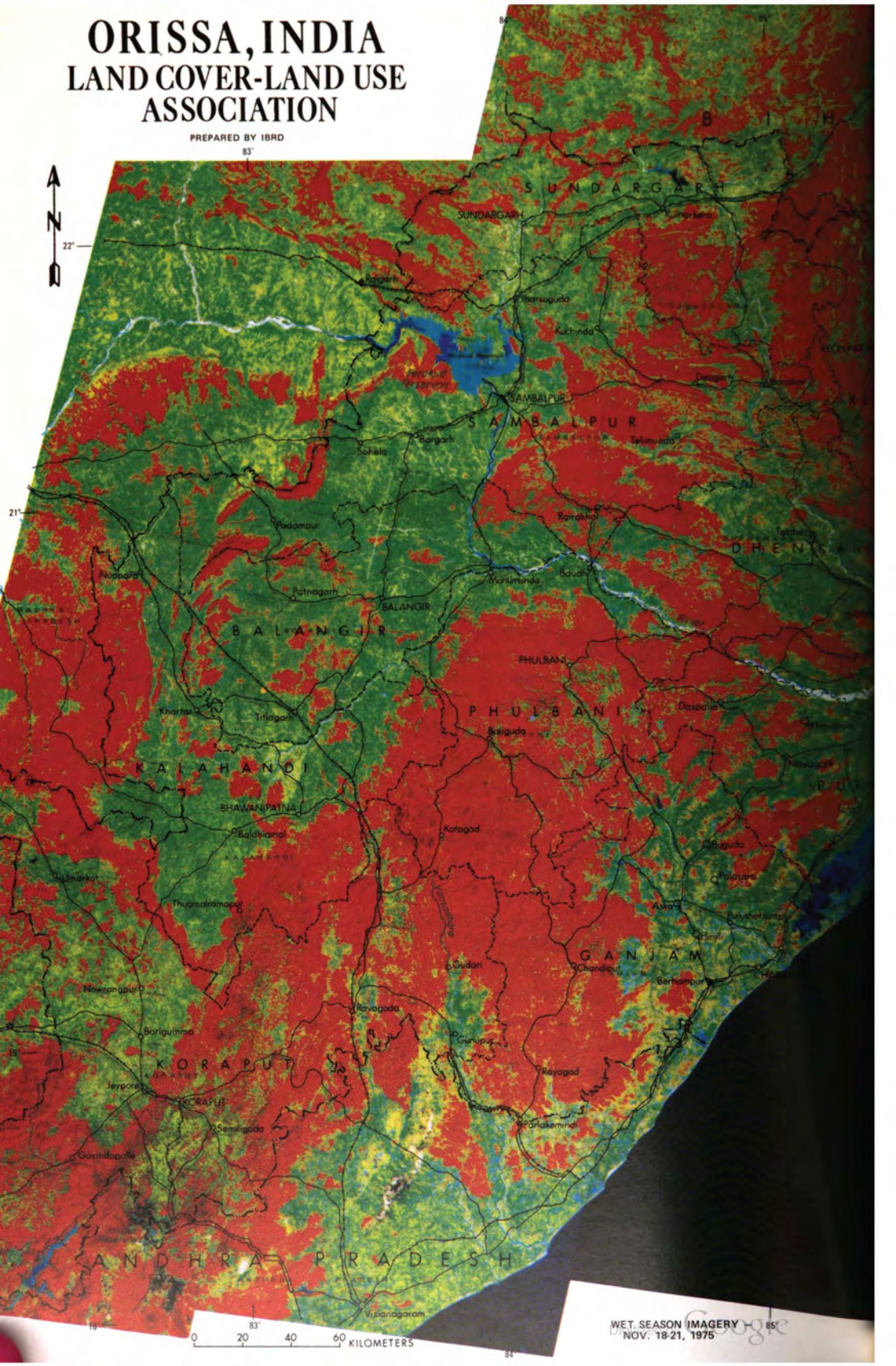
COLOR PLATE I: Illustration of Computer Tape Processing

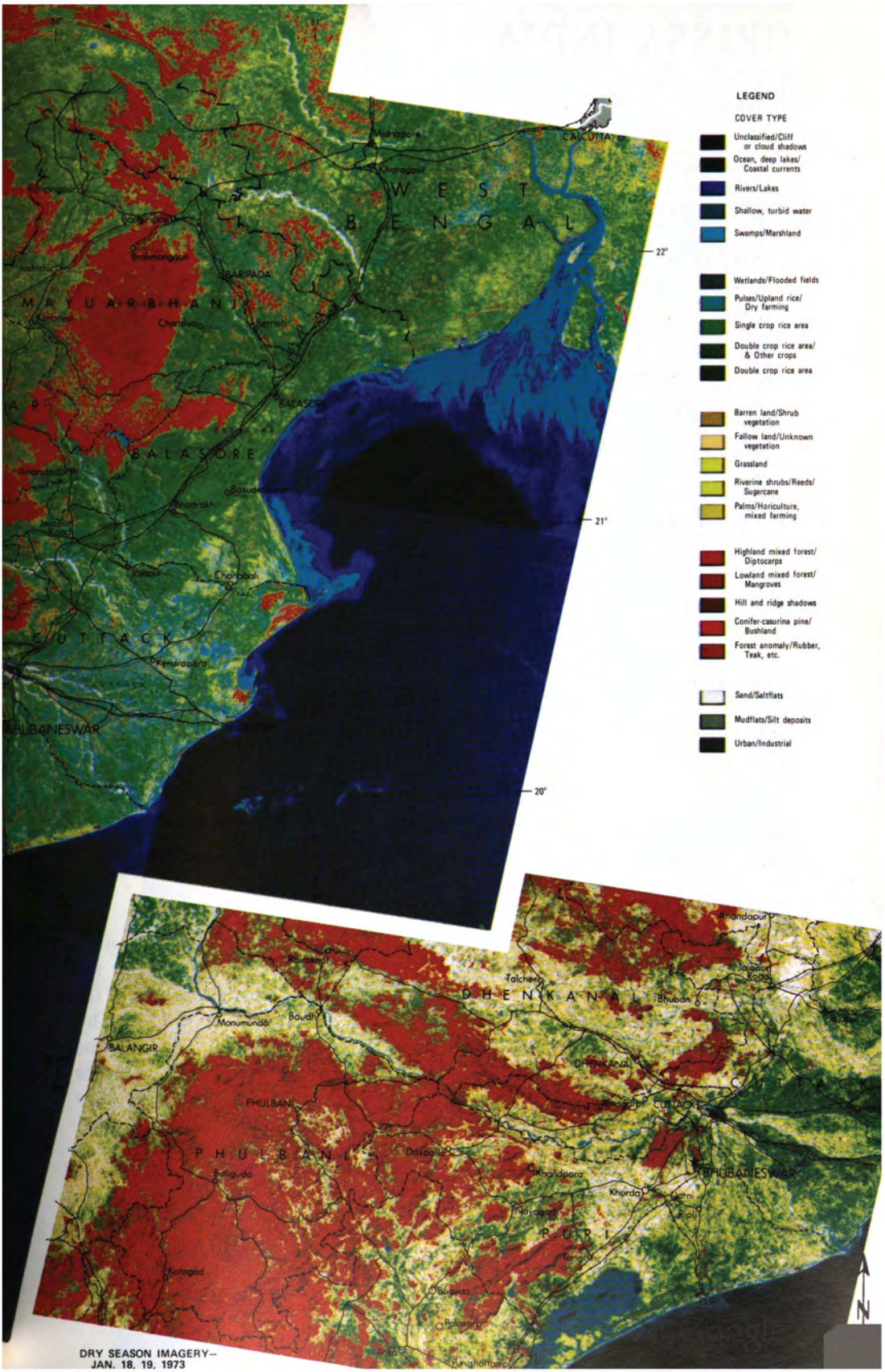
The Orissa, India, Land Cover–Land Use Association mosaic illustrates the type of detailed information one can obtain from sophisticated computer tape processing of LANDSAT data. The example shown is a tremendous reduction of a mosaic "map," measuring approximately 10 square feet at the 1:250,000 scale, which has a cartographic overlay showing roads, railroads, towns and political subdivisions of the state that are not fully visible to the naked eye on this reduction. The mosaic is composited from 13 LANDSAT scenes, each covering an area of 10,000 square miles, which were taken from orbital overflights on 4 consecutive days right after the monsoon wet season just prior to the harvest of the state's major rice crop. The inset mosaic, in the lower right corner, embraces portions of 3 scenes including the Mahanadi River delta at the height of the dry season in which the "second" rice crop, produced only under irrigation, shows up clearly as dark green areas.

Each LANDSAT scene, which includes almost 8 million separate reflectance signals, was categorized into 23 land cover–land use associations on the M-DAS Bendix computer system. This was done after extensive field checking by air and ground surveys of dozens of different land use sites. Each scene was geometrically corrected on the computer and converted to a film product on a drum recorder after which the cartographic data were superimposed on it. Positive enlargements were then made on a high resolution cibachrome film on which political subdivisions were digitized in order to determine the amount of land in paddy, dry-farming, sugarcane, grassland, and forest types, etc., for each of the 13 districts in the state of Orissa. An example of the type of statistical data on land use derived is presented in Table 3, which illustrates the acreage for 3 sample districts. The acreage of the respective crop or forest types will assist in determining crop yields and forest potentials in the future.

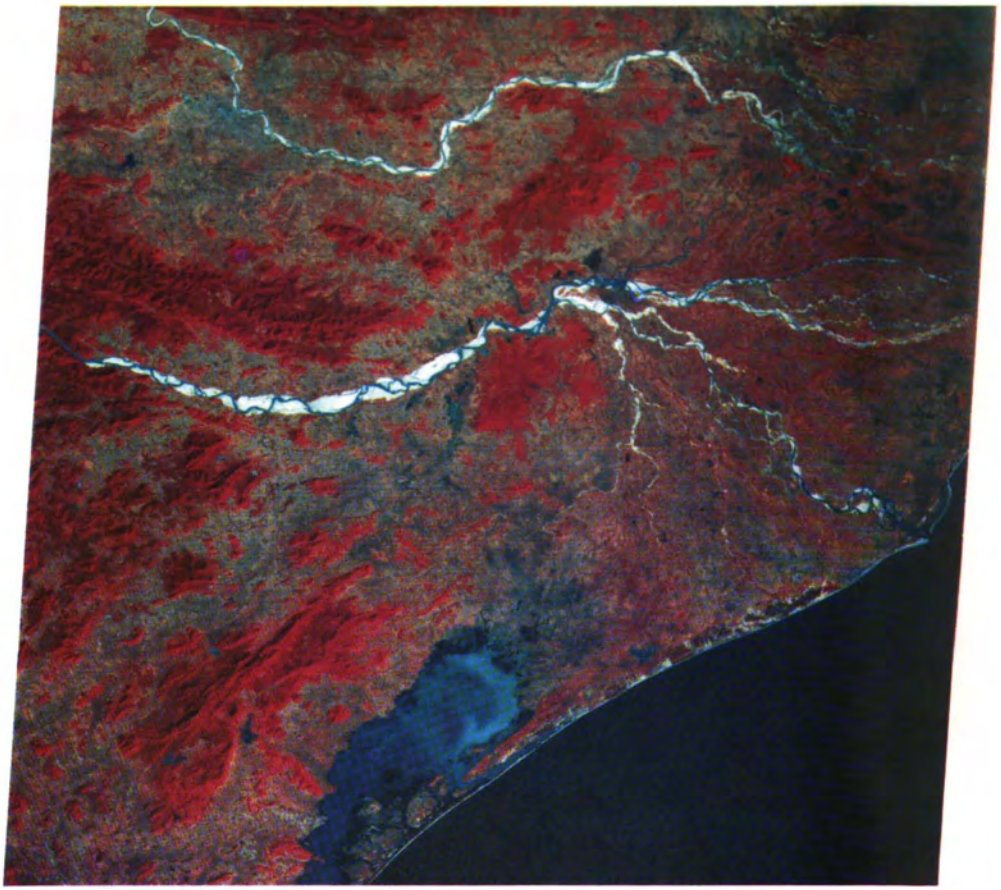
ORISSA, INDIA
LAND COVER-LAND USE ASSOCIATION

PREPARED BY IBRD





DRY SEASON IMAGERY–
JAN. 18, 19, 1973



COLOR PLATE II: Illustration of Film Processing

This color composite of one LANDSAT scene, covering 10,000 square miles or about one-thirteenth of the state of Orissa, India, illustrates the type of product that can be made from a merging of data from three of the spectral bands obtained from the multispectral scanner of the satellite. This film product, derived from 70mm negatives or positives, was enlarged to the scale of 1:1 million. It has not been geometrically corrected. Because the reflected data cannot be categorized from the film format, as can be done from the tape format, no statistical tabulations of categories can be derived, thereby limiting its use for agricultural analyses. However, the color composites made from the 70mm film products are relatively inexpensive, costing from one-third to one-twentieth of the cost of tape analysis, and frequently provide excellent hydrologic and geologic information in a minimum of time.

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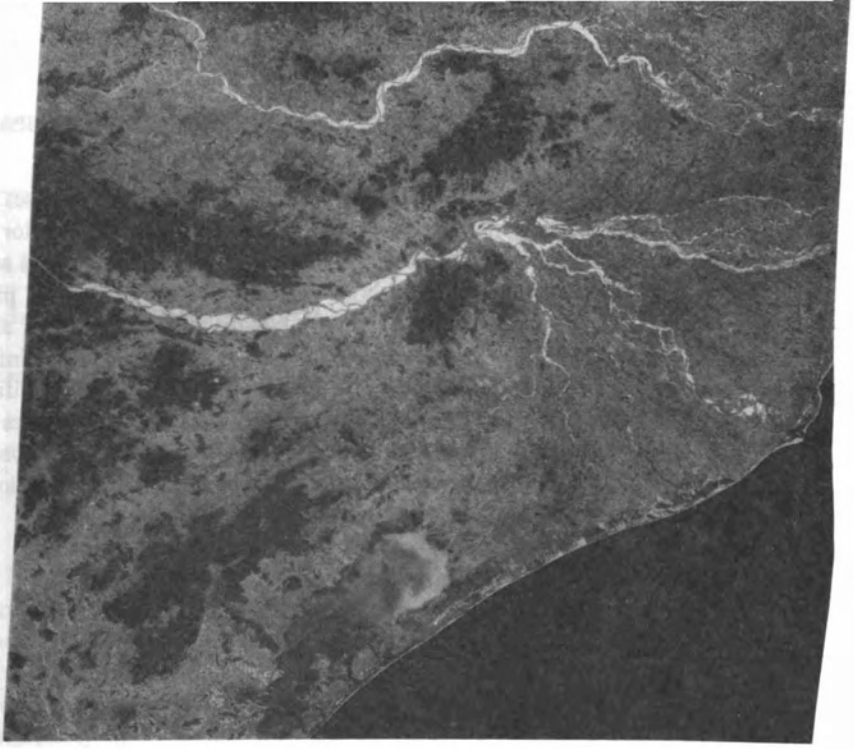

FIGURE 9 illustrates 2 of the 4 bands obtained from the LANDSAT multispectral scanner (November 19, 1975, scene of Chilka Lake, Orissa, India, EROS Identification No. 2301-04002). These images can be enlarged and used individually as black-and-white photographs, or composited for making color photographs, one rendition of which is on the facing page.

The band 5 image (top) highlights the vegetation in the grey tones. Darker tones represent forested areas. Also clearly visible are the alluvial sands of the meander belt of the Mahanadi River and the shallow waters of the lake. The band 7 image shows bodies of water in black.

LANDSAT imagery, nevertheless, is increasingly employed in analyses of coastal areas, especially where effluents and shallow waters differ in color or reflectance from the local waters and are, therefore, readily identified and delimited. This information is applicable to problems of environmental protection, navigation and fisheries. Oil spills and seeps, illegal dumping, and polluting effluents have been observed, both in shallow water and in adjoining wetlands. Certain fish stocks may also be located by identifying their habitats on the imagery. Navigation channels and inlets can be watched for changes in depths that may endanger shipping and boating. Repetitive coverage in coastal areas may be useful in determining major changes in rates of pollution, sedimentation, erosion, marsh drying or subsidence.

Disaster Warning and Assessment

Experimental results evaluated in a U.S. Geological Survey study in 1975 indicated that LANDSAT images have value for warning and/or assessment of certain types of disasters throughout the world. The findings for principal disaster categories, at the time the study was made, are summarized below:

TABLE 4 Summary of Disaster Applications of an Operational LANDSAT

Excellent–experimental results have proven the feasibility and usability.
Possible–experiments have not yet been completely successful but are promising.
Unproven–not yet tried or feasibility established.
Not applicable.

Type of disaster and analysis		LANDSAT Imagery	LANDSAT Data Collection System
Floods	Warning	Unproven	*Excellent
	Assessment	Excellent	Not applicable
Earthquakes	Warning	Possible	Possible
	Assessment	Possible	Not applicable
Volcanic eruptions	Warning	Possible	Possible
	Assessment	Possible	Not applicable
Drought	Warning	Possible	*Unproven
	Assessment	Excellent	*Unproven
Fire	Warning	Not applicable	Unproven
	Assessment	Excellent	Not applicable
Crop Disasters	Warning	Unproven	*Unproven
	Assessment	Possible	Not applicable
Hailstorms	Warning	Not applicable	Not applicable
	Assessment	Possible	Not applicable

Type of disaster and analysis		LANDSAT Imagery	LANDSAT Data Collection System
Glacier movements	Warning	Possible	Possible
	Assessment . . .	Excellent	Not applicable
Water pollution	Warning	Not applicable . . .	Possible
	Assessment . . .	Possible	Possible

*Accuracy improved in conjunction with imagery from the NOAA satellite series and data from weather stations.
Source: Robinove [62]

The most promising area of application is with respect to floods, which are also the most widespread, frequent, and damaging disasters that occur in the world. Remote sensing imagery makes possible the delineation of inundated areas, and in combination with land use maps, permits the identification of flood prone lands and the estimation of economic consequences of flooding, particularly with respect to agriculture. Satellite data can provide useful information for planning of flood control and protection measures. Flood mapping with LANDSAT imagery was demonstrated with conspicuous success in the case of the Mississippi River[63] and Indus River (Pakistan) floods, both in 1973. Coastal flooding caused by hurricanes and typhoons, as well as erosion and deposition along the affected coasts, can similarly be mapped and monitored after the storms.

Drought detection from LANDSAT, based on work in the African Sahel, is achievable only inferentially, largely because the drought phenomenon is a gradual one. Comparative analysis of LANDSAT scenes will indicate the changes that point to an impending drought, such as decrease in surface water area, decrease in the area and vigor of vegetation, and in some areas desertification in progress through the movement of sand dunes. Within an existing drought situation, LANDSAT images have been useful in the search for additional water supplies, assessment of the grazing and farming conditions of the land, identification of lesser affected areas, and monitoring and mapping of the processes of desertification.

LANDSAT imagery is exceptionally good and straightforward for the identification and mapping of forest and grass burns, and similarly for crops and forests killed as a consequence of one stress or another (lack of moisture, disease, insect infestations, and storms). Though conditions of stress may be identifiable, they cannot yet be assessed as to cause or degree.

In other disaster categories, LANDSAT imagery in conjunction with data from meteorological satellites and especially from ground based data collection platforms can be significantly helpful.

For nearly all disaster types, however, the LANDSATs, in this experimental period, are severely constrained by their relatively infrequent passage, the delays in data processing and the further delays in transmitting the needed information to those who could use it.

Human and Animal Health

The potential capability of remote sensing to identify areas that serve as breeding grounds or habitats for disease bearing insects has been studied from both airplanes and spacecraft.

In two aircraft studies in the United States, cameras using color infrared film covering the same spectral frequencies as the MSS bands on LANDSAT have been able to identify vegetation or localities that served as habitats for insects which may be disease carriers. The studies dealt with wetlands in Louisiana and stagnant water near Houston, Texas, that harbored mosquitos.[64]

The vegetation mapping that resulted from the Louisiana study contributed to an improved pesticide program which proved to be cheaper, more effective, and environmentally sounder than the earlier control efforts which involved applying the pesticides to the entire wetlands.

In support of a binational campaign to eradicate screwworm, which affects livestock in northern Mexico and southwestern United States, temperature data received daily from meteorological satellites combined with rainfall information have been related to the environmental requirements of the screwworm life cycle in an effort to predict the presence, absence, or relative abundance of the insect on the basis of weather factors alone.[65] In these studies LANDSAT data have been utilized to define vegetation ground cover of importance to the screwworm fly. Although the results of these studies are not conclusive, the techniques developed appear to have promise of useful application for insect control and eradication.

It is possible to conclude from these studies that remote sensing, either by aircraft or satellite, can be usefully employed whenever the relationship between a pathogenic organism and the environmental factors determining its survival is well understood and when these specific environmental parameters can be observed or inferred by use of remote sensing data.

This conclusion has been confirmed by a current rangeland study in Mali in which LANDSAT imagery at reconnaissance level has demonstrated its capability to distinguish clearly between savannah and nearby riparian forest known to serve as habitat for the riverine type of tsetse fly, which may bring sleeping sickness to both humans and animals.[66]

Some General Conclusions

Although based largely on American experience, a few observations can be made concerning satellite resource sensing that have relevance for the developing countries:

- As noted in an NAS 1974 progress review of LANDSAT experience, "the science and technologies of remote sensing for earth resource survey show substantial room for growth and improvement, providing society with a long-range capability of important dimensions".[67] Even with the present state of sensing technology, the flow of LANDSAT investigation reports and the technical progress in enhancement of LANDSAT data continue to reveal significant new capabilities and new applications of the technology, many of them of direct interest to developing countries.
- Remote sensing from satellites has unique characteristics whose benefits are not yet fully perceived—a large-scale uniformity of perspective, a regularity of repetitive coverage, an extraordinary facility for visual presentation and communication, a capacity to impose a comprehensive pattern on discrete elements of information, and a potential catalytic impact on specialists, planners, and decision makers impelling them to organize the gathering and application of resource information in a rational way. Moreover, the ability of the satellites to deliver resource data with uniform characteristics on a global basis may strengthen opportunities for international communication among resource scientists within and across disciplinary lines.
- The LANDSAT experience thus far has also exposed the limitations of the present sensors and orbits and the current arrangements for delivery of data to users. Identification of certain resource elements, which is within the theoretical capability of space sensing, cannot be accomplished with this generation of space platforms and sensors.
- Merging of multiple data sources in a system is of growing importance and is showing increasing promise. Thus employment of ground observations, aerial photography, LANDSAT data, and meteorological satellite data in concert, is occurring more frequently and is likely to expand.
- Both manual and digital techniques of data processing have their roles to play in the United States as well as in the developing world. Use of shape, texture, pattern and other characteristics provides image interpreters with a flexibility not available through multispectral digital processing alone. On the other hand, digital techniques offer advantages for signature interpretation. Recent studies have demonstrated the capacity of computers to use the texture of ground features along with the spectral data to identify vegetation with considerable accuracy.[68,69] One may anticipate that digital techniques will continue to improve and to make greater contributions to the analysis of satellite data.

• In all sectors, a gap still remains between the technical experimenters and the ultimate users of earth resource information—a gap that is likely to be bridged when the emphasis in the remote sensing program begins to concentrate on quasi-operational resource management projects involving the joint efforts of sensing technologists, planners, and decision makers.

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69. R.M. Haralick and R. Bosley, "Spectral and Textural Processing of ERTS Imagery," in *Third ERTS-1 Symposium*, I-B:1929-1969.

V Technological Prospects

A Technology in Flux

The technology of resource sensing from space is still in an early state of development; it is rapidly evolving. In the coming decade, if NASA's current plans are realized, presently functioning spacecraft and sensors will be superseded by more advanced systems with considerably improved capabilities that should make resource sensing more versatile, timely, and valuable.

The first two LANDSATs have demonstrated the capabilities of their sensors to provide useful data for resource inventory and monitoring of environmental change. They also have disclosed the limitations of this first generation of sensors and their inability to fulfill the numerous data needs that satellite sensing theoretically might be able to meet.

A variety of future space systems can be expected to provide more frequent coverage at higher spatial and spectral resolution than the current satellites. Moreover, future spacecraft dedicated to earth resource observations are not likely to operate in isolation. A larger system of data-gathering involving special purpose satellites, aircraft, and unmanned ground data-collection platforms is in prospect. The multiple data streams from these diverse sources will require integration to serve resource information needs for planning and decision-making at both global and national levels. At the same time, ground processing technology and the design of earth-based information systems that merge satellite and supporting data are likely to be improved. This integrated approach would be particularly valuable for the monitoring of dynamic phenomena, for purposes of forecasting agricultural production, observing change in rangeland, forests, water resources and land use, and forecasting and assessing certain types of natural disasters.

The spacecraft systems that will probably be available in the decade ahead are substantially known now because of the long lead times needed for development, but there is a difference in the degree of certainty with which one can posit technological prospects up to 1980 and the years that follow.

The technological changes planned for the next five years and the likely improvements these will bring to practical applications of earth sensing are now fairly clear. The advances in the early 1980s are more speculative. The following summary of projected technical developments in space sensing in

the coming decade and their potential applications in particular sectors are therefore divided into two time frames: 1976-1980 and 1981-1985.

Near-Term (1976-1980) Technology

LANDSAT Series

LANDSAT C,* to be launched in 1977 or 1978, depending on the continuing performance of LANDSAT 2, will be essentially similar to LANDSATs 1 and 2, with two important sensor system changes:

- The Multispectral Scanner System (MSS) is to have a fifth band (Band 8) to gather data in the thermal region (probably 10.4-12.6μm) of the radiation spectrum. This infrared band (IR) will have a coarser spatial resolution (about 240 meters as opposed to 80 meters for the other MSS channels), with a temperature sensitivity of 0.5°C.
- The cameras of the Return Beam Vidicon (RBV) system in three different spectral bands will be replaced by two identical panchromatic cameras operating in the 0.5 to 0.7 micrometer wavelength range. These cameras will be fitted with new optics to focus on two adjacent 50 by 50 nautical mile areas. This arrangement will improve the resolution from 80 meters in the present RBV to approximately 40 meters. Contiguous frames will be obtained along the path, covering the same 115-mile swath as the present MSS. They will produce planimetric photomaps on a scale of 1:100,000 or smaller. Where equivalent or better base maps do not exist, these photomaps could serve as a base on which to register the MSS thematic information.

Heat Capacity Mapping Mission Satellite (HCMM)

The Heat Capacity Mapping Mission Satellite, carrying a sensor with near-infrared (0.8-1.1 μm) and thermal infrared (10.5-12.5 μm) channels, will be launched in 1978 for experimental work. The greatest value of the satellite data is likely to be for geologic, hydrologic, and agricultural uses on a broad scale since the spatial resolution will be 500 meters. It will be sun-synchronous, with a 1:30 P.M. local time passage over the United States and a 2:30 A.M. nighttime passage, close to the times when surface soils attain their highest and lowest temperatures.

The HCMM data should make it possible to infer surface rock and soil composition (sand versus clay, bare solid acid igneous rock versus basic igneous rock, etc.), variations in near-surface soil water content, mapping of

*Becomes LANDSAT 3 when put in orbit.

large-scale thermal effluents, and monitoring of snowmelt for runoff prediction. Feasibility studies also will be carried out on measuring surface and subsurface soil moisture and on estimating plant transpiration and plant stress. Success with the HCMM experiment could lead to the design of a system to provide data on an operational basis.

Ocean Dynamics Measuring Satellite (SEASAT A)

The first of a planned series of ocean dynamics measuring satellites, SEASAT A will probably be launched in 1978. It will operate on an 800 kilometer orbit, making 14 1/2 orbits per day and providing day and night coverage of a given ocean site at 36-hour intervals.

SEASAT's all-weather passive and active microwave sensors, continuing and expanding experiments initiated on SKYLAB, will test the feasibility of regular monitoring of winds over the ocean surface, ocean temperatures, dynamics of major ocean currents, ocean storms, sea ice movement, and sea state.

Projected SEASAT A experiments will emphasize air-sea interactions to provide firm data for assessing the future role of more advanced SEASAT satellites with respect to such matters as ocean impacts on weather and climate, ocean impacts on ice and coastal processes, navigation hazards, and improvement of yield in fish, plankta, and kelp harvesting.

Meteorological Satellites

Additional sensors, increased frequency of coverage (twice daily to as much as 60 times daily when the full array of meteorological satellites is in orbit), and higher spatial resolution of some sensors to 0.5 kilometers or better, will make the meteorological satellites progressively more important for earth survey programs particularly in the combination of better weather information with LANDSAT data.

NIMBUS-G (1978) will have a spectrometer for ocean color imaging, plus a radiometer and scatterometer for sea state data, as well as sensors to detect stratospheric pollution.

TIROS-N (1978) is expected to contain a four-channel sensor for data with 1 kilometer spatial resolution in both the visible and infrared portions of the spectrum. It will also include an atmospheric temperature sounder and possibly a radiation budget instrument.

A second Geostationary Operating Environmental Satellite (GOES-B) will be launched in 1977 to join GOES 1 and an earlier Synchronous Meteorological Satellite (SMS) to provide, among other data, cloud cover images over the Western Hemisphere every half hour. The GOES system also monitors the

earth's magnetic field and gathers data from ocean buoys, seismometers, tide gauges, and other DCS platforms. The two GOES spacecraft will be major U.S. contributions to the World Weather Watch system, which will be rounded out by 1978 with the orbiting of additional satellites of the same type over the Atlantic, the Indian Ocean, and the Western Pacific by the European Space Agency, the USSR, and Japan.

Near-Term (1976-1980) Applications

Through 1980 the technical advances of chief significance to the developing countries will come from LANDSAT C and from gradual integration of meteorological satellite data into resource sensing programs. In combination, the new IR and modified RBV additions to LANDSAT C and the likely advances in applications of meteorological data promise the following effects in the various resource sectors:

Agricultural Production

- Better crop forecasting based on: improvement of crop identification from 2 to 10 percent over current LANDSAT performance, depending on the complexity of the crop area (IR)—the simpler the environment, the larger the improvement is likely to be; possible gains in yield estimation (RBV, IR); improvement in acreage estimates (RBV)
- Better delineation of soil boundaries at reconnaissance scale (RBV).

Rangeland Management

- Improved monitoring of vegetative conditions of rangeland (IR)
- Sharpened plant community boundary delineation for improved inventory (RBV).

Forest Management

- Slight to moderate improvements in all categories where LANDSAT has indicated potential: in sampling (RBV), monitoring of clear cutting (RBV, IR), burns (RBV, IR), dead timber (RBV), and broad plant association mapping in little-known areas (IR).

Water Resource Management

- Higher quality fracture and geomorphic analyses for ground water investigation (RBV)

- Improved estimates of rainfall over large areas of the tropics and subtropics (SMS/GOES)
- Development of near-surface soil moisture bookkeeping for crop and pasture yield estimates (meteorological satellites) and additional help in assessing near-surface soil moisture in arid and semiarid areas (IR)
- Improved estimates of small-area runoff as a result of the above two developments
- Improved forecasting of floods and assessment of flood damage.

Geologic Survey and Mineral and Petroleum Exploration

- Detection of thermal anomalies indicating possible faults; improved discriminatory power to separate different lithologies in arid areas (IR); (since the LANDSAT IR band is broad and of low resolution and the time of passage (9:30 A.M.) is suboptimal, its geologic contribution may be modest)
- Improved definition of structures, fracture patterns, and sedimentary rock sequence (RBV).

Both improvements will be of value for mineral and petroleum exploration.

Cartography

- Capability for revising additional features of line maps at a scale of 1:250,000 or even larger, because of the better spatial resolution and the probably improved spatial fidelity of the RBV
- Optimization of the quality of image mapping at a scale of 1:250,000 (RBV), compared to the imagery from LANDSATs 1 and 2 which is best suited to image mapping at 1:500,000.

Land Use—Urban and Regional Planning

- Improved identifications in areas of urban structures and of packed earth with and without trees (IR)
- Modest improvement in identification of boundaries and of classification categories generally (RBV).

Demography

- Improved sample design and sample extrapolation of population (RBV)
- Better delineation of urban areas and villages, and some help in establishing the land use relations in the surrounding area as a result of improved discrimination in urban localities (IR) and clearer boundary definition (RBV).

Environmental Protection

- Sharper observation of environmental problem areas that have temperature related or emissivity related effects–water pollution, oil spills, thermal pollution (IR)
- Improved definition of gradually deteriorating land areas such as those undergoing desertification (RBV); with frequency of coverage no greater than once every 9 or 18 days, little improvement anticipated for situations requiring more frequent monitoring.

Marine Resources and Coastal Engineering

- Better determination of small to moderate features of ocean circulation, wherever significant temperature differences can be correlated with the ocean circulation patterns (IR)
- Likely detection of small eddies, upwellings, oil spills, and waste dumping (IR).

In higher latitudes, some estimates of the dynamics of ocean circulation may become possible as a result of the two-day repeat LANDSAT "overlap" coverage, and may thereby aid fishing (IR).

Disaster Warning and Assessment

- Improved disaster assessment and monitoring in flooded areas (RBV)
- Possible improvement in monitoring of major volcanic eruptions and large remote area forest fires (IR). The 18-day repeat cycle of LANDSAT C, with possibilities of impenetrable cloud cover, will remain incompatible with the requirements for effective warning in most disaster situations.

Longer-Term (1981-1985) Technology

The technology of earth resource sensing from space is likely to advance along three lines in the early 1980s:

- Substantial improvements in the sensitivities of multispectral sensors
- Development and refinement of techniques to integrate data from meteorological and other satellite systems with earth resource sensing data for monitoring, especially for purposes of agricultural and hydrological forecasting
- Experimentation with, and use of, microwave sensing to acquire data through cloud cover.

LANDSAT D

Planning is in progress for a second generation earth resources satellite, designated as LANDSAT D, which will carry an advanced multispectral scanner known as the Thematic Mapper. This sensing system probably will have six (perhaps seven) channels that are more sharply defined and of higher radiometric and spatial resolution than the MSS systems aboard LANDSATs 1 and 2–256 levels of intensity compared to the 64 levels that presently can be telemetered to ground stations, and 30 meters (about 0.1 hectare or 1/4 acre) per pixel against the 80 meter (0.4 hectare or one acre) per pixel resolution presently available.

According to current projections, a LANDSAT D satellite, in about 1981, would be placed in sun-synchronous, near polar orbit at an altitude of 705 kilometers with a repeat cycle of 18 days. A second satellite would be launched sometime later to form a two-satellite system to provide repetitive coverage every nine days.

If its bands are optimized to sense land cover, as is the present intention, the Thematic Mapper would be particularly useful for agricultural sensing in developing countries and could bring improvement to virtually all other application sectors. However, the higher resolution and the additional channels would produce a sharp increase in data rate, from 15 to 110 million bits per second. This would impose significant additional requirements on the ground-based data reception and data processing subsystems.

Proposals have been made to place alongside the Thematic Mapper on LANDSAT D a duplicate of the improved first generation MSS that is being built for LANDSAT C. Such a five channel MSS would serve the needs of receiving stations and users not yet prepared to shift to the more advanced technology, would retain comparability with earlier LANDSAT data and could serve as a backup to the untested Thematic Mapper.*

Space Shuttle

Space Shuttle, a reusable manned space vehicle now being developed, is expected to be orbited in 1979-80. With a capacity almost as large as a Boeing 707 aircraft,† it will be able to carry an extraordinarily diverse array of

*Provision for the financing of LANDSAT D and the Thematic Mapper was included in the proposed budget for FY 1977-78 which the outgoing Ford Administration recommended to the Congress in January 1977. The submission, which is subject to Congressional review and decision, did not provide for the inclusion of a first generation MSS aboard LANDSAT D. A September 1976 CORSPERS report, which provides an analysis of the Thematic Mapper in relation to resource and environmental information needs in seven sectors of application, urged that LANDSAT D be made a dual capacity satellite equipped with both the Thematic Mapper and an MSS of the LANDSAT C type.[1]

†It will take payloads up to 15 feet in diameter and 60 feet long, and weighing up to 65,000 lbs.

instruments needed for different experiments and to serve as a platform from which other spacecraft, operational as well as experimental, will be put into orbit. The Shuttle is intended also for the refurbishment and retrieval of future earth resource spacecraft. Space Shuttle missions will be flown several times a year and will last from 7 to 28 days. They will provide a test bed for new techniques, concepts, and instruments required to improve the capabilities of later generation spacecraft and to make possible the use of combinations of large, heavy instruments.

The orbit of the Space Shuttle and the instrumentation it carries will vary with each mission. The contribution to remote sensing of the earth that will interest the developing world is likely to be mainly in the gradual accumulation, through the 1980s, of earth resources data from a variety of sensor systems, particularly from the high resolution cameras the Shuttle may carry on some of its missions. These data can be expected to improve the inventory of natural resources, especially geologic and natural vegetation features, and to serve land use coverage requirements in numerous areas. Because it will not fly regularly and continuously over the same scenes, however, the Shuttle, so far as can be judged now, will not serve routine monitoring needs. These would be met in part by LANDSAT D and perhaps special purpose satellites that might be developed in the years after 1985.

Synchronous Earth Observation Satellite (SEOS)

This satellite has been proposed as a possible combined meteorological and earth resource spacecraft to be placed in earth-synchronous (36,000 kilometers) orbit from which it would sense the entire Western Hemisphere. High-powered telescopes would allow for high resolution with long dwell times and repeated looks at particular areas.

Instrumentation for SEOS would probably include solid-state cameras, new generation telemetry, and spectrometers for pollution detection. The satellite is intended principally for studying short-lived phenomena—meteorological hazards such as extensive flooding or violent storms—and features such as estuarine dynamics, major fires, etc.

Penetrating Cloud Cover

The persistence of cloud cover for many months of the year places serious limitations on the potential value of space remote sensing for certain countries, especially those situated in the wet tropics. The LANDSAT sensors operate in the visible or infrared portions of the electromagnetic spectrum and are unable to penetrate clouds. Two approaches have been advanced for dealing with this problem—microwave sensors and frequent coverage with multispectral sensors aboard geostationary or low-latitude orbiting satellites.

Sensors in the microwave region (1 millimeter to 1 meter) are able to penetrate all clouds, most rain, and certain classes of vegetation.* One microwave sensor considered useful for resource sensing is the synthetic aperture imaging radar. A single frequency (L-band), horizontally polarized imaging radar with 25 meter resolution will be aboard the SEASAT A satellite. Present plans for SEASAT A, however, provide for reception of its radar telemetry by stations to be located principally in or near North America, with a maximum receiving radius of 2300 kilometers. Imaging radar coverage of developing countries from SEASAT A or from future such satellites would have a number of significant resource applications. These are detailed below, in the discussion of longer-term remote sensing applications, to illustrate their likely contribution and to emphasize the need for a careful study of their role in a remote sensing program specially oriented to the needs of developing countries.

The concept of an experimental multifrequency, multipolarization imaging radar on a Shuttle mission is under study. Because of its special characteristics, including its multiple look-angles and its sensitivity to textural differences, and by virtue of its increased discrimination, such a radar could enhance inventory capability in regard to crops, forests, rangeland and water yield. If radar strips overlap in an appropriate manner (side-lapping), stereoscopy may be obtained that would be helpful for geologic and other resource mapping. Should the proposed experiment be undertaken and prove successful, the way might be opened to the evolution of special and multipurpose radars on space platforms in the post-1985 period.

The European Space Agency is considering the possibility of developing a European earth applications satellite program based on active and passive microwave sensors.

Low-latitude satellites, both orbiting and geostationary, equipped with multispectral sensors, would have particular advantages for tropical zone countries affected by persistent cloud cover. These advantages would lie in the very frequent repeat coverage on each day made possible by satellites in a fixed position vis-à-vis the earth (equatorial-geostationary), or in the increased frequency of coverage by low-inclination orbiting satellites compared with that of satellites (such as LANDSAT) in polar orbits.† In addition to the greater likelihood of acquiring relatively cloud-free images, the geostationary satellite coverage would be valuable for thermal sensing of geologic and hydrologic features.

*Microwave sensors are of two kinds—passive and active. Passive microwave sensors record electromagnetic energy emitted by surface features. Active microwave (radar) systems use a transmitter to send out pulses of energy to targets; the sensor receives and records the returning signals.

†It may be feasible, with a single satellite, to obtain repeat times (that are not sun-synchronous) of 4 to 6 days, depending on the satellite inclination and area involved.

One disadvantage these low-latitude satellites would have is the lack of uniform illumination by the sun, although selections could be made of images taken at approximately the same time of day. An inquiry into the merits of a tropical resource staellite was initiated under Brazilian auspices in 1973. No other studies appear to have been undertaken since. Regular, repetitive data reception that would be made possible by a globally dispersed network of receiving stations or a data relay satellite such as TDRSS (see page 113), and possible use of imaging radar satellites such as SEASAT, especially over cloud-prone areas, might reduce the need for low-latitude orbit satellites. This option will warrant reexamination some years hence after more experience has been accumulated.

Longer-Term (1981-1985) Applications

If the LANDSAT D program becomes a reality, the longer-term future in remote sensing applications will center principally in the use of Thematic Mapper data for resource inventory and monitoring. Valuable additions to inventory data for developing countries may come also from high resolution cameras on Space Shuttle and, possibly, from imaging radar. Resource monitoring and crop forecasting to meet global as well as particular country needs may also gain significantly from advances in meteorological satellites and in microwave sensors, plus improvements which it is reasonable to expect in data processing and satellite transmission and delivery.

The extension of capabilities that it is possible to foresee in the various sectors of application in the 1981-1985 period and their potential interest for the developing countries or the world community are described below. The projections involve several assumptions which need to be made explicit:

The contemplated satellites and sensors will indeed be available.

Adequate performance of the new technology in concert with other means of data gathering will be achieved.

The necessary R&D on advanced analytical techniques such as modeling will be accomplished.

Agricultural Production

- Improved recognition of soil/crop contrast and sharper discrimination of soil boundaries.
- Substantial improvement in statistical sample designs for estimating acreage of major food grains generally, including those in small-field, multicrop

areas. This improvement could arise through use of (1) the 30 meter Thematic Mapper multispectral data, (2) infrequent but high resolution color and color IR photography from the Space Shuttle; and (3) 25 meter radar images of cloud covered areas especially in the tropics (if available over developing countries). For these remote sensing data to be useful, they will need to be merged with a statistically well designed ground sample.

- Significant improvements in yield estimation for various crops in the U.S. LACIE program through merging the following data in an appropriate computer modeling system: (1) crop yield/stress models for crops in addition to wheat, particularly corn, maize, sorghum, and rice; (2) meteorological satellite data; (3) ground meteorological data; (4) ground crop type and condition data in a proper sample design; (5) ground observations on yield estimates; (6) Thematic Mapper data; and (7) imaging radar data if available.
- Marked reduction in the error of harvest estimate at harvest time or a little earlier, if the above improvements are realized and can be utilized operationally in developing countries.
- Useful capability to detect and regularly monitor regional crop disease (rusts, blights, etc.) with the improved spatial and spectral resolution LANDSAT D would provide. This is not likely to be achieved before 1985 since a substantial body of data from the Thematic Mapper will be needed, along with meteorological satellite modelling and forecasting of predisposing disease conditions in the early stages for major grain crops.

Rangeland Management

- Substantial improvement in inventories of range types and in monitoring for range improvement with the help of LANDSAT D.
- Improved capabilities for monitoring of range feed condition, given a systematic integration of data from a variety of satellites and from different plant-environmental models. These would include models on pasture growth, soil moisture forecasting, and monitoring of water and energy budgets. The Thematic Mapper would have resolution characteristics sufficiently comparable to the SKYLAB S-190 B camera system to suggest their high value in discriminating active green vegetation, accurately classifying green vegetation with full ground cover, and sampling for estimation of range feed condition.
- Provision in the developing countries of an improved assessment base for exploratory well siting, for location of villages, for finding ground water and stock water supplies, and for effective pasture rotation grazing. Even the relatively gross monitoring capability in the thermal region of the SMS/GOES satellites will be of value in locating water supplies a few feet from surface. The Thematic Mapper would be correspondingly more useful because of its improved spatial resolution.

• Improvement in studies of green biomass phenologic stage and grazing intensity. Combined with use of microwave sensors on meteorological satellites, the Thematic Mapper would enable assessment of overgrazing and potential for wind erosion through detection of low soil moisture and severe removal of pasture.

Forest Management

• Improvements in forest inventories and associated maps through the Thematic Mapper's increased ability to identify small cultural features (such as reforested plots, clearings, logging roads, and similar features), thereby reducing the need, in timber evaluation surveys, for intermediate-level aircraft data for sample site and property locations. This would save on inventories and improve the efficiency of the samples.

• Gains in accuracy of classification of forest types as a result of the various improvements in the Thematic Mapper. These gains would be most likely in areas of clearly differentiated plant communities.

Water Resources Management

• Improved monitoring of three variables in the hydrologic cycle—snow melt, evapotranspiration, and soil moisture.

For those areas where substantial snow accumulations govern both hydroelectric generation and irrigation, measuring of the snow pack area and snow melt during the spring may be upgraded with satellite sensing, DCS and moderate ground sampling. These could lead to development of regional flash flood warning centers, and to savings through the increased accuracy of water-yield assessments and improved operations of hydropower facilities. Meteorological satellites, LANDSAT D, and special purpose hydrological satellites would have to contribute to this upgrading. Imaging radar would be particularly valuable in this respect.

Determination of evapotranspiration, which is inadequately measured everywhere, requires data on cloud cover and type, as well as ground and air temperature, wind velocity, etc. Through merging ground based data with data from synchronous and other meteorological satellites, a number of these factors may be estimated with sufficient accuracy to provide a major advance in understanding of water demand in areas of low and variable rainfall. Significant research in water-demand models is already under way, principally in conjunction with the LACIE program.

Soil moisture estimating procedures, with research now beginning, should be quasi-operational by the early 1980s. If successful, regional assessment of water yield, drought stress, etc., should be possible on much finer spatial and

temporal scales than is even now available in the technologically advanced countries. Future satellites with active microwave sensors, meteorological satellites, and LANDSAT D will play various roles in this estimation process.

- Improved monitoring of precipitation and temperature. Where precipitation is generally of the convective type (from cumulus clouds)—common in tropical latitudes—present indications are that, by employing SMS/GOES data, estimations of total rainfall on a 40-kilometer grid may be obtained as monthly averages with an error of 15 percent or less.[2] With additional improvements, the margin of error may be further reduced.
- Better water yield budgeting as a result of direct measurement of ground temperatures, likely to be operational within five years with the aid of meteorological satellites.
- Moderate improvement in meteorological forecasting of temperature, and to a lesser degree of rainfall, from 24 to 72 hours. Advances along these lines made during the last five years in the United States can be envisaged for developing countries in the 1980s. This could lead to more accurate prediction of floods and of severe weather effects on populations, as well as better water release practices in hydropower and irrigation systems.
- Increased knowledge and accuracy of short-term stream flow and major long-period water-yield estimation as a result of the above improvements growing out of use of combined data from meteorological, ocean dynamics, hydrological, and earth resource satellites.
- Improved forecasting of floods in developing countries through use of SMS/GOES-type satellites in conjunction with DCS and with other meteorological satellites.
- Much improved monitoring of floods and assessment of flood damage through cloud cover with the help of imaging radar, if available. Where no or few clouds are present, the Thematic Mapper and the high-resolution photographic and multispectral sensing systems which might be carried on the Shuttle will be of value.
- Improved forecasts of water demand leading to significant savings in efficient application of irrigation water. These forecasts would employ stress models for plants; the merging of meteorological and ground observations of net radiation, wind, temperature, and vapor deficit; SMS thermal infrared observations and other data. The Thematic Mapper could also be employed to monitor crop type and stage, and thereby provide additional improvements in forecasts of expected agricultural use of water.
- Improvement in knowledge of the spatial and temporal locations of surface water; suitable areas for detailed ground water exploration; and land use effects of water yield, on the basis of higher quality data from LANDSAT D or other earth resource satellites.

Geologic Survey and Mineral and Petroleum Exploration

• Improved geologic mapping, including better recognition of geologic structures, better definition of lithologic discontinuities, detection of small intrusive bodies such as dikes, delineation of small fracture systems, and improved band ratioing to detect zones of alteration which may indicate mineralization—all resulting from the 30-meter resolution and near-infrared bands of the Thematic Mapper.

• Coverage of mountainous or heavily clouded wet tropical areas unobtainable by any other means, by use of imaging radar. The stereoscopy achievable with the side-lapping radar images would also be important in improving broadscale geologic mapping and in further reducing the first-cut costs of geologic exploration in mineral search. (The quality of the stereoscopy from space will be equal to that obtained from aircraft.) Fore- and aft-looking high resolution photographic cameras, if carried on the Shuttle, would also provide more detailed stereoscopy for investigation of small intrusive bodies and fracture systems.

The incremental gain in geologic mapping and the greater efficiencies in mineral/petroleum exploration, which could arise from the Thematic Mapper, imaging radar, and Shuttle cameras, would be new, one-time benefits for developing countries.

Cartography

• Improvements in meeting planimetric cartographic needs because of the higher resolution in the Thematic Mapper—30 meters as compared to 40 meters in RBV cameras of LANDSAT C.

• Advantages for cartography offered by high resolution cameras that might be carried aboard the Shuttle during some of its missions.

Land Use—Urban and Regional Planning

• A notable increase in the ability to map land use classes and to identify more urban area characteristics in areas of moderate to high tree cover would come from the improved capability of the Thematic Mapper. The higher resolution photography that might become available from Space Shuttle missions would also be of value for urban land use studies in the areas covered. Because complex modeling is not needed for many land use tasks, these gains from the Thematic Mapper and Shuttle experiments could probably be realized easily and relatively inexpensively in the developing countries.

Environmental Protection

- Detection and monitoring of oil spills with imaging radar.
- Better monitoring capabilities for environmental problems that evolve gradually, such as soil erosion, pasture and range deterioration, and undesirable changes in wetlands communities. Many environmental problems either signalled or paralleled by plant community and density changes could be readily determined with the Thematic Mapper; some may be noted in data from Shuttle experiments. However, aircraft will have a continuing role in meeting environmental problems requiring very high resolution or frequent repetitive coverage.

Marine Resources, Oceanography, and Coastal Engineering

- Better information on ocean dynamics and on potential fishing areas, gained from SMS/GOES data on coastal currents and upwelling regions combined with data from the Thematic Mapper and from SEASAT's thermal and microwave scanners. Because of SMS coverage of latitudes between 45°N and 45°S, coastal areas of virtually all developing countries will be observed. Fish spotting, however, is likely to remain an aircraft function.
- Improved nearshore mapping of value for offshore exploration and for siting of underwater drilling, dredging, and mining, with the help of the ocean color scanner to be carried on an early NIMBUS satellite and the improved spatial and temporal resolution of the Thematic Mapper.
- Greater capabilities, as a result of improved resolutions, to determine smaller features of ocean circulation, to monitor wetlands, to give warning on oil spills and illegal dumping, and to survey changing conditions in shoaling waters. Cameras in the Shuttle would be helpful in delineating coastal alterations and in the definition of change in major storm affected features.

Disaster Warning and Assessment

- Improved flood area mapping by use of imaging radars with cloud penetrating capability, if the coverage is sufficiently frequent (36-hour interval of SEASAT, for example) so that many large floods would be observed at, or close to, their peak. This would enable more adequate forecasts with respect to the arrival of the crest and the extent of flooding downstream.
- Better postdisaster monitoring aided by the improved spatial, spectral, temporal, and radiometric resolution of the Thematic Mapper.

Other Data Gathering Platforms

In the coming decade the collection of earth resource data will also involve the use of sensing platforms other than spacecraft, particularly ground data collection systems and aircraft.

Data Collection Systems via Satellites

The Data Collection System (DCS) today is comprised of a small number of unattended environmental monitoring platforms in various parts of the world that can be monitored locally via telecommunications relay from LANDSAT, meteorological and other satellites. In the future many such ground platforms will probably be utilized to collect near real-time data for a wide variety of applications, as suggested in Table 5.

Both the monitoring platforms and the user terminals for receiving the DCS data from the satellites are relatively economical. Some platforms, which generally operate unattended for as long as six months, now cost $5,000 or less, and with increased production may approach $500 per unit in the near

TABLE 5 Parameters Monitored by Means of Data Collection Systems

Applications	Parameters	
Hydrology	Stream Flow Reservoir Level	Groundwater
Water Quality	Dissolved Oxygen pH Specific Conductivity	Temperature Turbidity Chemicals
Meteorology	Temperature Precipitation Humidity	Pressure Wind Solar Radiation
Volcanology	Earth Tilt Tremor Events	Fumarole Gases Temperature
Agriculture	Air/Soil Temperature Soil Moisture Evaporation	Solar Radiation Chemicals
Wildlife Resources	Animal Location Body Temperature Heart Rate	Encephalic Activity Respiration
Oceanography	Air/Sea Temperature Salinity Turbidity	Wave Height Wave Period Currents

future. Local user terminals are priced at about $150,000 including the antenna and receivers.

Aircraft Platforms

A number of resource survey requirements that until recently could be met only by aircraft can now be accomplished by sensors on satellites, whose anticipated future performance should allow for yet wider substitution. Nevertheless, aircraft will continue to have an important role in providing high-resolution data and aerial sampling and calibration data required for a balanced, multistage sensing system. Moreover, certain sensors perform well on aircraft but not on spacecraft. These include many of the geophysical instruments, ultraviolet and gamma radiation devices, and, to some extent, laser and various passive microwave devices.

No single aerial platform meets all requirements and a variety of aircraft types will continue to be used for different purposes: helicopters; light aircraft operating to altitudes of 5 km (16,500 feet); heavy aircraft to 10 km (33,000 feet); and high altitude aircraft, one make of which will soon be commercially available, to 20 km (65,500 feet). The flexibility of flight path and schedule unique to aircraft makes them effective platforms for obtaining imagery in areas of persistent cloud cover and for special purpose sensing, using instruments such as photographic cameras, radar, radiometers, and scanners ranging from single channel thermal to multispectral units.

Ground Segment: Data Reception, Processing, Management and Analysis

Important changes may also be expected to take place in the next 5 to 10 years in the characteristics, capabilities and costs of the ground equipment of satellite sensing systems, and these could have an impact on the ability of developing countries and regional groups to acquire the mechanisms and apply the products of the new technology.

Data Reception

Nations or regional groups planning to establish reception stations in the future to acquire multispectral data from the LANDSAT C and planimetric data from its RBV can procure off-the-shelf equipment. The costs of a reception facility are not likely to change much in the next five years (see pages 114-115).

Two major developments may affect national and regional plans for data reception beyond 1980-1981. The first is a plan under consideration by NASA to establish a Tracking and Data Relay Satellite System (TDRSS) about 1980. Utilizing two geostationary satellites, TDRSS would receive telemetry from all data gathering satellites, including the LANDSATs, for transmission to a single receiving station in the United States. This would obviate the need for onboard recorders and provide a backup or alternative reception mode to existing local receiving stations. The latter would, however, continue to have direct access to the current type LANDSATs.

The second important event affecting reception of satellite sensing data would be the orbiting of the proposed LANDSAT D. If an MSS sensor with resolution and waveband characteristics of the current LANDSATs were included in LANDSAT D along with the more advanced Thematic Mapper, it would extend into the 1980s the serviceability of ground reception and processing facilities geared to lower resolution data. Equipment modifications of a scale yet to be determined would be required for a station to receive and process the data from the Thematic Mapper with its much higher data rate.

Data obtained through TDRSS relay could be speedily retransmitted in digital form by communication satellites to users elsewhere in the world, or forwarded to them by more conventional transmission methods. One possibility envisaged for the distribution of data obtained through TDRSS is by a link with the EROS Data Center. The Center would retransmit data, in raw or processed form, to requesting national or regional units as well as individual users abroad, much in the style of its present operation, though at a greatly accelerated pace. Near-real-time retransmission could be accomplished, if needed, by means of communication satellites to local INTELSAT earth stations. To accommodate the high data load from the Thematic Mapper, however, development of as yet unavailable special sending and receiving equipment would probably be necessary. The financial and operational implications of this roundabout reception-retransmission mode for developing countries have not yet been assessed.*

Data Processing

Technological change taking place in computers generally and in remote sensing data processing instrumentation in particular will affect the use of

*As this report was being completed, an initial study addressing these questions became available. A report[3] prepared for the Agency for International Development by the Environmental Research Institute of Michigan in August 1976 concluded that use of communications satellites to retransmit to regional centers abroad local data collected in the United States via TDRSS would be far more costly than other means of data delivery.

data products in developing countries. Emerging machine-assisted procedures not only simplify a variety of otherwise slow and complex tasks, but make possible the extraction of significantly greater and more detailed information from the digital data. The growing sophistication and versatility of the ground hardware now under development in important respects compensate for the inadequacies of the satellite sensor system, render possible the rapid processing of large volumes of raw data, and for certain purposes reduce significantly the number of highly trained personnel needed.

A typical data processing system will perform radiometric and geometric corrections on the raw video data, display video data for editing and screening, categorize video data to identify selected ground features, and record video data on film or computer compatible tape. The overall cost of such a system is not likely to change much before 1980, despite improvements that may be effected in individual parts.

NASA has estimated current equipment and operating costs of a minimum requirement station and a full ground station. The minimum requirement station would receive LANDSAT MSS data and process up to 10 scenes a day to provide high quality film and CCTs for a small user community. The full ground station would process up to 40 scenes a day and distribute a large number of film, photographic and tape products. It would also include capabilities for RBV data reception and processing and both "quick-look" and precision data processing. The operating costs do not include building maintenance, security, utilities and other housekeeping costs. The estimates follow:

Initial Costs (In Thousands of U.S. Dollars)

	Minimum Requirement Station	Full Ground Station
Antenna and Receiving Equipment	$ 400	$ 500
MSS Recording and Preprocessing Equipment	120	440
RBV Recording and Preprocessing Equipment	———	550
Quick-Look Film Processor	———	200
Timing and Display Equipment	10	150
LANDSAT "Housekeeping" (PCM) Data Recording Equipment	———	30
Photo Lab	60	250
MSS Processing Equipment (Applies corrections to data and converts it to CCT or film)	800	1,500

	Minimum Requirement Station	Full Ground Station
RBV Processing Equipment (Applies corrections to data and converts it to CCT or film)	———	400
Precision Processing Equipment	———	500
System Installation and Test	135	250
Manuals	50	250
Spares	75	400
Special Test Equipment	100	300
On-Site Training	150	280
TOTAL	$1,900	$6,000

Annual Operating Costs (In Thousands of U.S. Dollars)

	Minimum System	Full Ground System
System Operation and Maintenance	$600	$1,200
Expendable Items (Film, magnetic tapes, etc.)	100	400
Special Equipment Maintenance Contracts	50	75
TOTAL	$750	$1,675

While progress from general computers to minicomputers to microcomputers will probably result in sharp reduction in the cost per computation, rising operation costs can be expected from the increased use of the technology, the increased data load, and therefore the number of computations. Savings on capital or operating computer costs are likely to be absorbed by increased throughput and by purchases of peripheral digital analysis equipment such as would be required to serve a number of analysts processing different LANDSAT scenes simultaneously.

For many resource management purposes, the speed of processing and the timely receipt of processed data products, whether in image or digital form, are important considerations. The rapidity of processing depends only in part on the capacity of the equipment. Of the 8 to 10 hours it takes today to process a normal LANDSAT scene, only about one-tenth of the time involves use of the computer. The total time required to perform functions such as data screening, training set selection, image generation, etc., is generally determined by the operator and the speed with which peripheral equipment, such as tape units, discs and film recorders, can function.

The time it now takes users everywhere to obtain present type LANDSAT products should be materially reduced as additional receiving and processing facilities come into operation around the world and as plans of NASA and the EROS Data Center at Sioux Falls to introduce processing equipment with higher throughput are implemented. With these changes, data delivery time from the EROS Center at least should be reduced by late 1977 from the present 3 to 8 week period to no more than a week.

Data Management and Analysis

Faster digital equipment is bound to improve the capability of data storage and dissemination systems which will be shaped to the resource information needs of the users. An increasing number of automatic subsystems will become available, but the need for them will depend on the size and nature of the tasks to be performed. For example, quality products such as color photographs can be produced more accurately by automation than by even the most skilled specialists.

The central piece of analytical equipment is likely to remain the interactive data analysis terminal (IDAT). Since the total time required to analyze a LANDSAT scene makes minimal demands on the IDAT computer subsystem, further R&D efforts will be devoted mainly to improvements in IDAT system peripherals and software that would allow concurrent use of the core equipment by a number of analysts. The current acquisition cost of an IDAT system—$250,000 to $500,000, depending on the peripherals included—is not likely to change substantially in the next five years.

References

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2. E. Merritt *et al.*, *EARTHSAT Spring Wheat System Test 1975: Final Report*, prepared for L.B. Johnson Space Center, Houston, Texas, U.S. NASA, Contract #NAS-9-14655 (Washington, D.C., Earth Satellite Corporation, April 1976), pp. 6-1 to 6-43.
3. Environmental Research Institute of Michigan, *A Preliminary Assessment of AID's Requirements for a LANDSAT Follow-on Satellite*, Prepared for the Office of Science and Technology, U.S. Agency for International Development (Ann Arbor, Michigan, 1976).

VI Use of Remote Sensing in Developing Countries

The two preceding chapters have examined the technology of space remote sensing essentially from the standpoint of its present and probable future *data collection* capabilities, dwelling primarily on hardware and data extraction aspects of remote sensing. It is in *data utilization*, however, where manpower, institutional, and operational constraints predominate, that the technology meets its real test, and where its prospects for the developing world must be judged.

The contributions of remote sensing in resource evaluation depend on the simplicity or complexity of the resource under examination, and on the type of contributions the sensors are called upon to make. At one extreme are situations involving a single, readily determined item, unobtainable by other means in developing countries in a timely fashion. Examples include flood area mapping and detection of newly cleared agricultural lands in frontier regions. At the other extreme are evaluations of a resource system, such as crop production, which employ contributions from many types of space, air and ground data, modeling of the parameters of the system, computer management of data, and exercise and refinement of statistical weighting procedures. In between these extremes lies a wide range of feasible mixtures of remote sensing and other data.

Thus far, both developing and technologically advanced countries have tended to seek applications principally in the simple situations. This is natural because these are more readily implemented, require only modest research and development, and the contribution of the remote sensor in these cases is explicit, direct, and more easily understood. In addition, incorporation of the remote sensing data does not or need not disturb ongoing methods of data evaluation. In short, these situations are where data gaps are simply filled, and the present ways of doing business are little disturbed.

The application of remote sensing as part of a fully integrated system of modeling, accounting, budgeting and forecasting of, say, water yield or crop production, on the other hand, is revolutionary in many ways. Extensive

R&D, including plant growth model development, must still be undertaken to make it practicable; when achieved, the new data system may need to modify significantly or replace existing procedures, with sizable human problems of adjustment, dislocation and retraining. In the developing world, probably only those countries with larger scientific establishments and effective institutional structures, or those able to band together in regional efforts, will be able to assimilate this high technology, total systems approach to resource evaluation.

Chapter IV emphasized applications of the first type, i.e., simple, easily adopted, univalued remote sensing techniques. Chapter V emphasized the more fully integrated systems of the future which will require the acceptance of the high technology approach as well as the financial, institutional, and scientific capacity for its implementation.

In practice, neither of these situations is likely to prevail as the technology advances, and as nations and international agencies adjust solutions of particular problems to an array of financial and social constraints. Just as the developing countries lie on a spectrum of economic and scientific capability, so too will the remote sensing approaches taken by them extend over a wide scale.

Choice among the various options will require careful consideration on the part of the developing countries and of external aid granting agencies. This much can safely be said: Space remote sensing still faces a protracted period of technical development. There is a parallel lag in the responsive adjustment of human, social, and political instruments by which the technology will be harnessed to useful ends. While the technology in its early form already shows many uses, its ultimate technical shape and social worth may not be apparent for another decade or longer. Between the simple but immediate benefits and the larger but more distant ones that the technology appears to hold in store, there is a "learning curve" that all would-be user countries—technologically advanced and developing alike—will need to experience, and on which each individually needs to embark.

The Entry into Remote Sensing

A surprisingly large number of countries have already made initial moves. Some 120 countries, of which two-thirds are among the less developed, have procured LANDSAT products from the EROS Data Center. In 1975, more than 50,000 LANDSAT frames were purchased by public and private users for areas outside the United States. As shown in the accompanying regional charts (see Tables 6 to 8) and elaborated below, a large number of developing

countries have had some direct exposure to the new technology and many have taken initiatives to accommodate to its exigencies.

How is this diffusion or technology transfer process of skill and facilities occurring? The pattern, sufficiently widespread to permit categorization, consists of three phases of involvement.

Phase 1: General Awareness

No country has become active in the analysis and interpretation of LANDSAT data without first passing through this phase. Many developing countries, such as Brazil, Bolivia, Iran, Egypt, and Thailand, have progressed far beyond it. Others are just entering it.

Typically, one or more scientists, technicians, or administrators within a country learn about LANDSAT and proceed to examine and evaluate satellite images obtained over areas of interest to their country. Initial interest in different countries has developed in a variety of settings—universities, academies of science, research institutes, government agencies. Specialists who have provided leadership include crop scientists, geologists, soil scientists, hydrologists, civil engineers, geographers, foresters, electrical engineers, and surveyors.

A positive first reaction will usually lead to further steps to obtain a better grasp of the technology and to develop a capacity for its application.

Phase 2: Reconnaissance Surveys (Scale of 1:250,000 or smaller)

This phase consists primarily of the use of LANDSAT imagery for the preparation of generalized maps from which useful information about the land, vegetation, geologic, and water resources can be derived.

Some developing countries may be limited in their capabilities to interpret and utilize satellite imagery because they lack trained photointerpretation personnel and/or basic analytical instruments and cartographic facilities.

But where some equipment and skilled manpower are present, a country should be able to acquire a substantial amount of valuable resource information from a set of LANDSAT scenes of its domain. In addition to photomaps at a scale of 1:250,000 or smaller of areas otherwise inaccessible or poorly mapped, it can gain a measure of its agricultural, forest and range lands, identify its surface water resources, add important morphological features to its geological information, and locate such resources as can be simply discriminated by the sensors and corroborated by ground verification. Generally, the data for these simple, easily acquired benefits can be extracted from one-time coverage scenes of an area or from a few scenes taken at different seasons.

REMOTE SENSING ACTIVITIES IN AFRICA	Source of Information	Agency/Institutional Involvement						Identifiable Remote Sensing Programs/Projects							Facilities and Personnel Available							Education and Training			Activities of External Organizations Within the Country			
		Remote Sensing Infrastructure	Interest or Involvement Identified					Basic	Type of Basic Data						Basic Capability		Data Collection			Data Interpretation								
			Governmental Agencies	Military	Individual Scientists	Commercial/Private Sector	Academic Sector	Identified?	Cartographic	Aerial Photographic	Landsat	Other Spaceborne	Other Sensors	Automatic Data Processing	Photographic Reproduction	Cartographic Capability	Aircraft Capability	Sensor Capability	Data Collection Military Only	Manual Interpretation	Automatic Data Processing	Academic Programs Offered?	Users Agencies Conduct Training Programs	External Seminar/Workshop Participation	International Agencies	Bilateral Assistance	Commercial/Private Sector Activities	Notes
Algeria	●	3	●	●	●				●	●	●		●	■	●	●	●		●	7		■	E	●		●	●	
Angola	●	4				●			●	●	●											■		■			●	
Botswana		3	●		●				●	●	●		●	6	●	●				7		■		●	●	●		
Burundi	●	4	●					■	■	●				■		■	■					■		■				
Cameroon	●	3	●		●		●			●	●	●		■	●					(7)		■		●			●	
Central African Republic	●	2	●		●	●	●		●	●	●	●	■	■	●	■	■	■	■	7	■	●	E	■	●	●	●	
Chad	●	2	●		●				■	●	●	●	●	■		■	■		■			■	E	●	●	●	●	
Congo Rep.	●	4	●					■		●	■				●	■	■					■		■			●	
Dahomey	●	4	●		●				●	●	●	●				■	■			(7)		■		●	●		●	
Egypt		2	●		●		●		●	●	●		●	●	●	●	●	C,S		8	●	●	I	●	●	●		
Ethiopia	●	4	●		●		●	■	●	●	●											■		●			●	
Gabon	●	2	●		●	●			●	●	●	●	●	■	●	■	■	■	■	(7)	■	■	E	■			●	
Gambia								■	■	●	■											■		■				
Ghana	●	3	●		●		●		●	●	●	■	●	■	●	●				7		■	E	●	●	●	●	
Guinea	●	2	●		●				●	●	●											■		■			●	
Ivory Coast	●	4	●		●		●		●	●	●				●	■	■			(7)		■		●			●	
Kenya	●	3	●		●	●	●	●	●	●	●				●	●	●	C		7		■	E	●	●	●	●	
Lesotho		4	●		●		●			●	●			6						(7)		■		●		●		
Liberia		4						■	●	●	■											■		●				
Libya	●	2	●		●				●	●	●	●	●		●					(7)		■	E	●		■	●	
Malagasy	●	3	●		●			■	●	●	■				●	●	■		■			■		●		●	●	
Malawi								■	●	●	■			■								■		■				
Mali	●	2	●		●				●	●	●	●	●	■	●	■	■		■			■	E	●	●	●	●	
Morocco	●	3	●		●	●			●	●	●	●			●	●				(7)		■		■		●	●	

Mauritania	●	3	●		●				■	●	●	●	●			■	■		■			■	E	●	●		●	
Mauritius								■	●	●	■				●							■		■				
Mozambique								■		●	■				●	●						■		■				
Namibia								■		●												■		■				
Niger	●	3	●		●				■	●	●		●	■		■	■		■			■	E	●	●	●		
Nigeria	●	3	●		●				●	●	●		●		●	●		C		(7)		?	E	●	●			
Rhodesia										●	?											?		■				
Ruanda		4						■	■	●				■		■	■		■			■		■				
Senegal	●	4	●		●			■	■	●	●	●			●		■		■			■	E	●	●		●	
Sierra Leone		4	●		●			■	■	●	■											■		●				
Somalia	●									●	●		●	●						8	●	■		●			●	
Sudan	●	3	●		●				●	●	●			6	●	●				(7)		■	E	●	●	●	●	
South Africa	●	3	●	●	●		●		●	●	●	●	●	6	●	●	●	C,O		8	●	?	I	●	■	■	●	
Swaziland											●					●				(7)		■		●				
Tanzania	●	2	●		●				●	●	●	●		6	●	●	●		●	●	●	■	E	●	●	●	●	
Togo								■	●	●	■											■		■				
Tunisia	●	3	●		●				●	●	●				●	●				(7)		■		●		●	●	
Uganda			●		●			■	●	●	■											■		●				
Upper Volta	●	2	●		●				■	●	●	●	●	■		■	■		■			■	E	●	●	●	●	
Zaire	●	1	●	●	●	●			●	●	5	6	●	6	●	●	●	C	●	8	●	■	E	●	●	●	●	
Zambia	●							■	●	●	■				●	●						■		■			●	

● Positive

■ Negative

● Proposed

1 National remote sensing committee or coordinating body established

2 No coordinating body established but lead-agency can be defined

3 Various official sources

4 No infrastructure

5 Internal capability in existence or developing

6 External capabilities

7 Visual only

8 Machine assisted

C Camera

S Scanner

O Other (radiometer, magnetometer, radar, etc.)

I Independent (internal staff and expertise)

E Externally

TABLE 6 Remote Sensing Activities in Africa.

REMOTE SENSING ACTIVITIES IN SOUTH AND EAST ASIA AND THE NEAR EAST	Source of Information	Agency/Institutional Involvement						Identifiable Remote Sensing Programs/Projects							Facilities and Personnel Available							Education and Training			Activities of External Organizations Within the Country			
		Remote Sensing Infrastructure	Interest or Involvement Identified					Basic		Type of Basic Data					Basic Capability		Data Collection			Data Interpretation								
			Governmental Agencies	Military	Individual Scientists	Commercial/Private Sector	Academic Sector	Identified?	Cartographic	Aerial Photographic	Landsat	Other Spaceborne	Other Sensors	Automatic Data Processing	Photographic Reproduction	Cartographic Capability	Aircraft Capability	Sensor Capability	Data Collection Military Only	Manual Interpretation	Automatic Data Processing	Academic Programs Offered?	Users Agencies Conduct Training Programs	External Seminar/Workshop Participation	International Agencies	Bilateral Assistance	Commercial/Private Sector Activities	Notes
Bangladesh	●	1	●		●		●	●	●	●	●	●		●	●	●	●			7	●	■		●	●	●	●	
Burma		4			●		■	●	?	●					?	?					■	■		●	●	●		
India	●	1	●		●		●	●	●	●	●		●		●	●	●	C		●		●		●	●	●	●	
Indonesia	●	4	●	●	●	●	●		●	●	●				●							■		●	●		●	
Korea	●	3	●		●			●	●	●	●				●	●	●	C		7		■		●		●		
Malaysia	●	2	●		●				●	●	●	●			●	●	●	C		8		■		●				
Mekong Area	●	1	●				●		●	●	●			5	●	●				8	●	■	E	●	●	●	●	
Pakistan	●	2	●		●		●	●	●	●	●				●	●	●	C		8		■	E	●	●	●		
Philippines	●	1	●		●	●	●		●	●	●				●	●		C				■	E	●	●	●	●	
Sri Lanka	●	4	●						●	●	◉				●	●	●	C		7	●	■		●				
Taiwan (Rep. of China)	●	3	●		●			●	●	●					●	●	●					■		●				
Thailand	●	1	●	●	●		●	●	●	●	●		●	6	●	●	●	C,S	●	8	●	●	E	●	●	●		
Aden		4						●	■	●					■	■						■						
Iraq	●	2	●		●				●	●	●				●	●	●			7		■					●	
Iran	●	2	●		●	●	●	●	●	●	●	●	●	●	●	●	●			8	●	■		●			●	
Jordan	●	4							●	●	●				●	●						■						
Kuwait	●	4			●			●	●	●				5	●	■				●	5	■		●				
Lebanon	●	4			●				●	●					●	●	●			●		■		●				
Muscat	●	4						●	■	●	●				■	■						■					●	
Oman	●	4						●	■	●	●				■	■						■					●	
Saudi Arabia	●	3	●		●	●		●	●	●	●				●	■				●		■		●		●	●	
Turkey	●	3	●	●	●		●	●	●	●	◉				●	●	●	C	●	7		■		●	●	●	●	
Yemen	●	3	●						●	●	●				■	■						■			●	●	●	

REMOTE SENSING ACTIVITIES IN LATIN AMERICA	Source of Information	Agency/Institutional Involvement						Identifiable Remote Sensing Programs/Projects							Facilities and Personnel Available							Education and Training			Activities of External Organizations Within the Country			
		Remote Sensing Infrastructure	Interest or Involvement Identified					Basic		Type of Basic Data					Basic Capability		Data Collection			Data Interpretation								
			Governmental Agencies	Military	Individual Scientists	Commercial/Private Sector	Academic Sector	Identified?	Cartographic	Aerial Photographic	Landsat	Other Spaceborne	Other Sensors	Automatic Data Processing	Photographic Reproduction	Cartographic Capability	Aircraft Capability	Sensor Capability	Data Collection Military Only	Manual Interpretation	Automatic Data Processing	Academic Programs Offered?	Users Agencies Conduct Training Programs	External Seminar/Workshop Participation	International Agencies	Bilateral Assistance	Commercial/Private Sector Activities	Notes
Argentina		3	●	●	●		●	●	●	●	●	●		5	●	●	●	C,S	■	8	●		I,E	●		●		
Bolivia	●	1	●	●	●	■	●		●	●	●	●	●	●	●	●	●	C		●	●	●	●	●	●	●	●	
Brazil	●	1	●		●	●	●	■	●	●	●	●	●	●	●	●	●	●		8	●	●	I	●	●	●	●	
Chile		1	●	●	●	●	●	●	●	●	●	●	●		●	●	●	C		7		●	I	●		●	●	
Columbia		3	●	●		●	●	●	●	●	●		●	6	●	●	●	C,S	■	8		●	E	●	●	●	●	
Costa Rica		4	●		●			●							●									●	●	●		
Ecuador			●	●		●		●	●	●	●				●	●	●	C		8		■		●	●	●		
El Salvador		2	●					●	●	●	●	●			●	●	●	C	■	8		■			●	●		
Guatemala		2	●	●					●	●	●				●	●	●	C	■	8	●	■		●		●		
Honduras		3	●							●					●	●				7		■	■	●		●		
Jamaica		3	●				●		●	●					●	●			■	7		■	■	●		●		
Mexico		2	●	●	●	●	●	●	●	●	●	●		●	●	●	●	C,S	■	8	●		I	●		●	●	
Nicaragua		4	●							●		●			●					7		■		●	●			
Panama		2	●	●		●	●		●	●	●	●	●	6	●	●			■			●		●	●	●	●	
Paraguay		4	●	●					●		●	●			●	●			●	7		■	■		●	●	●	
Peru	●	1	●	●	●	■	●		◉	●	●	●	●	●	●	●	●	●		●	●	■	■	●		●	■	
Venezuela		3	●		●	●		●	●	●	●		●		●	●	●	C		8				●		●	●	

● Positive

■ Negative

◉ Proposed

1 National remote sensing committee or coordinating body established

2 No coordinating body established but lead-agency can be defined

3 Various official sources

4 No infrastructure

5 Internal capability in existence or developing

6 External capabilities

7 Visual only

8 Machine assisted

C Camera

S Scanner

O Other (radiometer, magnetometer, radar, etc.)

I Independent (internal staff and expertise)

E Externally

TABLE 8 Remote Sensing Activities in Latin American.

TABLES 6–8 compiled from information provided by the Environmental Research Institute of Michigan, Ann Arbor, Michigan; the Earth Satellite Corporation, Bethesda, Maryland; and the U.S. Geological Survey, Reston, Virginia.

Digitized by Google

Phase 3: Surveying and Monitoring by Digital Analysis (Scales 1:25,000 or smaller)

The use of LANDSAT multispectral data in digital form opens new possibilities through computer analysis and manipulation of data. LANDSAT scenes in digital form can be used for generating special purpose images for visual analysis, for delineating features of interest by computer-assisted recognition of spectral patterns, or for a broad range of statistical analyses including the generation of a quantitative data base for part or all of a country's land area. Use of digital data and computer techniques permits rapid and variable-scale (i.e., magnification) analysis of spectral patterns, quantitative comparison of spectral responses in data acquired at different times, and rapid analysis of spectral differences between targets that are too small to be detected by the human eye. These capabilities are useful in monitoring and quantifying both natural and man-caused changes in the environment, and, when the changes of interest are detectable from analysis of spectral signatures, computer techniques are often faster and cheaper than manual extraction of the same information.

The use of digital analysis provides a country a variety of options for overlaying LANDSAT multispectral data obtained over the same region on different dates. Data such as soils maps, topography maps, population density maps, and geology surveys may be digitized, adjusted to an appropriate scale and added to the data bank for overlay and correlation studies with LANDSAT data. Such overlays may be used to produce potential soil productivity maps, land use capability maps, and a wide range of correlation studies.

A few advanced developing countries are already engaged in quantitative analysis of LANDSAT multispectral data, and others are moving in this direction. But for most countries a domestic operation using these techniques will be delayed if not prevented by the requirements for highly trained personnel and the cost of specialized hardware and software.

Where internal means are lacking, developing countries have contracted with external firms both for desired products such as specially enhanced imagery, and services such as computer-assisted analysis and interpretation. Knowing what can be done by digital processing therefore is important; even when unable to do its own, a country will find it useful to have some specialists familiar with digital analysis who are able to commission needed services from abroad and to work effectively with foreign consultants.

Quantitative analysis by computers places a special premium on interdisciplinary work. The analysis of digital data requires the statistical manipulation of masses of data. Resource scientists thus need to work interactively with specialists in statistics, mathematics, and computer programming. The same digitized LANDSAT scene contains data of interest to several

resource disciplines. Analysis and interpretation of a particular feature may be achievable only by a chain of collaborative analysis involving specialists in a number of fields. A land use analysis, for instance, may require: a first study of a scene by a hydrologist to determine the drainage pattern; a second study by a geologist to determine the surficial materials and geology; a third study by a soils scientist who, on the basis of the first two, is able to prepare a soils map; a fourth study by a vegetation analyst interacting with the geologist, hydrologist, and soil scientist to determine the vegetation pattern; perhaps a fifth study by a physical planner interacting with the previous four, who must determine the optimum design for a transportation net or location of a new town; and, in culmination, a sixth study by a geographer who, working together with all the others, produces the land use analysis.

Meeting Organizational Needs

The more numerous and diversified the users of remote sensing are, the more economically feasible it is for a country to sustain a national analysis capability. Because of the technology's demand for interdisciplinary work, and the need to make the most of scarce specialized manpower and facilities, remote sensing generates incentives for new operational and organizational arrangements for the handling of resource data. At present, new units variously charged with planning, coordinating, and carrying out remote sensing activity can be identified in a score or more developing countries. The differences among them in structure, responsibilities, programs and services reflect a common search for an approach that will suit each country's long-term purposes. The policy approaches and project agendas adopted by a number of the more enterprising countries illustrate this diversity.

Units Within Individual Agencies or Ministries

Initiative for introducing remote sensing technology and designing a program for its use frequently comes from a government ministry or technical department concerned with a resource sector such as agriculture, hydrology, geology, etc. The ministry or department may dedicate its new capacities to the exclusive pursuit of its own mission or may acquire a coordinating function in drawing other units into the use of the technology. In some countries, remote sensing studies are being pursued separately in a number of ministries and institutions.

In *Argentina* the primary interest of the first LANDSAT investigation, carried out under the auspices of the country's space agency, has been to

test space sensing capability to determine acreage and condition of crops, especially wheat. The Ministry of Agriculture and Livestock has established a remote sensing operation with an associated data processing center capable of both manual and computer processing. Program plans include work in range management, agricultural land use census, and mapping of drainage networks. A second area of LANDSAT study addresses geologic and mineral survey. The departments of agriculture, forestry, and geology of the University of Buenos Aires conduct manual interpretation studies with LANDSAT imagery.

Existing Central Institutions

In certain countries, the remote sensing operation has taken root in diverse specialized institutions and government organizations—a space agency, a science academy, a research institute, or a university—that manifested an early interest. For some, an advisory or coordinating committee representing the user interests assures a link to ultimate data users in resource departments and elsewhere.

Brazil's highly advanced and well-equipped program is lodged in the National Institute of Space Research (INPE). It operates a ground station which records more than 350 LANDSAT images a day, provides data on agriculture and forestry to the Ministry of Agriculture, on geology to the Ministry of Mines and Energy, and on a broad range of subjects to the Ministry of the Interior, all of which contribute to the Institute's budget for these services. Other clients now include private firms and neighboring countries. The Institute has ties with educational institutions, and runs its own seminars, workshops, and courses on remote sensing.

Egypt's Remote Sensing Project is lodged in the Academy of Scientific Research and Technology, Cairo. The three research groups—for geology, agriculture, and physics—have connections with ministries of agriculture, irrigation, petroleum, industry and reconstruction, and with agencies concerned with environment, outer space, energy, and survey. LANDSAT imagery has been used in developing geological, land use, drainage, and structural lineation maps; studies of groundwater, soils, petroleum, and minerals, and civil engineering projects; and other applications on both sides of the Nile, in the Aswan Dam area, in the Ismailia master plan, in tunnel siting on the Suez Canal, and in the Western Desert, where it has led to the discovery of large gypsum deposits and iron ore occurrences.

In *Indonesia* remote sensing activity is centered in three national bodies: The National Aeronautics and Space Institute acquires LANDSAT products from the United States and distributes them to other central agencies. The National Institute for Mapping is developing a capability to produce 1:250,000 scale photomaps with the aid of LANDSAT imagery. It helps government departments prepare thematic maps, provides training in visual interpretation and works with user agencies to collect "ground truth"

data. The Institute for Indonesian Science is preparing a program of training activities with the cooperation of about 40 government and private organizations. An effort is underway to integrate LANDSAT data with the current National Inventory of Crops and Natural Resources. The Mining Institute has identified previously undetected geomorphic features in LANDSAT data and the geological survey is using LANDSAT imagery in its geologic mapping.

Pakistan's more modest sensing activity is also located in its space agency. Data products are offered to other interested agencies. Emphasis has been on studies of sedimentation and coastal processes of the Indus delta, coastline mapping, and surface water. Further studies underway or planned are to assist in development of the deltaic region, in assessment of crop condition, in identification of salinity and water-logging, and in survey of snow and of water resources. A new geologic map based on LANDSAT data has been prepared.

Peru's remote sensing activity is the joint responsibility of the long established National Office for the Evaluation of Natural Resources (ONERN) and the Geophysical Institute. LANDSAT imagery has been used to help classify and map jungle forests. Remote sensing holds special interest because of the inaccessibility of large parts of the country. With Canadian assistance, Peru is undertaking a detailed area resource survey using LANDSAT and aircraft data. Similar data will be used in a crop inventory experiment with the cooperation of the Food Ministry.

Tanzania's principal base for remote sensing work is the Bureau of Resource and Land Use Planning (BRALUP) at the University of Dar es Salaam. LANDSAT data combined with data from other sources are helping BRALUP researchers and foreign consultants to develop hydrologic and soils maps of the Arusha region.

In *Thailand* the National Research Council, through a National Coordinating Committee, is the focal point of remote sensing activities. Committee members include government administrators, scientists, and representatives of the ministries and agencies which utilize remote sensing data, in some cases in a quasi-operational manner. A LANDSAT derived forest inventory has already influenced national policy decisions; based on satellite data, a new structural geology map, important for mineral and hydrocarbon prospection; is nearing completion. Thailand is the only country with an AID-sponsored resident remote sensing advisor; it is actively preparing itself for wide use of remote sensing.

Coordinating Committee

National responsibility for remote sensing in some countries has been given to a special coordinating committee, usually a preliminary step taken to

accumulate sufficient knowledge and experience for the design and establishment of a national remote sensing program.

In the *Philippines* the existing National Committee on Mineral Exploration and Survey Operations has organized a coordinating body for remote sensing that includes representatives of the several bureaus of the Departments of Agriculture and National Resources, the Coast and Geodetic Survey, the Air Force and the University of the Philippines. The LANDSAT investigation has dealt with surface water, land use, cartography, and geology. LANDSAT imagery is anticipated to play an important role in mineral exploration and in geologic study of outlying areas. An intensive integrated resource assessment of a major island using LANDSAT and other data sources is being planned.

New Agency

A few countries have created new organizational units intended to serve as prime movers in a national remote sensing program and as national utility centers providing remote sensing products and services to governmental and nongovernmental users.

The ERTS-*Bolivia* program, an offshoot of the Geologic Service of Bolivia, enjoys special status since 1973 by Presidential decree as a central interdisciplinary unit. Financial support derives from the institutions it serves and the sale of its services. Its advisory council represents the various interested ministries, relevant public services, and the university. Technical staff members are drawn on secondment from various line agencies and thereby assure linkage with the user community. LANDSAT and aerial imagery have been used to develop the first physical map of Bolivia. Imagery has been applied to studies of geology, hydrology, soils, and volcanism. Plans are to complete a national inventory of natural resources. LANDSAT imagery has helped to identify what may be a major iron deposit. A beginning is being made with digital analysis of LANDSAT data.

India's National Remote Sensing Agency, a unit of the Department of Science and Technology, was established in Hyderabad in early 1975. Its objectives are to guide remote sensing research, provide services to user departments, conduct resource surveys, maintain data banks, organize training programs and publish research results in remote sensing from satellites, aircraft, and balloons. Remote sensing services are intended especially in agriculture, forestry, water, land use, geology and mapping. India's space agency plans to orbit an earth survey satellite with a return beam vidicon sensor in 1978.

Functional Desiderata of a Remote Sensing Service

For many reasons no organizational or operational formula for a national remote sensing effort can yet be said to have gained widespread favor. Re-

quirements for resource information and environmental monitoring vary greatly from country to country. What is technically desirable may not be politically feasible. An organizational structure or an operating procedure that might work well in one country or sectoral field might not work in another.

Despite differences among nations in information needs and in political/administrative constraints, experience would indicate that certain functional features and operating principles warrant consideration by a country proposing to undertake a remote sensing program. (Reference below to a "center" does not imply that a country program should be confined to a single entity.)

- *Concentration of scientific skills*: A remote sensing center should have a critical mass of scientific skills and trained people, well versed in the technical aspects of remote sensing technology, with a stable core staff giving the center continuity and growing capacity to serve the needs of the user community.
- *Interaction among people with diverse disciplinary training*: The richest data yield from remote sensing materials generally comes from analysis and interpretation conducted by people with expertise in different resource disciplines. Digital analysis requires in addition inputs by specialists in computer, mathematical, and statistical sciences.
- *Strong links with user agencies*: A center must forge and maintain close two-way links with user agencies. Center-user interaction should concern level of data flow, desirable data forms, and significance and priorities of data gathering. Secondment of user-agency personnel to the center can be an important stimulant to user-center interaction.
- *Ground truth studies*: A center should include capabilities (staff, instruments, access to air and land vehicles) for ground truth studies—a vital aspect of remote sensing data analysis. Ground truth work provides an important means of consolidating user-center links if both sides participate in it.
- *A "service" outlook*: A center should be primarily a service institution for a wide range of governmental and nongovernmental users. But to remain intellectually vital, and to assure the availability of properly indoctrinated personnel within the user community, a center should also play an important educational and training role and engage in research to extend the application boundaries of remote sensing data.
- *Flexibility in handling other data systems*: A center should be able to handle data and information from a variety of sources such as aircraft, ground platforms, and weather stations.
- *Archival function*: A center will need to play an important data storage and retrieval function, providing convenient access to remote sensing material and correlative data bearing on the country and region concerned. A center

should also be the principal repository of technical documentation relating to remote sensing.

- *Overview analysis*: Resource data user agencies, being primarily responsible for individual sectoral data analysis and decision making, ordinarily do not develop multisectoral issues or scales of view. A remote sensing center, in monitoring key environment variables, is well suited to acquire over time the capacity for a national or regional scale overview.

It needs to be emphasized, however, that access to a technology capable of greatly enlarging and accelerating the acquisition of resource data, and possession of a national apparatus capable of transforming them into information products, may be of little consequence in the absence of institutional structures geared for appropriate decision making and implementation. The more data collection gains in breadth and rapidity, especially with respect to changing environmental conditions, the faster the response time demanded of the user if data collected are to retain their value. To be actionable in the first instance, data must be tailored both in format and content to the user's operational requirements; but these, in turn, must be adapted to opportunities for more timely and presumably better decision making that the new technology makes possible. Thus, an interactive process between data user and data producer must be engaged and sustained to ensure not only that the product continues to meet the user's immediate needs, but that the user's perception of "need" and ability to act keep pace with the product's growing capacity to be of service to him.

Successfully achieved, this interaction may in the long run induce significant change in the way a country organizes its resource data collection and analysis system, and in the way it manages its resources.

Meeting Manpower Needs

For the present, the shortage of qualified manpower is the major factor limiting the developing countries' capacity to absorb remote sensing technology. The educational requirements a country typically must contend with cover a broad spectrum—from a brief but concentrated exposure of senior officials to the practical and policy aspects of the technology, to in-depth training of technicians and scientists who will be an important link in the chain of activity that extends from initial data processing to ultimate utilization.

If remote sensing technology is to be effectively transferred to the developing countries, a variety of educational opportunities must be made available. Some of these may indeed exist in one or another of the developing

countries. Other types are currently available only in a few specialized institutions in the world.

Educational programs for remote sensing technology may be divided into two broad categories: general information and in-depth training.

General Information

The educational objectives in this category are generally short term and are designed to introduce a basic understanding of the technology and its applications, and to bring practitioners experienced in other sensing and data collection techniques up to date on new developments. Activities at this level can be designed for specific groups (administrators, technicians, scientists) and can take the form of seminars, workshops, conferences, short courses, or travel/study programs. These can be conducted anywhere in the world; in the last two or three years such exercises have taken place in Brazil, Canada, Egypt, West Germany, Ghana, Indonesia, Mali, Thailand, the United Kingdom, and the United States, among other countries.

An important and often neglected group these early activities should reach is the country's political, managerial, and planning leadership. Informational and introductory training projects, which constitute the bulk of the effort thus far undertaken, have been oriented primarily to scientific and technical personnel and have generally failed to reach upwards into the developing nations' decision making levels. A balanced understanding of remote sensing technology, of its usefulness and limitations, by people with key policy, planning, and resource management responsibilities, is important if a country is to proceed with sound and orderly adoption of the technology.

In-Depth Training

The objective of in-depth training should be to provide scientists, engineers, and technicians with the essential scientific and technical background and skills necessary to process, analyze, interpret, and utilize remotely sensed data by visual and/or computer-assisted methods. A minimum educational requirement for training as a remote sensing technician is a high school or equivalent diploma. For someone who is to provide creative leadership in the field, university scientific training in a resource or other user discipline or in mathematics/statistics is desirable. Instruction can take the form of shorter term (3-12 months) nondegree programs, or longer term (1-4 years) graduate degree programs. Many scientists and technicians in developing countries have training and experience in certain conventional areas of remote sensing,

especially in aerial photointerpretation. A very limited number have experience in the quantitative analysis and interpretation of multispectral data. Resource scientists and managers, in particular, can benefit significantly from short-term nondegree programs in visual interpretation of satellite imagery and aerial photography. Agriculturalists, hydrologists, foresters, geologists, cartographers, and land use experts, among other specialist groups, all can profit from initiation in the use of this new tool to enable them to apply it to their individual fields of specialty, and especially to interact productively with remote sensing analysts and technicians.

For visual interpretation, there are numerous institutions in North America and Europe and a few in Asia, Africa, Latin America, and Australia offering a variety of programs. The International Institute for Aerial Survey and Earth Sciences (ITC) in the Netherlands, and the similar centers it helped to establish in Colombia, India, and Indonesia are especially active in this type of training. The Brazilian National Institute of Space Research (INPE) has received students from Latin America and other developing regions for remote sensing training. The Inter-American Geodetic Survey in Panama provides photointerpretation training for countries in Latin America.

Because quantitative analysis by computer methods requires close collaborative interaction among resource, computer science, and statistical specialists, nondegree training in this area is often most effective when taken by a group assembling this range of skills. Opportunities for computer based training, however, are still limited to a relatively few institutions in North America, such as EROS Data Center (USGS); Environmental Research Institute of Michigan; University of California, Berkeley; Colorado State University; University of Kansas; University of Michigan; the Laboratory for Applications in Remote Sensing, Purdue University; and the Remote Sensing Center, Texas A & M University. A small number of private corporations also have training programs.

A developing country opting for an extensive remote sensing applications program, with plans to utilize a large amount of satellite and/or aircraft multispectral data, must accept a commitment to an in-depth educational effort.

Essential to the development of such a program is university training. As use of remote sensing techniques advances beyond the elementary stages of resource inventory and small-scale cartography, to utilization by national and subnational agencies for decision making, depth of training and maturity of judgment become particularly important. Scientists, engineers, and decision makers with specialized, university level education must be available for technical direction and management of such programs. Resource agencies at this point will also find it to their interest to have a number of specialists on their staffs with advanced degrees in remote sensing subjects.

Many universities in North America, several in Europe, and a few in other parts of the world offer advanced degrees in which thesis research may provide training in, and applications of, visual interpretation of remotely sensed imagery. A limited number of universities in the United States provide Master's and Ph.D. degree programs in various aspects of quantitative remote sensing.

The continuous advances made in the techniques and instrumentation of data processing and analysis require practitioners to keep abreast of new developments. Various professional societies, academic institutions, and technical assistance agencies conduct workshops, seminars, and travel-study exercises in various parts of the world for this purpose; these exercises also provide a forum for the exchange of ideas and experiences among specialists from different countries.

Magnitude of Training Needs

For the benefit of the bilateral and multilateral aid and technical assistance agencies, the Committee thought it useful to form an estimate of aggregate trained manpower likely to be required by developing countries over the coming decade. The estimate was obtained by postulating the needs of a hypothetical medium-level developing country by discipline or area of specialized need (Table 9).

TABLE 9 Trained Manpower Requirements of a Hypothetical Developing Country.

	Number of persons to be trained each year			
	Visual Analysis		*Quantitative Methods*	
Discipline/ Specialization	*Nondegree**	*Degree***	*Nondegree**	*Degree***
Agriculture	4-5	½-1	2-3	½-1
Forestry	1-2	0-½	1-2	0-½
Geology, Mineralogy	3-4	½-1	1-2	0-½
Hydrology	2-3	0-½	1-2	0-½
Land Use	4-5	½-1	2-3	½-1
Survey, Cartography	4-5	½-1	2-3	0-½
Total for 1 year	18-24	2-5	9-15	1-4
Total for 10 years	180-240	20-50	90-150	10-40

*Nondegree training involves supplementary or specialized instruction in the applications of specific remote sensing techniques; in general, duration of training is 3-12 months.

**Degree training involves university courses and research which includes in-depth instruction and experience in the applications of remote sensing technology; 1-4 years.

With due allowance for the fact that countries vary in size, level of development, and the character of the resource base, a rough estimate of the aggregate training needs of 100 or so developing countries over the next decade would therefore be: *Nondegree training (3-12 months)* for 18,000 to 24,000 persons in visual interpretation, and for 9,000 to 15,000 in computer assisted quantitative analysis. *Degree programs (1-4 years)* for 2,000 to 5,000 persons in visual interpretation, and for 1,000 to 4,000 in quantitative analysis.

Given the pace of remote sensing technological development and the rising interest manifested by developing countries, the estimate rests on the assumption that by the mid 1980s most of them will have acquired at least a basic capability to serve their domestic needs, drawing on their own manpower and on personnel of regional and other external services that might become available. It deserves emphasizing that the vast majority of those projected to receive training will not be withdrawn or diverted from their professional occupations or commitments, but given a supplement of skills they can apply in their chosen fields. Indeed, for most future practitioners this supplement may well be obtained in the course of conventional technical and professional schooling, as curricula of resource and related disciplines incorporate remote sensing in their instructional programs, much as they earlier incorporated the nascent computer sciences.

It should also be noted that some countries will probably rely heavily on visual analysis, whereas others will employ computer-assisted quantitative techniques to survey and monitor their natural resources. Their choice of techniques will be greatly influenced by their objectives, and availability of human and material resources. Many countries will be able to accomplish a great deal, as experience has shown, with even a few competent people.

Nonetheless, the figures cited above represent a sizable claim on the world's training capacity in remote sensing. At present, this capacity falls short of the task and will be even less adequate should demand for training in remote sensing in the technologically advanced countries rise appreciably in the next few years, as is probable. Training orientation and capacity in instituitions of both industrialized and developing countries, therefore, will need to be adjusted and expanded in coming years. Bilateral and multilateral assistance agencies can play a useful role to this end, and it would be in their common interest to act in concert.

Current Possibilities for External Assistance

Nations requiring short-term advice and assistance with respect to remote sensing—in processing, analysis, and interpretation of imagery, or in mounting a national remote sensing program—can find a small but growing community of specialists whose services are available for hire. Most of these specialists

operate through commercial or not-for-profit consulting firms—thus far mainly American—which assemble a broad array of skills and are able to provide a wide range of services. Many of the commercial firms have acquired an extensive international clientele, and their representatives can be found in all parts of the world. University specialists associated with a number of academic research centers in remote sensing similarly engage in consulting, on their personal or institutional account. In applications relating to the geological sciences and mapping, the U.S. Geological Survey has extensive relationships with and provides assistance to counterpart organizations in developing countries, either on direct commission with countries concerned or with financing provided by the Agency for International Development.

The availability of expert consultants, recruitable on one basis or another, should be of some assistance in enabling countries as yet unequipped with remote sensing capabilities to contend with immediate needs, such as may arise, for instance, in dealing with more knowledgeable foreign firms negotiating access to their resources. The eventual spread of such consulting services to the developing world—e.g., the establishment in some places of indigenous firms, or, more probably, multilaterally supported regional service centers—should serve to lessen further the effects of imbalances in technical competence that are bound to exist, especially for countries not in position for some years to build up a significant remote sensing capability of their own.

Bilateral and multilateral organizations providing technical and economic development aid, of course, constitute another major channel of assistance. The World Bank, for instance, is making increasing use of remote sensing for the planning and supervision of development projects it sponsors, through which it has introduced the technology in a variety of applications to a growing number of developing countries. The United Nations Development Program, the Food and Agriculture Organization, World Meteorological Organization, UNESCO, the Outer Space Affairs Division of the UN Secretariat and several other UN units engage variously in project funding, technical services, or informational activities, all designed to transfer the technology to developing countries.

In addition to the Agency for International Development of the United States, development assistance agencies of Canada, France, the Netherlands, and West Germany, among others, also offer developing countries various types of aid related to remote sensing. However, most of these efforts have been on a modest scale, a reflection in part of the current paucity of qualified personnel in this field outside North America.

Meeting Equipment Needs

A major virtue of remote sensing technology is that use of its products is now accessible, in some degree, to virtually all developing countries. The

variety of data products–hardcopy prints, films, and magnetic tapes–makes possible a range of information extraction procedures, from simple to very complex, with equipment requirements that can be scaled to match. The timeliness, detail, and precision of the data extracted are not the same for all approaches, but even at the low end of the spectrum of technical options (photointerpretation of hardcopy print) they are sufficient to yield resource inventory and other information that can be of great value to a developing country.

The level of equipment investment a country needs to envisage bears close relation to the degree of technical flexibility and self-sufficiency it wishes to have or to attain.* These objectives, which should be a function of both its human and financial resources as well as its data collection needs, can be reached gradually, by modular additions to an initial capability. Not all parts of what constitutes the ground segment need press equally upon every country, even as an ultimate acquisition goal. The ground segment of the sensing system, it will be remembered, contains four subsystems: the reception subsystem (antenna and receivers); the data processing subsystem (equipment to correct, reformat, and record the data in distributable form); the data management subsystem (facilities for storage, cataloguing, reproduction, and dissemination of the data); and the data analysis subsystem (equipment for extracting information from the data in a form useful to ultimate users).

It is the data analysis subsystem that generally will be of immediate concern to a developing country, and in which it may wish to achieve early domestic capability. Interpretation of photographic products available from an existing distribution center offers the easiest and least costly start. Some countries possessing appropriate computer facilities may be in position to begin use of similarly available data in computer compatible tape (CCT) form.

The data management subsystem can be addressed in part at the national level, for with increasing involvement in remote sensing activity local storage, cataloguing, and related management procedures of space derived and correlative data will be necessary; management of space data will also need to be addressed at regional level by facilities serving a number of countries.

For the great majority of countries the data reception and data processing subsystems need not arise as a question either of national choice or of unilateral investment. For direct coverage of the earth from the present generation of LANDSAT sensors, fewer than a score of receiving stations with ancillary processing facilities will suffice; most of these stations could be

*For an objective and detailed description of the structure and operation of ground facilities–and of equipment options and their costs–the reader is referred to the report of the International Astronautical Federation, *Ground Systems for Receiving, Analyzing, and Disseminating Earth Resources Satellite Data.*[1]

established with explicit regional service functions and maintained by multilateral cooperation. (One possible pattern of reception stations is given in Figure 10.)

Regional Service Centers

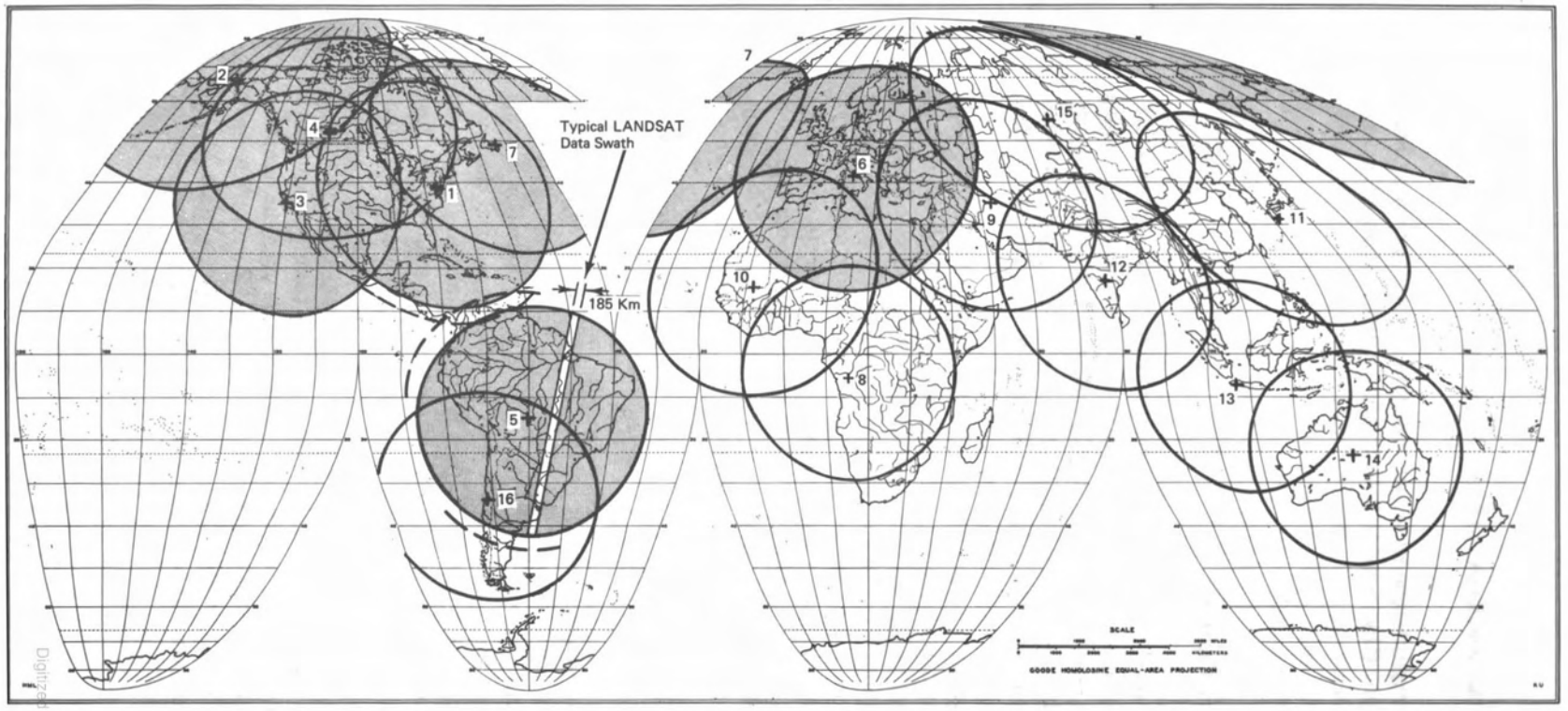
The main drawbacks to reliance on distant reception and processing facilities have been the uncertainty of data availability and the delay in obtaining the data that are available. With the global dispersal of reception-processing-distribution facilities, advances in processing equipment, and the possible future use of communication satellites for retransmission of data, these delays in the future should be greatly diminished.

The seven receiving stations currently in operation in the United States, Canada, Brazil, and Italy provide direct coverage for most of the Western Hemisphere, as well as Europe, North Africa, and parts of the Near East.

Additional stations are in varying stages of development. Iran has a station under construction, and Canada is opening a second facility to complete its national coverage. Zaire and Chile have concluded agreements with NASA and planning for station construction is now under way. Serious interest in establishing stations has been expressed by Argentina, Australia, India, Japan, New Zealand, Norway, Sweden, and Upper Volta (the latter on behalf of a group of African states). Should all these plans materialize, it will be possible to receive directly from LANDSAT (rather than by delayed transmission) data for most of the world's land surface (excluding parts of China and the Soviet Union).

The 28 million square kilometer coverage area of each reception station creates a de facto regional entity limited only by the overlapping coverage area of a neighboring station. Despite this, there is as yet no station in being whose management and financial base reflect its inherent regional character. The UN Economic Commission for Africa is currently planning an African remote sensing program which, if implemented, would result in the first combined data reception, processing, distribution, and training facilities that are truly regional in spirit and scope.

The advent in the decade of the 1980s of the LANDSAT D craft carrying the Thematic Mapper and possibly of other satellites contributing to earth resources and environmental sensing may impose changes upon the reception mode that now permits global direct coverage by means of a relatively small number of efficiently distributed receiving stations. One solution to the reception problem posed by a future diversity of data streams might be the



Satellite Orbital Altitude 914 Km
Minimum Antenna Elevation

0° — — — —
5° ———

LANDSAT Reception Stations

Station	Host Nation	Approximate Location		Station	Approximate Location	
		Longitude	Latitude		Longitude	Latitude
1	USA	77W	39N	9	53E	36N
2	USA	149W	64N	10	4W	16N
3	USA	117W	35N	11	131E	31N
4	Canada	106W	53N	12	78E	17N
5	Brazil	57W	15S	13	107E	6S
6	Italy	13E	42N	14	133E	23S
7	Canada	53W	49N	15	84E	56N

FIGURE 10 A trend toward LANDSAT worldwide data reception appears with seven existing stations and nine proposed or hypothetical additional stations. (Prepared by Milton M. Beilock)

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TDRSS data relay system,* which could funnel telemetry from several satellites into a single collection point in the United States. As noted earlier, present type reception stations installed abroad, with benefit of minor equipment adaptations, would continue to receive multispectral data directly from LANDSAT D and its successors if they carry the current type MSS sensor aboard the spacecraft.

As noted earlier, minor equipment adaptations would enable present reception stations located abroad to continue to receive MSS-type telemetry from the LANDSAT D spacecraft were this satellite to be equipped with both a first generation sensor and the Thematic Mapper, as has been strongly urged.

Direct reception of the vastly greater Thematic Mapper telemetry is likely to entail more substantial modifications in the ground equipment, or a higher level of initial investment than is indicated by the figures cited on pp. 114-115. The design of the sensor, of its downlink data communication subsystem, and of the necessary new groundbased reception and processing hardware is still at too early a stage to allow precise estimation of cost. However, NASA's R&D effort on the Thematic Mapper and associated systems has been oriented to assuring continued direct readout by ground stations around the world within cost and operational parameters not markedly different from the present ones.

Whatever the arrangements ultimately devised for data reception, the case for regionalized facilities for technical support and services in remote sensing is likely to retain its merits. Of these, economies of scale and efficient use of scarce resources are probably the most important, although side benefits in increased regional understanding of common resource and environmental problems and cooperation in their management should not be slighted.

Regional support facilities should include a range of processing facilities for correction and conversion of telemetry into usable data products, and a data storage and dissemination center for collection, cataloguing, storage, retrieval, reproduction and distribution of LANDSAT and correlative data (meteorological, cartographic, and other). The scale of operation and scope of functions may vary somewhat from area to area. Local requirements will differ with respect to speed of service, storage capacity, ease of access, frequency and volume of output, demand for standardized or customized products as well as for consultation aid in manual or computer-assisted analysis and interpretation.

A second set of capabilities that merit associating with the first in a regional facility relates to the provision of education and training to user personnel of participating countries, and extension-service technical assistance to individual country remote sensing units.

*See Chapter V, page 113.

Theoretically, these several parts of a regional operation need not all be sited together; the physical location of the LANDSAT data reception station in particular may be dictated more by geography than by convenience; for the rest, combining the parts into an integrated regional operation would make for efficiency and heighten the service and training potential of the regional staff.

Studies detailing the concept of regional remote sensing facilities have been published by the United Nations.[2,3] With commitment of multilateral support, the regional facility endowed with the several functions cited above could become a major instrument for easing the entry of developing countries into the use of remote sensing technology and meeting the needs for specialized manpower that all must contend with.

The Problem of Product Prices

It should be recognized that dispersal of reception and processing facilities, complemented by such ancillary services as countries may wish to add to them, will generate new financial burdens. These will pose problems that may be difficult to resolve.

The modest charges applied to remote sensing products sold by the EROS Data Center undoubtedly played an important part in the rapid growth and diffusion of demand in the first four years of LANDSAT. These charges, reflecting actual costs incurred for reproducing prints, films, and tapes, yielded an income that covered only a small part of the Center's operating expenses. American and foreign purchasers of EROS products were thus beneficiaries of a substantial U.S. subsidy. To obtain a higher measure of cost recovery the EROS Center raised its pricing schedule in January 1977. The large sales potential represented by the U.S. market alone—including federal, state, and private sector users—makes it unlikely that in the near term the EROS price structure will differ markedly from the current one.

A different situation would seem to await users of remote sensing products in developing countries. As they enter into service, local receiving and processing centers will take over responsibility for distribution of LANDSAT products within their respective areas. Foreign station agreements with NASA stipulate that they sell products at a "fair and reasonable charge" based on actual cost. But varying determinations as to what generally constitutes cost and the small-sized and slow growing markets to be found in the developing world may well result in "fair and reasonable" price schedules that sharply exceed those of the EROS Center (as the practice of one station has already shown). This will assuredly be so if national or regional operators attempt to

make stations pay their way. Yet short of a policy of cost recovery through sale of products, developing country station operators can expect to face deficits and therefore the need for a protracted period of subsidization to sustain their operations.

Reduction of potential markets as a consequence of overlapping (and competing) coverage from two closely spaced stations will of course exacerbate their problem. A further factor that will affect the financial viability of foreign stations is an annual "token" access fee that NASA has recently instituted to establish the principle of cost sharing. The initial annual charge, $200,000 per station, is to be levied irrespective of a station's actual or potential volume of business. NASA is studying alternative cost sharing arrangements for the future.

Benefit-Cost Assessment

In contemplating the investments that acquisition of national and regional remote sensing capabilities will require, developing countries will confront a question that in principle should attend the adoption of any new and important system. A decision to commit resources should be based, at least in part, on a careful weighing of costs and benefits. The complex and mutable character of space remote sensing, however, makes benefit-cost analysis particularly intractable for the purpose and ultimately not very meaningful.

Cost estimation can be a relatively straightforward (if not always reliable) procedure once the elements of cost have been defined in a benefit-cost equation. The objective of the analysis will determine the degree of their inclusiveness. Thus, two major benefit-cost studies recently completed in the United States included on the cost side all expenditures associated with the development and operation of the LANDSAT space and ground segments because they sought to assess the total value of the system as a national endeavor.[4,5] Similarly, a recent United Nations study presented comprehensive cost estimates for alternative options of an internationally owned total sensing system.[6] Other studies have estimated the anticipated capital and operating costs of regional reception and processing facilities, and of regional training and service facilities.

A growing literature describing completed projects that were based on remote sensing data provides figures comparing in each instance costs incurred using space derived data with prevailing costs using conventional data sources.[7] In this respect gain is simply the cost saving made possible by the substitution of one technique by another to get a certain job done. Such cost

effectiveness analysis is warranted in discrete tasks that allow the performance of alternative methods to be compared against a specific set of constraints and objectives. (Since the latter will differ from case to case, accumulated results in the literature cannot be expected to have more than a broad indicative value.)*

Benefit estimation in a more general sense, as would be occasioned for example by the prospective decision to create a national remote sensing user capability, presents problems of a wholly different order. If a remote sensing capability is to be viewed as an institutional resource, benefits must be placed in a relatively spacious time frame that would allow the "learning curve" effects to manifest themselves. Moreover, benefits must be assessed not only in terms of cost savings or improved performance that might be obtained over current conventional data gathering functions, but also in terms of new functions that remote sensing uniquely might make possible. Distinction in the benefits also will need to be made as to whether they are tangible and quantifiable (clear economic returns), or tangible but not quantifiable (improved decision making), or intangible (educational or scientific values).

It will be seen that the results of any given study will be typically very sensitive to the particular set of assumptions that is made, both with regard to the projected technical performance of the remote sensing service facility in question, and with regard to the management decisions consequent upon the use of the facility's output.

One must be very cautious in extrapolating from the results of studies of U.S. use of remote sensing to the potential net benefits such systems might produce in other parts of the world. In the first place, the organization of such major activities as agriculture, forestry, mineral exploration and extraction in the United States differs greatly from that of other nations. Second, wide differences exist in the information systems available to the individuals and organizations engaged in such activities in the United States and elsewhere.

One contrast between the major U.S. studies recently completed illustrates the difficulty of undertaking cost-benefit analyses in a field so dominated by uncertainties. The studies gave the appearance of coming to divergent conclusions; both were positive, but one study's findings were very conservative and the other's very expansive. A significant and apparent reason for the sharp difference was that in the case of one analysis the focus was on the estimation

*Under current financial arrangements, such cost-effectiveness calculations can be helpful to user countries even though they obviously leave out of consideration such items as satellite and sensor R&D, actual costs of satellites and launchings, maintenance of launch sites, and the operation of the satellites in orbit. Virtually all of these costs are currently met by the United States.

of potential net benefits. In contrast, the other study made an attempt to estimate net benefits that might actually be realized in the relatively near term.

In any application, the estimate of potential benefits can be a useful first step, because if they are large it suggests that the field is worth further investigation. Typically, in order to realize potential benefits, significant ancillary social and private investment may be required and, in some cases, an activity may have to be substantially restructured. The central point here is that remote sensing data as such are of no economic value. They take on value when they are translated into usable information that will actually affect the behavior of individuals and organizations so as, for example, to change the level of output, to reduce uncertainty, etc. (A related important point, especially in parts of the developing world, is the need to include in the analysis the implications for the distribution of income and other social gains.)

In the technologically advanced nations, there already exist information systems that "users" are familiar with and accustomed to integrating into their decisions and activities. To them, remote sensing data may often represent primarily a cost-reducing method for acquiring raw data, although it may be necessary to adapt the system and change certain institutional arrangements. Where users are already educated to the use of information in this general category, it is easier to predict that the data will, in fact, be used and the kind of net benefit (which may be in part or in whole simply a cost saving) that their availability may produce.

In contrast, in the developing world, especially in activities such as agricultural production, information systems are nonexistent or primitive, and potential users may be unfamiliar with how to integrate into their decision processes information of the sort that might become available through the use of remote sensing and ancillary technology. In this situation, the potential benefits may be even larger than they are in the case of developed societies, but the realization of this potential may require profound changes in practice, institutions, and behavior. This kind of major change may be years in the making, and may require substantial investments going far beyond the costs connected with a remote sensing activity.

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VII International Problems and Prospects

The technology of resource and environmental sensing from space, as noted in earlier sections of this report, has gained a momentum that appears destined to carry it to higher levels of proficiency and serviceability. At the same time, a growing number of countries, particularly in the developing world, are pressing to acquire the skills, equipment, and experience needed to apply satellite data to their resource management and development activities.

Yet these processes are not taking place in a political vacuum. The novel character of this space technology and the potential of its terrestrial impacts have forced up a series of difficult political, economic, and administrative questions to which the international community eventually must respond. For five years, the UN Committee on the Peaceful Uses of Outer Space and its Legal and its Scientific and Technical Subcommittees have been examining both the promise and the problems that resource sensing activities pose to the world. Matters such as control of data dissemination, sharing of costs, and the shaping of an international regime for the management and use of this technology are currently on the agenda.

However drawn to satellite sensing they may be for its value to development, a number of countries have been fearful that political and other costs may be hidden in its benefits. These concerns have not halted the development of the technology in its experimental phase nor hindered the growth of their interest in its advantages. But it is fair to assume that the pace at which the technology, in its broadest sense, will evolve and obtain acceptance in many parts of the world may be determined, to no small degree, by the way in which these issues will be addressed and resolved.

National Concerns

A singular ambivalence has marked the attitude of many nations to the subject. A few that have pushed vigorously to become competent in the use of remote sensing have also been most forward in voicing concerns about the

dangers the technology does, or might, pose for their interest—their sovereignty, security, and welfare. Although these concerns appear to have lessened after four years of widening exposure to LANDSAT data, they continue to animate the legal and political aspects of the United Nations debate.

Sovereignty Issues

Two legal issues involving remote sensing and the principle of national sovereignty have been discussed for several years in sessions of the UN Outer Space Committee and of its Legal Subcommittee.

One issue is whether a nation may engage in remote sensing of another nation without the latter's prior consent. In the early 1970s, Brazil and Argentina jointly proposed a draft treaty with a prior consent clause that gained support chiefly from several other Latin American countries. Most nations, however, either appear unconcerned about earth sensing satellites passing over their territory or feel that the issue, by now, is academic.

The second issue is whether one nation "sensing" another's resources has the right to transmit the data thus obtained to a third party (a public or private entity in the sensing country or outside) without the authorization of the country sensed. A prohibition against such dissemination without prior consent is contained in the Brazil-Argentina draft as well as in a joint France-USSR draft, and appears to have a wider base of support. This question has been the focal point of the UN debate.

At issue is whether a nation has exclusive jurisdiction not only over its actual resources but also over information about its resources. Some nations are led to argue for this proposition by virtue of domestic laws that define certain categories of resource information as privileged governmental matter. Others do so because they consider that imagery that portrays their natural resources and their physiography in fact purveys information of strategic interest. The concern is that outside parties might, in the words of the Brazilian draft treaty, "utilize the information thus obtained to the detriment" of the sensed nation.

Closely allied to the issue of sovereignty is the notion of invasion of national privacy. However much they acknowledge the benefits of the technology, some countries appear uneasy to have their privacy not only "invaded" from space by externally controlled sensors, but stripped away through unrestricted dissemination of the imagery.

Suggestions have been made for meeting these reservations pragmatically by means of either a "technical fix" or a "procedural fix." The technical solution envisages the development of a space-ground system that would confine the satellite's observations to within a country's frontiers and "dump" coded telemetry to each country individually and exclusively. The

procedural one would give a sensed nation priority access to data pertaining to itself before its general release after a preestablished lapse of time. Both solutions involve complexities that would seem to generate more problems than they solve.

The United States and other countries that advocate a policy of open dissemination assert that infringement of sovereignty and related issues are all moot points; they contend on practical grounds that open dissemination is the only policy possible if the technology is to be improved and employed for the greater benefit of all countries. To impose limitations on dissemination would be to forego two preeminent benefits of satellite sensing—the broad-area, synoptic view of natural characteristics and of environmental and resource factors that may be multinational in scope; and, for purposes of global monitoring (of crops, for instance), the timely availability of dynamic data important to the international community as a whole in matters requiring concerted action.

Fear of possible harm resulting from open dissemination should be weighed, in this view, against two factors: (1) the advantages accruing to countries from increased knowledge of the earth's environment and its resources; and (2) the fact that today nations have more effective means at their command to safeguard their interests than to impose restrictions on raw satellite-derived data.*

Economic Concerns

Behind the legal disputations over sovereignty lies a fear among some developing countries that remote sensing technology might confer advantage less to themselves than to other parties—their neighbors, other industrialized countries, and multinational firms, especially the oil- and mineral-extraction companies and agricultural commodity traders. Some of these outside parties are viewed as better equipped than the sensed country to make satellite imagery yield useful information and, therefore, to emerge in a superior bargaining position when negotiating for rights to some exploitable resource.

This assumption may be questioned on several grounds: First, developing countries are entering into mature, mutually beneficial resource exploitation relationships with foreign interests, without forswearing their rights to such

*The argument for restriction of data dissemination had greater strength when the data was received by, and disseminated from, a single point, as was the case with the EROS Data Center in LANDSAT's initial years. The spread of receiving stations (some providing overlapping coverage) and data distribution centers to various parts of the world changes the situation markedly. For instance, a station-owning country, with access to the data pertaining to all the client-countries in its area of coverage, becomes itself a third party and is cast along with the satellite owner as a "sensing" country.

ultimate sanctions as nationalization or expropriation. Second, physical control of resources and of access to resource sites are the trump cards, not possession of tentative and unverified data. Third, as developing countries acquire their own remote sensing expertise, whether indigenous or procured from outside consultants, the margin of information disadvantage can lose a good measure of its significance.

These defenses the developing countries may have with respect to extractive industries do not apply to the field of agriculture. The impact a possible future system of regional or global crop yield forecasting may have on the behavior of agricultural commodity markets and on national economies heavily committed to agricultural imports or exports is not yet clear and is now under study in several research centers.

Security Concerns

Fear that unrestricted dissemination of space imagery might endanger national security is less openly articulated; nevertheless it is a factor for a number of countries. Covetousness, irredentism, disputed border claims, and historical rivalry with neighbors make some nations uneasy about the ready availability of imagery they suspect might be of political or military significance to unfriendly nations close to home.* Restrictions placed by many countries on the public availability of medium- and large-scale maps of border regions and other sensitive areas are a good illustration of this concern. Such restrictions have, on occasion, been a severe handicap to ground truth observation undertaken to verify space observations for an internationally financed development project. Even conventional maps have sometimes been withheld under security classification, despite the fact that they show less detail than publicly available satellite imagery.

LANDSAT experience thus far indicates that imagery of 80-meter resolution, even under considerable enhancement, reveals few cultural features, and then only of the grossest kind: linear features such as roads, runways, and urban street grids. The 40-meter resolution expected from the LANDSAT C Return Beam Vidicon sensor and the 30-meter resolution contemplated for the Thematic Mapper should provide improved resource data and better definition of cultural features. Judging from recent discussions in UN bodies concerned with remote sensing, these resolution levels appear to be broadly acceptable. SKYLAB photography of various parts of the world at even high-

*The United States and the Soviet Union monitor each other by means of satellites capable of very high resolution imagery. Their mutual use of so-called "national technical means of verification," as provided for in the Arms Limitation Agreements, has gained international acceptance as a crucial element in the prevention of nuclear war and has not emerged as a source of concern to other nations.

er resolution—about 17 meters—has been publicly available and is in general circulation.

Higher resolutions—to the 10-meter level and better—have been recommended for certain specific remote sensing applications in the United States.[1] According to a recent UN experts' report, "Present opinion in the user community suggests that 10-meter spatial resolution would be adequate for most applications. The current 80 m resolution of LANDSAT is acceptable to some data users and more would be satisfied with a somewhat better resolution, perhaps 30 m."[2]

Multispectral sensing at the 10-meter level on a global basis would result in such a tremendous increase in data rate and volume that the data management would become impractical. A 10-meter resolution system could be workable, however, on a selective spot-imaging basis. Such an approach would have to prove its cost-effectiveness advantage over airborne sensing, which has the added virtue of operating within a nation's airspace and of being subject, legally and technically, to its control.

For nations troubled by the public availability of imagery of present or anticipated resolution levels, the problem of satellite imagery ultimately reduces itself to this: whether to sustain security inspired cartographic restrictions, or to satisfy the needs of resource managers and planners for resource and environmental information essential to a nation's economic progress. The security concerns, however, could adversely affect the chances of arriving at a generally acceptable international arrangement for the management of a remote sensing system. If such concerns persist, they will have to be taken into account in any consideration of possible future proposals to move to the higher levels of spatial resolution.

Dependence and Accountability

The international discussion of remote sensing has revealed two other issues that, contrary perhaps to the ones examined above, are likely to acquire more force and urgency with time.

The first is the matter of the willingness of countries to depend on the goodwill and steadfastness of a single-country supplier of a critical service. Should remote sensing technology ultimately fulfill its promise, it will become indispensable for many countries. User nations will have made significant investments in facilities of various kinds. They will have geared their data gathering and decision making processes, both in the public and private sectors, to the peculiar characteristics and assured availability of satellite imagery. Their interest in the stability and continuity of the service—on which their domestic systems will have come to rely—will consequently be considerable.

For political as well as practical reasons, there is some question whether user nations would be willing to remain indefinitely at the mercy of a service, vital to themselves, controlled by a single country. Growing dependence can be expected to lead to growing demand for participation in the management and future of the global service. If participation were denied, it would stimulate entry of competing systems under other auspices, which, to the extent they are redundant, would be wasteful of resources.

The second issue concerns the accountability that the technologically proficient nation operating in the international "commons" should acknowledge to the international community. In the past decade or two, extensive activities by many nations in two common domains of humanity—the oceans and space—have prompted measures designed to safeguard the interests of all countries in their use, and to impose on nations operating in those realms a measure of responsiveness to other members of the community. The capability to engage in remote sensing—to use the space "commons" as a means of gathering data about the earth's cover—is to avail oneself of a public good, whether for individual or collective benefit. The emerging view is that this should entail a corresponding obligation to account to, and to heed the wishes of, a body that reflects the interests of the larger community.

In sum, a number of elements—as venerable as sovereignty and as novel as a space-based global utility—combine to create a climate favoring the establishment of an international framework within which the international issues raised by this new technology can be rationally dealt with.

The Trend Toward Internationalization

Although dominated from the beginning by the United States and the Soviet Union, the space enterprise has become international in scope. Communications satellites already operate under formal multilateral arrangements, and the data of meteorological satellites are internationally shared. Many cooperative schemes exist for launchings of experimental packages for scientific research. All space operations are subject to the UN Outer Space Treaty, whose first article declares that the exploration and use of outer space "shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind."

The United States is alone, thus far, in orbiting an experimental satellite dedicated to sensing of earth resources and making the collected data available to all nations. But the international outreach of this activity is already strong: more than 50 countries have cooperated in remote sensing experi-

ments; 120 countries have acquired imagery or tapes from the EROS Data Center in Sioux Falls, South Dakota; 3 countries other than the United States have receiving stations in operation; and several others will have such stations soon. The United Nations committees are actively examining various options for a future international regime of governance or operation of remote sensing systems. Several special characteristics of remote sensing point to the need for serious consideration of the idea of remote sensing systems managed on an internationally agreed basis.

The Dictates of the Technology

Resource survey satellites are a prime example of space technology oriented entirely to earth applications. Forty times a year LANDSAT satellites pass over every acre of every country in the world with the capacity to limn each nation's surface features and to observe the changes made in its landscape by both the inhabitants and the natural elements. By its very nature space resource sensing is a technology that "involves" every nation. And virtually every nation is hoping to share in its benefits.

The potential capability of a single space system to meet a significant portion of the world's resource data needs, the variety of critical uses to which its products may be put, the dependency that many countries may build on it—all these give a space resource system (whether composed of one or more spacecraft) the character of an international utility. Such a function dictates some form of international cooperation or framework for the economically efficient and politically acceptable management of a resource sensing system.

Global and Regional Needs

In the first years of experimental use of remote sensing products, attention was directed primarily to applications within individual countries. But indications are that LANDSAT data and data from its successor satellites will be of increasing value for certain transnational problems of interest to regional groups of nations and to the world community generally.

LANDSAT multispectral data show promise of providing needed information on water levels of the reservoirs of river systems embracing several countries, whose protection may demand concerted action by all. In geology large structural patterns frequently cannot be resolved when viewed on a country-by-country basis. LANDSAT data have added to the understanding of the earth-ravaging desertification process in the African Sahel and have given warning of locust breeding conditions in Africa that were liable to endanger crops on the Arabian peninsula.[3] The present technology has also demonstrated a capacity to detect pollution in international lakes and rivers and has

pinpointed oil slicks in the open sea. In combination with data from meteorological and other satellites, it is likely to have more to offer to global environmental policing in the future.

Of greater significance yet, in this era of new perceptions regarding global resource limits and shortages, is the anticipated capability of a satellite system to provide worldwide data on crop prospects (still to be proven); regional water availability; regional forest, rangeland, and desert conditions; and likely areas for mineral exploration. These are of vital concern to entire regions and, in some cases such as food, to the entire world. To put into effect the proposal of the 1974 World Food Conference for a coordinated system of food reserves will require frequent and reliable global estimates of food crop yields. Earth resource data, along with global meteorological information, are counted upon to make a critical contribution toward this goal.

With their globally uniform view of the world's surface, earth survey satellites open the way for standard data formats for world inventories of various renewable resources—timber, forage, and, it is hoped, agricultural crops. Such inventories, quickly made and frequently updated, should give the world community a powerful new tool for more rational management of the biosphere.

Responsiveness to National Concerns

Some of the fears and suspicions evoked among nations by remote sensing are associated with the unilateral character of the current management and control of the system.

At present, basic decisions pertaining to the sensing requirements to be met (and technical implications with respect to sensors, channels, orbits, sun angle), the principles guiding the distribution of the data, and most other matters related to remote sensing are all made by the United States. In the absence of any alternative system, the U.S. Government's decision alone will determine the continued availability of future space data. Potential users of satellite data, therefore, may hesitate to alter their methods of data collection and decision making. They may also be reluctant to invest in analytical systems based on this technology until assured of the continuity of the program (to which the United States is not yet formally committed). As other studies have shown, uncertainty about the future of the system is as inhibiting to potential users in the United States as it is to those elsewhere.[4]

An operational system of remote sensing under some international arrangement could help to dispel many of the national fears. It would remove the issue of program continuity from the domestic political or budgetary hazards of a single country. It would, moreover, open the way for broad participation in decision making and reduce the sense of global dependence on the self-

interest and goodwill of a major space power. The degree to which these ends can be met will depend to some extent on the form that a future international regime will take.

Moves Toward Internationalization

From the inception of the earth resources program, the U.S. Government has been alert to international implications of remote sensing. In addition to reporting about its work to the United Nations and participating in the UN discussions on remote sensing, the United States, through NASA, has begun a modest consultative process with representatives of foreign-owned receiving stations by means of a LANDSAT Ground Station Operations Working Group. The United States has also offered to deposit a tape copy of all resource satellite data with an appropriate international facility, has advocated the concept of ground stations abroad serving a regional function, and has offered for discussion a number of guidelines for the international conduct of remote sensing when the system shifts from the experimental to an operational mode.

Though the United States has not yet formally committed itself to an operational (i.e., permanent) resource sensing system, growing appreciation of the satellite data's value among U.S. domestic users makes it unlikely that this country will halt its program. Even in the remote event that this should occur, however, other powers having space capabilities (e.g., the USSR or Japan), groups of countries (European Space Agency), or other consortia would have an incentive to orbit resource sensing satellites of their own, or to commission a working system from the United States.

The United States may find it to its interest to move beyond the initiative it has already taken to seek broader participation in its efforts. The operational advantages of unilateral decision making in the development and management of a technological system are obvious, but there may be appreciable benefits in arrangements that allow other nations to play a genuine role. An international regime could provide a mechanism for sharing the costs of developing and operating the space segment, costs hitherto borne entirely by the United States. Similarly costs could be shared for ground segment investments, which so far have been made by individual countries. Moreover, in the event that individual countries or groups wish to make their own entry with a satellite in space, an international regime could help discourage wasteful duplication. It could also assure coordination of initiatives so that new satellites and sensors complement existing ones and are compatible with the network of ground stations in place.

The stake of the United States in broader participation lies mainly in its interest in encouraging international cooperation to deal effectively with the

worldwide, interdependent problems of resources, environment, food, population, and human welfare. A cooperative international regime for resource sensing from space could make a major contribution, both substantive and symbolic, to that objective.

Possible International Arrangements

It is useful to consider separately the possible international arrangements for the space segment and the ground segment of a remote sensing system since they differ markedly. The prospects for early movement toward multilateral arrangements for the ground segment appear considerably better than for control and management of the satellites.

Ground Segment

An international arrangement covering the ground receiving segment of a resource sensing system can range from a loose network of national or regional receiving stations to centralized ownership and direction of a global network under international auspices. Five possibilities are examined below:

1 National Stations The existing pattern of relationships is based on bilateral agreements between the United States and countries that wish to establish national receiving stations. The United States has followed a longstanding policy, employed in other space related ventures, of entering into cooperative arrangements based on mutual interests and the ability of the collaborating nation to bear the costs of its own part of the activity. Location of station sites has thus been determined essentially by the initiative and volunteered commitment of individual countries. The ease of dealing with individual nations on a bilateral basis has caused the United States to follow this route in the hope that a sufficient number in different regions would come forward to hasten the development of worldwide capacity for direct data reception.

Dependent on such national initiatives, NASA has not attempted to lay out an ideal global design for the locations of data reception stations. In the best of circumstances, it has been estimated that fewer than 20 stations properly located (each with a 3,000 kilometer radius) would suffice to assure direct coverage. Political and other considerations, including possible indisposition of a station-owning country to service a neighbor it considers hostile, may eventually lead to more stations being constructed. However, proliferation of receiving stations (as occurred with INTELSAT) is neither operationally necessary nor economically desirable.

The U.S. agreements require station-owning countries to supply data products to other countries in their sphere of coverage, in effect performing locally the distribution function heretofore assumed solely by the EROS Data

Center. Unless it passes to its domestic and foreign clients the full costs involved in the production of data products, the station-owning country is bound to be faced with the burden of subsidizing the service for its domestic and foreign users. Countries undertaking commitments for a national station need to give careful consideration to long-term operating costs, which may be substantial, and the prospects of cost recovery, which initially may be limited.

Another problem with ownership of stations by individual countries is that each host nation is left to determine the type and capacity of the ancillary data processing equipment it acquires without necessarily considering the user requirements (in volume and servicing speed) of countries within its coverage.

A policy of organizing satellite reception through individual country agreements may therefore result in a heterogeneous pattern of locations, service performance, and relationships that is not the most advantageous for a future system offering complete and efficient global coverage.

2 Regional Stations Regional stations have advantages beyond the mere avoidance of wasteful duplication that might come from multiple stations with overlapping coverage. If several countries in a region set up a station cooperatively, they can share its costs and strengthen its financial position. They also can have a voice in deciding the extent of processing, storage, analytical, training and technical assistance services they will want to attach to the station to serve their common needs. The very act of working together to organize and manage a cooperative receiving station could have the added value of introducing or reinforcing patterns of cooperation on regional problems, especially the resource and environmental problems that the earth resource satellites are intended to address. A regional arrangement may make it easier, in some cases, to assure service to a state that is politically at odds with others in the area. (A nation denied local service could still have its data supplied by other stations from tape recorder readout, if available, or direct transmission via the proposed TDRSS.)

The United States has indicated its willingness to enter into agreement with regional units for regional stations. The first regional operation that could come into being may be that proposed by the European Space Agency. This arrangement would include the existing receiving station in Italy, a planned station in Sweden, and a proposed back-up station in Belgium. The UN Economic Commission for Africa is also considering establishing a regional receiving station in Upper Volta, converting the planned national Zaire station into a regional facility, and setting up regional processing and training facilities elsewhere.

Should current expectations and feasibility studies materialize into functioning stations, NASA will be coordinating a mixed set of true regional stations and national stations variously serving regional needs. If the components of such a network display a lack of uniformity in commitment and policies

and a concomitant lack of support facilities and services, the network may fall short of what may be expected of a global public utility type operation.

3 Coordination Through Specialized Agency Better coordination of receiving stations and ancillary services, and the provision of various forms of multilaterally funded assistance, could be effected through an international body specially mandated for the purpose. This could come about as a cooperative venture on the initiative of the regional and national centers, lodged within or outside the UN system; it could also originate within the UN system and assume the form of a new UN affiliated agency, or as an added function to, or subsidiary of, an existing UN agency with significant remote sensing interests.

United Nations studies exploring the concept of such a coordinating and service agency have identified a variety of functions it could perform: to serve as a world data depository and dissemination center, to help standarize formats and indexing systems, to set procedures for disseminating data, to provide technical assistance, and to serve as a forum for discussion of technical, financial, and legal problems.[5]

The International Atomic Energy Agency (IAEA) in Vienna, Austria, may be a useful model for a cooperative body established to advance the use of a single and novel technology with enormous potential impact and to promote international consultation on codes and practices related to this technology. The IAEA, a UN affiliated unit, has a dual mandate: to assist member countries in gaining the benefits of nuclear power and of other nuclear applications, and to guard against the diversion of nuclear materials for potentially nonpeaceful purposes. Only the first mandate is relevant to our discussion.

The Agency conducts a broad program of nuclear related research, training, scientific exchange, technical assistance and pilot projects in such fields as agriculture, medicine, industry, and mining.[6] Many of its projects are conducted in developing countries and in cooperation with the UN Development Program and the Food and Agriculture Organization.

An international body designed to promote space resource sensing applications need not have its own satellite and ground reception facilities. Like the IAEA, it could concentrate on programs to help its member states (especially those in the developing world) take best advantage of the technology, directly and/or through a network of regional data processing, training, and service facilities; it could also coordinate the service policies and activities of the ground receiving stations.

Whether organized within or outside the UN system, an international entity performing some or all of the functions described above could be compatible with continuation of a U.S. owned and managed space segment.

4 An International Unitary System A network of regional stations and distribution centers could be owned and managed by a UN functional body, or by an independent consortium of sponsoring nations. The manager could also own and manage the space segment and operate the two segments as a fully integrated global system for resource sensing. In principle, this arrangement could offer, among other advantages, lowest cost worldwide coverage through the most rational dispersion of receiving stations, an international technical staff to operate the space and ground segments, and a subscription capitalization and cost-sharing formula reflecting the relative economic standing of member countries (judged by their Gross National Product, as one option), their need for service, or other accepted criteria.

At first glance this approach appears to be made for efficiency, uniformity, and flexibility of operation. But a single agency that owns the core hardware of the space and ground segments and that is operated by a central management under international direction may invite too many problems under one roof to assure functional viability. Moreover, the heavy initial capitalization and the necessarily complex financial management entailed by such a scheme would alone serve to make it a distant candidate—but in the long run not an impossible one.

5 Global Single-Point Reception The advent of a data relay satellite system, offering single point readout of global sensing, such as the proposed TDRSS, might provide a radical alternative to a network of ground stations. Current and potential operators of ground stations would have to determine whether to rely exclusively on the single point data reception in the United States, with retransmission of data abroad by various means, or to maintain a capability for direct local reception. In either case, the useful functions envisaged for the regional centers with respect to processing, analysis, distribution and training would still need to be carried on. Thus, the possible multilateral arrangements presented in the preceding alternatives remain pertinent. The likely impact of a TDRSS on national and regional receiving stations deserves careful study.*

Space Segment

Possibilities for ownership and management of the space segment of a resource sensing system also allow for diversity of choices. These range from an indefinite continuation of the current situation, characterized by wholly U.S. owned and operated experimental satellites, to a permanent operational

*See comments by Professor Rathjens, page 191.

system managed by an international agency. Numerous alternatives exist in between.

Consideration of arrangements for the space segment must take into account that the United States is engaged (as described in Chapter V) in a long-term R&D effort designed to produce a technology for resource and environmental sensing suited to meet U.S. as well as global needs. The technology development effort includes a diverse array of sensors with individual and specialized functions that may be placed on a variety of platforms ranging from ground level to geosynchronous orbit. The availability of useful data from these various sources would greatly enlarge the scope of applications of earth sensing technology. NASA's present R&D schedule for resource sensing has a time horizon stretching into the 1980s. The Thematic Mapper space and ground systems alone, with their more sophisticated data products, may require several years to prove themselves and to gain wide operational use.

In due time, however, the United States and the world community will have to face the question of what kind of an international framework they should devise for an earth resource sensing system. The four models described and commented upon here present a set of alternative paths that may be labelled for convenience: unilateral, multilateral, multinational, and international. Intended to stimulate reflection, they should not be construed as exhausting the range of possibilities.

1 Unilateral—U.S. National System The present scheme of a U.S. national earth resources satellite system, with initiative and operational responsibility residing exclusively in the United States, could be formalized and extended indefinitely. U.S. control and direction would address the service needs of public and private users in the United States in the first instance, and probably would be compatible with continued servicing of ground receiving stations abroad. The international sanction could be provided by a treaty or resolution that would set forth guidelines of the type being discussed by the Legal Subcommittee of the UN Outer Space Committee. This, of course, assumes that agreement is achieved on its terms in general and on the issue of data dissemination in particular. By subscribing formally to such an international legal instrument and reporting periodically to the United Nations, the United States could be said to satisfy the principle of international accountability. Coordination of interested parties could be effected through the LANDSAT Ground Station Operations Working Group, with the participation of station owners and perhaps major users, which could acquire an increasingly important but informal consultative character.

The viability of this arrangement would depend largely on the attitudes of the service dependent nations. Conceivably, with the passage of time, they might come to accept the United States as the sole source of LANDSAT-type

resource imagery. Fears and concerns noted earlier might fade as nations and users abroad accumulate experience with the technology and gain confidence in the capability of a service focused primarily on U.S. domestic needs to meet their requirements without prejudice. So long as the United States is willing to bear the development costs and a good portion of the operational costs, acceptance of a single source might also come by default. The high cost of a duplicate rival space system, which is not easily recovered, might effectively deter the entry of a competing service.

But it is also conceivable that world reaction might be quite different. U.S. adherence to internationally agreed guidelines or treaty provisions notwithstanding, other countries might find it unacceptable to rely totally on a single country for an essential service, and might press for a more participatory arrangement.

A U.S. refusal to accede to a legal instrument or to institutional arrangements desired by a majority in the United Nations because of terms unacceptable to it could produce a climate of confrontation. The consequences of a United States "go it alone" policy would be inimical to the larger interests the United States wishes to pursue in the world community—such as a cooperative global approach to global problems—and in the use of the space "commons." Other nations, alone or in consortia, might be led to determine that a situation of total dependence on a refractory United States was sufficiently intolerable to force investment in a parallel and redundant space system. Such an outcome would be undesirable on several counts: it would be wasteful of resources, as noted earlier; it is also likely to engender a conflict in data dissemination policies and practices; and it would reduce the opportunity of complementary space initiatives among cooperating space-capable powers.*

2 Multilateral—Consortium A consortium could be formed by any number of countries that want to join in a plan to direct the space segment of a sensing system on a cooperative basis. The consortium could own or lease its satellites or contract with one or more countries for the development, launch, and operational management of satellites on its behalf. The consortium could start out as a venture that draws principally on industrially advanced and

*This discussion is predicated on the assumption that the very nature of earth resource sensing demands that the operation of the space segment be a public sector or governmentally controlled activity. It is fair to assume that international fears and concerns with respect to the issues of equity, sovereignty, and security would be intensified were the sensing function performed as a private, profit-making venture. On the other hand, it is possible that, with respect to the treatment of data products, including processing, analysis, and distribution, some countries might wish to call on the services of private firms.

other wealthy nations willing to invest in an enterprise that would provide a service to the world. It could also allow for some form of initial participation by noninvesting nations that are significant consumers of sensing products. A model that most nearly illustrates this scheme is INTELSAT, the international consortium that operates the long distance commercial communications satellite system.

The conditions under which INTELSAT operates and those that would obtain in the operation of a consortium for resource sensing satellites differ in certain respects. First, each of INTELSAT's founding countries had a well-established domestic communications service and an existing pattern of service demand and toll charges for international circuits. Resource sensing activity, by contrast, does not have an established consumer market, nor is the demand potential for remote sensing products subject to estimation at present. Second, the consortium of public and private telecommunications companies was reasonably assured that INTELSAT would be a profitable enterprise; a resource satellite consortium may not have this prospect, for reasons discussed below.

However, a consortium arrangement may still be a useful and financially flexible framework for satellite sensing, even in the absence of an established market and assured profitability, if the investing nations are prepared to share the capital and operating costs of the system. Certain aspects of the INTELSAT experience may have special relevance for remote sensing. INTELSAT began life by contracting with its U.S. member, COMSAT (a government-chartered private corporation), to manage the U.S. developed communications system on its behalf. Similarly, a resource sensing consortium could contract with one or more space-capable nations to develop and manage a collectively owned system and to provide services to the consortium.

Established outside the UN system by the voluntary participation of individual countries, INTELSAT is directed by a board whose members' votes are weighted according to traffic load forecasts. While the board has had vigorous disagreements on technical and other policies, it has not suffered so much from politicization as have some UN bodies.

INTELSAT's brief history is distinguished by a phased approach to internationalization. The organization grew out of an ad hoc international committee of 20 user nations and reached its present membership of 91 countries. As the organization expanded and country traffic percentages changed, the status of the U.S. participant, COMSAT, was transformed: from being the majority partner it became the biggest minority partner. Its initial role of total management was reduced to that of contractor for technical and operational management services.

When INTELSAT began, there was no experience in other countries in the construction and operation of communications satellites, and U.S. dominance

during INTELSAT's infancy and maturation was useful in enabling the United States to perfect the technology and to provide strong operational direction. However, this position inspired resentment among member nations, and it was significantly altered when the first agreement was renegotiated into a definitive convention. The consortium approach, if adopted for a resource sensing system, could benefit from a similar two-stage development. However, the conditions for the phase out of single nation dominance could well be formally provided for in the original agreement.

3 Multinational—World Weather Watch Type The United States may not long remain the sole nation engaged in resource sensing from space if interest displayed by several other countries leads them to orbit satellites of their own. The interest of the European Space Agency in a satellite equipped with an all-weather active microwave sensor has already been noted. The Soviet Union, Japan, the Netherlands, and India, among other countries, also might develop satellites with capabilities for resource sensing and environmental monitoring.

Several countries individually owning and operating resource sensing satellites and producing complementary and mutally reinforcing data might find it agreeable to adopt a multinational management formula patterned on the World Weather Watch (WWW). The WWW, proposed by the United States in 1961 to the United Nations, and functioning now under the coordinating auspices of the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU), provides weather data for the entire globe. Several aspects of the WWW scheme appear relevant to a potential resource sensing system:

- *A service to the world.* In addition to the United States and the USSR, which have geosynchronous weather satellites in operation, Japan and the European Community are preparing to make their own contributions to the space segment of the WWW system, with the commitment to exchange weather information among themselves and to make it available to all other countries. By 1978 all four satellite-owning parties will have launched and will be operating geosynchronous meteorological satellites similar to the US SMS type already in fixed orbit. This arrangement continues the long tradition of information exchange in the meteorological field. It also recognizes that the inherently global nature of weather systems mandates information sharing and cooperation on the widest basis. This collaboration of powers that have space capabilities and the free contribution to the world of the fruits of their technology provide an instructive precedent for resource sensing.

• *Data centers network*. The WWW global ground data system rests on a network of some 8,000 recording stations, regional data centers, and three global data centers. Each nation is responsible for its own receiving and recording equipment and for the contribution of its data to the total data stream. Satellites owned and operated by the space segment participants link effectively into a well-coordinated, international ground system of data acquisition, storage, processing, and dissemination.

• *Coordination through an international agency*. Although satellites are individually owned and controlled, the WWW system achieves cohesion and effectiveness through the coordination of the WMO. A similar coordination function for resource sensing could be lodged in the United Nations or in a new organization created for the purpose.

The viability of the WWW model, however, depends on the voluntary, though necessarily interdependent, participation of the satellite owning parties, since a global weather image is possible only by concerted monitoring from all geosynchronous spacecraft. Where data interdependence is not so compelling, involvement with satellite partners is less binding, and the need for accountability to one another or to the international community is perhaps diminished. The great majority of nations, beneficiaries of the investments made by the satellite powers, may feel more dependent or less involved than they would feel in a system based on the foregoing model or the one that follows.

4 International Scheme An international body—the United Nations or an entity broadly corresponding to its membership—could purchase a satellite system from a supplier country and organize for its operation in any of the several modes discussed earlier. This model chiefly differs from the consortium previously discussed in two ways: first, its membership at the outset is broader, compared to the initial consortium membership, which is drawn only from interested and financially able countries; and second, the broader international body offers the possibility of combining international ownership of the space segment and of the ground stations and ancillary facilities. An operation of this kind—whether of one or both segments—could be capitalized on a scale of assessments similar to that established for UN membership dues, or by special contribution.

A scheme providing for quasi-universal membership would effectively meet the objectives of participation, self-determination, and equitable burden sharing. However, it might be more vulnerable to political factionalism than a smaller consortium of like-minded countries. As a consequence, it might, for instance, be less prone to vigorous pursuit of continued technological innovation at the cost of early obsolescence of its invested capital.

Issues Raised by an Operational System

The LANDSAT program is considered experimental by the United States and is accepted as such by the international community. Although there are certain domestic and international pressures to proceed to an operational system and thereby assure continuity of data, there are also strong considerations that argue for extension of the experimental phase for several years.

From a technical standpoint, there is no sharp distinction between the two conditions. Much of the technology and many investigations of its applications are clearly experimental, yet satellite data products are being used routinely for certain purposes in a limited operational mode. The distinction, however, may be valid and useful for two reasons. First, as we have seen in Chapter V, the technology of resource sensing, centered in the LANDSAT series at present, may during the next decade include other spacecraft with complementary capabilities, functions, and operational requirements. While the primary development effort has been on the LANDSAT series, it is but a part that cannot yet speak for the whole. Second, the shift from experimental to operational would entail a number of political and organizational consequences, both domestic and international, that all parties concerned may not yet be ready to incur.

U.S. Domestic Issues

A decision to proceed to an operational system will require the U.S. Government to designate a permanent U.S. institutional base for it. The law that created NASA leaves open to argument whether that agency could be responsible for an operational system. The U.S. Congress, by appropriating funds to NASA for the purpose, could decide this point. Until now, however, NASA has refrained from operational activities and has restricted itself to research and development. Its earlier satellite innovations for communications and meteorology, when they approached the operating stage, have been transferred to operating agencies (COMSAT and NOAA).

There are several viable options the U.S. Government can take in assigning the management of a resource sensing satellite system. These include giving the task to an existing operating agency, creating a new agency, or giving NASA authority to accept an operational function. Legislative measures favoring different solutions have been introduced in Congress, but none has moved beyond Committee consideration. The question is likely to be deferred until Congress is ready to examine and act upon broader issues that concern the overall organization and management of the U.S. scientific and

technological enterprise. The concept of a National Space Applications Council,* charged with administering and coordinating satellite services relating to weather, environment, communications, navigation, ocean monitoring, as well as resource sensing, may be taken up at that time.

International Issues

A U.S. Government decision to proceed with an operational resource satellite system for domestic purposes would soon bring to a head the question of an international framework that has been discussed in the United Nations. While the resource sensing effort was deemed experimental, the UN could limit its attention to the deliberations and studies of the Outer Space Committee regarding the principles of an international legal regime governing resource sensing (including the issue of data dissemination) and the elements of a possible institutionalized participatory system. A shift to operational status, signifying the U.S. commitment to a permanent system, would signal the international community that time was at hand to reach decisions on international guidelines or arrangements.

At the least, on the technical side, the change would require a switch from experimental to operational telecommunications frequencies assigned by the International Telecommunications Union (ITU). Ground receiving stations would be obliged to reequip themselves to be able to receive on new operational frequencies.

Financial Issues

A U.S. decision to go operational with a satellite sensing system will bring to the fore the problem of future financing of the earth resource sensing enterprise. The LANDSAT program was undertaken with U.S. domestic interests primarily in view. The U.S. Government has underwritten all its R&D, capital, and operating costs,† enabling users both in the United States and in

*Proposed by the National Research Council's Space Applications Board in its report, *Practical Applications of Space Systems.*[7]

†To date, the U.S. investment in the LANDSAT program amounts to some $250 million, broken down as follows: building and equipping LANDSATs 1 and 2, $56 million each; estimated cost of LANDSAT C (3), $35 million; each launch, $4-6 million; tracking and ground facilities, $50 million; investigations program for first two LANDSATs, $29 million; annual operating cost of the two current LANDSATs and the main receiving station, $8 million; construction and equipment of EROS Data Center, Sioux Falls, S. Dakota, $17 million; annual running cost of EROS Center, $10 million.

NASA's proposed R&D budget for resource sensing and monitoring is $67.3 million for the fiscal year 1977 and for all earth oriented applications is $198.2 million. Annual expenditures of at least this order of magnitude are anticipated for the next several years.

the rest of the world to acquire its data products at a charge covering only data reproduction costs.

If an international scheme for operating a global remote sensing system does emerge, complex financial and policy questions will have to be faced and solved. Who will bear the capital costs, and how will they be apportioned? How will continuing R&D be financed to ensure that the technology does not become frozen? How and to what extent should operating costs be recovered through sale of products?

It is not possible today to foresee the form that a future remote sensing system will take and the type of financial structure that will be best suited to its development and support. It is conceivable that the continued improvement in sensing and analysis capabilities will lead to new data applications which will in turn expand data requirements, and that this will create sufficient opportunities in the long term for the sale of satellite derived data, possibly along with analytical services, to make the entire system self-supporting.

It is possible, also, to visualize a different prospect. One may postulate a practical ceiling to world demand for satellite sensing products since the global surface is finite, demand for repeated coverage of large areas of the land mass probably will level off, each desired scene in photo or tape form can serve a multiplicity of purposes and, perhaps at some loss in quality, can be cheaply reproduced in quantity for local secondary distribution. Should this prove to be the case and if the only means of cost recovery is to be the sale of data products (i.e., tapes, film, and prints) at a reasonable price, an operational system would not be able to recover total costs for the satellite owners whether they be individual countries, national investors in a consortium, or an international institution.

In any case, if remote sensing products are to be made accessible to the largest possible number of users around the world, an internationalized resource sensing scheme may have to be supported, at least for a period, by governmental and other contributions or assessments. The way the burden is shared would depend largely on which of the various international management options described earlier is chosen by the international community.

Urgency or Delay

The foregoing discussion has already dealt with several opposing forces that are at play in the complex experimental-versus-operational decision that would settle the status of a resource sensing system. It is useful also to examine the same question in a time perspective to see which factors would indicate the necessity to move rapidly toward a resolution of the issue and which would call for delay.

Those favoring an early move to an operational system cite the following reasons:

- A decision to go operational would represent a commitment by the U.S. Government to assure the continuity of the program. Fearing an uncertain future, major U.S. public (federal and state) and private sector potential users have been reluctant to adapt their information and decision systems to LANDSAT data.
- An operational system institutionalized domestically and internationally would have better means and opportunities to gear itself for the efficient delivery of services and assistance to users at home and abroad. This would assure the more rapid diffusion of capabilities and benefits from the system.
- International agreement for institutionalizing a regime may be realized more easily if centered upon one operating satellite system, such as LANDSAT, and would then foster an atmosphere of cooperation free of feelings of dependency and reduce the likelihood of a polarization of views.
- An international mechanism established in the wake of a decision to go operational would foster coordination, standardization, and complementarity among future entrants in space resource sensing; it would also be responsive in the technical configurations of its spacecraft to specifications reflecting special needs of certain geographical regions or categories of nations.

On the other hand, the following reasons can be cited favoring delay in moving to the operational phase:

- The technology should be given time to mature. Major changes and additions (by the United States and others) to the satellite resource sensing system, requiring more experimentation and validation, are planned for the years ahead. LANDSAT is but the forerunner of a U.S. family of complementary earth sensing satellites and of sensing satellites orbited by other countries. There are many unknowns concerning their functions, performance, and their consequences for the international community. It would be unwise to foreclose options for an international system by designing one around a single satellite.
- Fundamental issues such as international institutionalization, data dissemination, and cost sharing, on which there have been clear differences of opinion in the world community, can be resolved in time as countries accumulate and share experience and conduct informal consultation. This applies especially to the question of data dissemination, which is receding in importance as the various data collection systems come into play and procedures for data distribution are worked out pragmatically.
- An operational system set in an international framework (such as obtains in communications and meteorology) becomes feasible when some

critical number of would-be participating countries are able to meet essential preconditions. In the case of INTELSAT, members lacked only the receiving-sending stations to enter into, and profit from, the system. But resource sensing requires a significantly more thorough assimilation of the technology by a substantial number of countries to provide a suitable base for collective management of a system.

The Implications for Policy

Having looked at the technology of earth resource sensing, its implications for the developing world, and the issues it evokes with regard to its ultimate management, the Committee concludes:

- Remote sensing from space brings the world to the threshold of a new era in the collection of data and use of information about the earth's resources and natural environment at a time of changing perceptions of limits to certain of these resources, of dangers facing various ecosystems, and of the urgent necessity to manage them more effectively in order to satisfy human needs.
- Much of the promise of space remote sensing lies in the future; it rests not only on the introduction of more powerful and versatile hardware but especially on practitioners learning to extend the technology to an ever widening circle of applications. Nonetheless, for a significant range of applications of particular interest to the less developed regions of the world, technology of remote sensing can yield important benefits now; its usefulness will increase as remote sensing technicians, resource scientists, planners and decision makers develop a common vocabulary and methodology and learn to work together.
- To implant the necessary skills, facilities, and organizational capacities to enable developing countries to take full advantage of the technology requires a sustained, systematic, and concerted effort on the part of international assistance agencies and probably the creation of new international institutional devices to promote this end.
- There are several persuasive reasons for moving toward some form of internationalization of earth resource sensing. Organized and managed as an international cooperative enterprise, remote sensing could bring into sharper focus both the complex resource challenges facing the global community and the necessarily interdependent responses required to deal with them. The problems of identifying, using, and managing the world's resources, and of maintaining the earth's life-supporting environment call for collaborative action on an international scale. By its very nature, orbital remote sensing is

global in its perspective and impact; its character and effects make institutionalization on a broad basis of national participation particularly compelling.

- Practical considerations also argue for an international approach. Problems relating to coordination of effort, compatibility of technology, cost sharing, and equitable access to data and to analytical services are more likely to be resolved in an international framework. The form for such a framework and the timing of its adoption will demand thoughtful study.

Based on the foregoing, the Committee commends for attention certain initiatives and policies that should help bring about, sooner rather than later, a situation conducive to wide and "comfortable" acceptance of the technology to the advantage of the United States and the international community, including the developing countries.

Phased Approach

With the space platforms and sensors still at an early stage of development, the international community would best be served by the vigorous pursuit of research and development efforts to improve the capabilities of the satellite technology. Several years will be needed for experimentation and testing of sensors with different spatial, spectral, and temporal resolutions. In the Committee's judgment, it would be premature to declare the space segment of the remote sensing system operational and to proceed toward its incorporation in an international framework before there is a system whose performance is adequately responsive to user requirements. As an earth sensing prototype with the possibility of evolving in a few years into a multiple-unit sensing ensemble (in which U.S. efforts may be joined by those of several other space powers), the LANDSAT series thus far does not constitute a sufficient or timely base on which to build—and thereby "freeze"—an international institutional structure.

There is no reason, however, for these considerations to apply to the ground segment. With the spread of national and regional receiving stations, and global direct reception likely to be assured within a few years, it cannot be argued much longer that remote sensing, from the standpoint of ready availability of its products and widening applications and routine use, remains purely "experimental," or that certain useful organizational steps cannot be taken.

As a first step the Committee recommends

> That an international mechanism be established to promote consultation on technical and managerial aspects of remote sensing among representa-

tives of receiving stations, of satellite owning countries, and of countries substantially engaged as remote sensing users.

The mechanism, among other purposes, would facilitate sharing of experience among the station managements; assure worldwide standardization of product formats; provide a forum for discussion of common problems such as product pricing, competing interests due to overlapping coverage, servicing of consumer requirements, technical obsolescence of equipment and "retrofitting" costs; and provide a channel for expression of user needs to the manager of the space segment (currently NASA).

The proposed mechanism could evolve from the existing NASA sponsored LANDSAT Ground Station Operations Working Group, or come about as an added function of an existing entity such as the UN Outer Space Committee, or be created anew. The choice of an appropriate formula should be influenced also by whether or not the mechanism is intended to evolve into the primary vehicle for an expanded multilateral program of technical assistance in remote sensing to developing countries. Ultimately, it might provide the nucleus or point of departure for whatever institutional framework is selected for the international management of the space segment on a permanent operational basis.

Taking this route, the United States would enter into active multilateral consultation with nations dependent on its space system as station owners and consumers and would effect a transitional step from its present unilateralism to a future international scheme.

Continuity of Service

To declare the space segment "experimental" and, withal, to encourage "operational" use of its products is to nurture ambiguity and uncertainty fundamentally adverse to the spread of the technology. The United States should resolve this paradox by giving formal assurance that its experimental system, barring technical failures, will furnish uninterrupted coverage and data service even before the system is adjudged formally operational and its permanency assured. The Committee recommends

That the United States officially declare its intent to proceed for some finite period with further development of space segment technology of a resource sensing system subject to no more than the usual uncertainties, and to make every effort during this experimental phase to provide continuity of sensing coverage and data transmission to stations and product users everywhere.

Regional Multilateralization

As discussed earlier, the part of the sensing system offering the best opportunity for multilateralization and cost-sharing is the ground segment (including receiving station and ancillary services). A regional approach—as distinguished from present practice in which an individual station-owning nation agrees to service its neighbors—would encourage and assist countries to establish, finance, and operate reception stations jointly; this would be a beginning toward the internationalization of the remote sensing effort, at the level that is most ready for it.

It would have several distinct advantages:

- The risk of duplication, overlapping, and conflict, as well as waste of technical and human resources potentially involved in the proliferation of national stations would be greatly diminished, though this is not to gainsay the need for a certain minimum redundancy for backup purposes.*
- Countries without stations of their own would not be dependent for service on an individual satellite-owning nation, on its capacity and efficiency, on its goodwill, and ultimately on the vagaries of its domestic politics and economics.†
- Cost sharing formulas accommodating member countries' relative economic standing could be worked out more easily.
- Cooperatively owned regional stations would mesh effectively with regional service centers with capabilities for processing, storage, dissemination, analysis and interpretation, technical assistance, and training.
- Active participation of developing countries in the creation and operation of regional stations and service centers would stimulate high level governmental attention to the activity and thereby probably induce greater use of satellite data in planning and decision making processes.
- Regional cooperation in a resource sensing ground facility may strengthen the cooperation of participating countries with regard to broader regional resource issues and regional economic development.

The Committee recognizes that since groups of nations generally move more slowly than individual nations, there may be delays in getting stations

*Because of the current 3,000 kilometer radius coverage of a receiving station, the cooperative grouping of countries for joint management of a station and its ancillary facilities may not conform to a conventionally defined geographic region. A multilateralized regional scheme could well encompass two or more station complexes.

†In certain areas, intractable political problems may nontheless make necessary alternative arrangements for data receipt. These arrangements could include establishment of an individual country station, or reliance on onboard tape recorders for delayed data receipt via a more distant and friendly receiving station, or, in the longer term, real-time transmission through the proposed TDRSS system to a U.S. receiver.

into operation to fill out a global network for direct data reception. The important advantages of proceeding on a regional basis, however, and of establishing a firm base of regional responsibility for a common utility would appear to outweigh these considerations. Indeed, the interest already being shown by the European Space Agency and the UN Economic Commission for Africa to pursue efforts on a regional basis suggests an inclination in this direction. The Conference of Ministers of the Arab States Responsible for the Application of Science and Technology for Development, held in Rabat in August 1976, recommended that the present remote sensing center in Egypt be transformed in the near future to a regional center for all Arab states. These regional initiatives warrant support and encouragement. The Committee endorses the call of the UN Outer Space Committee for regional development of ground facilities and recommends

> That the United States, together with other nations and with international bodies concerned with resource and environmental sensing from space, work toward the internationalization on a regional basis, wherever possible, of receiving stations and of ancillary services (including processing, analysis, dissemination, training and technical advisory services) as a desirable means of inducing cooperation and cost-sharing in the management and operation of a ground complex.*

Planning for the Space Segment

The Committee has reviewed briefly several possibilities for a cooperative international regime to govern the space segment of an earth resource sensing system. It has done so in the conviction that in due time the United States will have to regularize the management and operation of its resource sensing satellite system within some international framework, much as it has found it appropriate to do in the case of communications and meteorological satellites.

With this prospect in mind, the Committee urges that the U.S. Government pay careful attention to the international consequences—legal, political, economic, and technical—of any final disposition it might make with regard to the domestic administration of an earth resources sensing system. In the Committee's judgment, domestic and international considerations appear so intimately intertwined that planning for the future management of resource sensing in the United States should proceed hand-in-hand with the development of a U.S. position on appropriate counterpart international arrangements.

This Committee's specific charge was to examine but one aspect of the problem of resource and environmental sensing from space, namely, its usefulness for developing countries and the implications thereof. It is not pre-

*See comments of Professor Rathjens, page 191.

pared to express a preference among the several alternatives for internationalization it has discussed, save its conviction that internationalization in some form is a desirable object of policy. Accordingly, the Committee believes the time is at hand for the United States to begin earnest consideration of the type of international framework it would like to see come about, and to engage in informal consultations with other nations similarly interested. The timely formulation of U.S. domestic goals compatible with eventual international arrangements would ensure that the United States, in its own decision making, does not inadvertently foreclose desirable options for an agreed international regime. The Committee therefore recommends

> That the U.S. Government make a public commitment now to the eventual establishment of an international regime for the space segment of resource sensing systems;
>
> That the U.S. Government begin now to develop its own proposal for a future regime; and
>
> That the U.S. Government, in regard to decisions affecting the future of this technology in the United States, set a course with the aim of facilitating its ultimate incorporation into an agreed international system.

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VIII A Development Assistance Program in Remote Sensing

No nation today has adequate facilities, trained personnel, and institutional arrangements to employ effectively and take full advantage of the data about its various resources furnished by LANDSAT. However, the industrialized countries, with their solid base of resource data collection, analysis and management systems, will be able to assimilate the new technology, both technically and operationally, with relative ease once they decide to do so. The developing countries, with some exceptions, do not have this head start.

Because of this disparity in circumstances, the advent of resource surveying and environmental monitoring from space, with its potential for beneficial impact on so many areas of human endeavor, could add a critical new element to the technological gap that separates the industrialized from the developing countries, and further accentuate the differences among the developing countries themselves. Yet, paradoxically, over the next decade at least, remote sensing appears to offer a better prospect of utility and significant payoff to the developing nations than to the industrialized countries. As the evidence of widespread though still simple use of remote sensing data suggests, the developing countries have not been indifferent to its promise.

To enable interested developing countries to realize the benefits inherent in remote sensing, as rapidly and fully as their individual capacities and interests permit, will require a coordinated and sustained program of assistance, drawing on the technical and financial resources of both bilateral and multilateral aid agencies. In this, the Committee believes the United States is destined for a role of leadership, which it should accept as an inevitable concomitant of the very enterprise it has shown in developing the technology. Although the United States has been mindful of this responsibility—as its efforts to date demonstrate—we believe it should acknowledge a particular interest, an exceptional capability, and a special obligation to promote the transfer of this technology to the developing world.

We say this for several reasons. First, since World War II the United States has engaged itself, and renewed its commitment many times, to make the benefits of its science and technology available to the developing countries in their quest for economic and social betterment. Moreover, as a signatory of

the UN Outer Space Treaty, it has undertaken to use space "for the benefit and in the interests of all mankind." Earth resource sensing gives the United States an exceptional opportunity to act on this commitment by sharing with the developing countries a product of its science and technology that is potentially of wide ranging consequence to them. However, sensing from earth resource satellites has little significance to those lacking the means to exploit its special product. To put a satellite in orbit and to give unrestricted access to what it sends back accomplishes but half the job; the other half is to see to it that those who require it obtain the "key"—recognizing the various types and degrees of access it may offer—that will unlock its benefits. As sole provider at present of earth resource data from space, the United States should consider it in its interest that this key be held by as many countries as want to have it.

Second, the United States, by virtue of its primacy in the technology, is exceptionally placed to engage in activity aimed toward its transfer and diffusion. The large preponderance of skills and much the greater part of ongoing applications research are centered in this country; the deepest and most forward looking perceptions of its remarkable potential for resource management and monitoring have been advanced by American remote sensing scientists, resource specialists, and theoreticians. But remote sensing, in terms of its applications, is an evolving and expanding art to which contributions can be made by practitioners everywhere, as has already been demonstrated. Thus, diffusion of basic competences can also bring in a harvest of new techniques from which the entire community may gain.

Third, the ambivalence harbored by some countries toward earth resource sensing—the fear that along with its benefits for those who are able to use it there is enhanced vulnerability, at the hands of others, among those who are not—presents the United States as technological innovator with an unusual challenge and responsibility. Whether real or illusory, a perceived imbalance in information gain, which raises a country's felt risk of being victimized by parties technically more proficient (neighboring countries or international companies eying its resources), creates an unfavorable climate for the propagation of the technology. At the least, this concern should be mitigated by helping a country acquire an indigenous capability at a level sufficient to give it a measure of self-confidence, particularly the assurance that what it lacks in skills and facilities at home it can, for many purposes, reliably procure from sources elsewhere.

There is another compelling justification for the United States to bear such responsibility earnestly. Its policy of unrestricted dissemination of satellite-derived data rests on the principle that all countries should have equal access to all data. However, countries do not have equal capability to make the data about their own land yield meaningful information. Thus, to be credible, an open data policy should, as a necessary corollary, go hand-in-hand with a

deliberate commitment to make acquisition of capabilities possible on the widest basis.*

While calling on the United States to exercise leadership, the Committee does not wish to minimize the important contributions that other aid channels, bilateral and multilateral, can also make in the endeavor. The World Bank, the UN Development Program, and UN operating agencies such as the Food and Agriculture Organization have each begun to stake out significant areas of initiative in the use and diffusion of remote sensing technology; they deserve full encouragement by the United States and other member countries.

Indeed, as noted in the previous chapter, the Committee believes that a resource sensing system, because of its nature, pervasive impact, and certain disquiets it evokes, calls for some form of international institutionalization. While this may take time coming about, a scheme that would address on a regional or global basis such matters as coordination of ground segment activity, technical assistance and buildup of user capabilities could take shape more readily. U.S. resources for the transfer of remote sensing technology to developing countries could in that event be committed in increasing measure to such a body. However, until such time as one is created, much of the job will remain with U.S. agencies.

Assistance Policies of the United States

The U.S. Government has dealt with developing countries in the field of remote sensing through three official agencies: the National Aeronautics and Space Administration (NASA), the United States Geological Survey (USGS), and the Agency for International Development (AID). Before addressing itself to AID as the chief instrument for channeling U.S. assistance abroad, the Committee believes that several observations intended for the first two are in order.

National Aeronautics and Space Administration

By enlisting the collaboration of scientists and resource managers abroad in research on applications of remote sensing, and encouraging foreign countries to acquire their own LANDSAT receiving stations, NASA has been commendably alive to the need to foster a sense of international participation

*That this proposition has gained acceptance in the U.S. Government may be inferred from the address by Secretary of State Henry A. Kissinger to the American Bar Association in Montreal, August 11, 1975: "...While we believe that knowledge of the earth and its environment gained from outer space should be broadly shared, we recognize that this must be accompanied by efforts to insure that all countries will fully understand the significance of this new knowledge...."

in the development of a technology of global significance. It has done so out of the same spirit that characterized its other ventures in space—scientific cooperation and a desire to stimulate the broadest scientific input to its efforts on a voluntary basis. Although it is not NASA's responsibility to help the developing countries to assimilate the technology, it early recognized that resource survey satellites would have particular value for them.

In the future, however, a policy still more responsive to the concerns of the world at large appears desirable. As NASA engages more substantially in the development of space systems for earth oriented applications, its innovations in space will increasingly become consequential to the lives of people everywhere. Space technologies of the future are expected to deliver a growing diversity of services;* what in the days of lunar landings was largely a spectator public is becoming a consumer public—one of global dimensions.

Two implications may be seen in this. First, NASA will need to give increasing attention to the problems of technology transfer and diffusion so that developing countries will be able to avail themselves speedily of advances important to them. In particular, NASA should work in increasing intimacy and collaboration with AID and other assistance agencies that have a role to play in this process. Second, as the consumer public for satellite data reaches worldwide dimensions, NASA should extend its consultation soundings, now largely confined to the American "market," to the larger constituency abroad to enable it to have a voice in the definition of future programs. The LANDSAT Ground Station Operations Working Group could be expanded, for instance, to include significant users of space data, or a separate advisory body could be established to represent international user interests.

One area in which consultation with the international constituency would seem highly desirable is in the technical configuration and operational performance of future earth observation systems. For some developing countries use of current LANDSAT data is severely limited by the problem of cloud cover; a technology such as microwave sensing that can overcome this could be of great interest to them. The extent of interest among developing countries in obtaining direct coverage of their land areas by SEASAT A imaging radar should be determined. With international users of MSS data, particularly countries or regional groupings that have or expect to have reception facilities in operation, consultations such as those held by NASA in late 1976 in Ottawa are needed to address the various options which may be available for the Thematic Mapper downlink communications subsystem, especially if there is any prospect of a significant change from direct satellite data trans-

*See *Outlook for Space*, a report to the NASA Administrator by a study group, NASA, January 1976. (See Selected Bibliography.)

mission to the round-the-world network of stations likely to be in place by the time LANDSAT D goes into orbit.

Another important matter a consultation process might help to resolve relates ultimately to the pricing of remote sensing products distributed by national and regional receiving stations abroad as they take over this function from the EROS Data Center. The relatively small size of markets in the developing world is likely to result in price schedules significantly higher than those obtaining in the United States. NASA's newly adopted policy of levying an initial annual $200,000 cost sharing fee on foreign stations should therefore receive careful weighing. If the fee is passed on to buyers through still higher product pricing, the effect may well be to discourage would-be users in developing countries from purchasing the data products from the regional stations and consequently to retard the development of markets. While otherwise unexceptionable, the principle of cost sharing imposed at this early stage could be self-defeating.

U.S. Geological Survey

Concerned with the international supply of scarce mineral raw materials, the U.S. Geological Survey has a long history of collaboration with its counterpart agencies abroad, especially in the developing countries. It has endeavored in recent years to put strong emphasis on the international application of LANDSAT data, and it has become the major U.S. vehicle for transfer abroad of remote sensing technology as applied to earth sciences. On its own or with funding from AID and NASA, the Survey has since 1971 conducted over a score of remote sensing seminars and workshops in Asia, Africa, and Latin America, as well as international training courses at the EROS Data Center, which it administers. Over a thousand scientists and technical specialists representing most developing countries have participated in these exercises. In addition, the Survey has provided technical assistance and advisory services in remote sensing on a reimbursable or AID-sponsored basis to a dozen developing countries. In some areas, it helps relate remote sensing to existing cartographic activities, as in Latin America where it has continuing rapport with national survey organizations through the auspices of the Inter-American Geodetic Survey (IAGS).

Clearly, the Geological Survey constitutes an important U.S. asset for the dissemination of remote sensing skills, one to which the United States will need to make increasing resort especially to help meet the developing countries' large requirements for trained personnel. In this regard, training programs in the future will need to provide for longer term, more in-depth instruction than the four- to six-week familiarization exercises offered thus far.

Agency for International Development

For the past five years AID has sponsored a modest program of assistance to developing countries principally to acquaint them with the use of remote sensing data and to support experimental application projects. AID has organized and funded training seminars and symposia; sponsored experimental projects in such fields as range and water management, geology, demography, and geobotanical research; provided advice to countries on integrated use of the technology; and begun to use remote sensing products in the formulation and execution of development projects.

This AID level of engagement in satellite sensing activity has been very cautious, reflecting the early uncertainty regarding the technical efficacy of the new technology. Now that a more positive, if still qualified, assessment of its capabilities is possible, the technical basis exists for a more confident commitment. The Committee therefore recommends

> That the United States, through AID and through multilateral bodies where possible, engage itself in a sustained, long-term and systematic effort over the next decade to transfer to interested developing countries the capability to utilize the technology of remote sensing from space.

In the Committee's view, AID's level of investment for this purpose should be of a magnitude at least ten times greater than it is now. This increase, from a base of well under $1 million per year, does not appear unrealistic to the Committee relative to the scale of the total AID program ($2,850 million for the year 1976-77) and the fact that the technology may bear favorably upon so many sectors qualifying for development assistance. Such an increase in funding levels would necessarily involve an appropriate increase in AID technical staff to plan and supervise the program.

Many developing countries have indicated they would welcome assistance in the remote sensing field. They have made this known in response to UN inquiries, in numerous remote sensing workshops held here and abroad in recent years, and in the growing number of applications for assistance to aid-granting agencies.

A Program for AID

The Committee believes an AID strategy of remote sensing technology transfer should contain the following elements:

- Pilot country projects
- Sectoral demonstration projects

- Provision of technical facilities
- Information and training programs
- Research projects
- Application of remote sensing data in execution of AID-sponsored development projects
- Technical and financial assistance to regional centers.

Pilot Country Projects

Projects to implant an integrated, indigenous capability to analyze and utilize remote sensing data should be organized in a number of countries showing a diversity of characteristics. The AID-sponsored project in Thailand and the multilaterally sponsored project in Bolivia are prototypes of what is proposed. The AID program of pilot country projects should seek to test and demonstrate ways in which external assistance can best be applied. Subject to individual needs and absorptive capacity, a country project might include elements such as:

- Provision of a broad gauged remote sensing specialist on an extended basis (3-5 years) to advise and assist in the development of a remote sensing program operated by the country's own trained personnel
- Information and education programs to expose administrators, resource managers, planners, and political leaders to the potential value and limitations of remote sensing data for the country and their individual fields of responsibility
- In-country and external training programs of various levels and duration for resource managers and technical specialists in interpretation and analysis, and for technical support staff
- Support toward acquisition of needed facilities and equipment to reproduce, store, and analyze remote sensing data
- Advice on institutional arrangements within a governmental framework to optimize use of remote sensing data in multidisciplinary and multisectoral applications
- Advice on external sources for advanced processing and interpretation services, or procurement of such services within the context of a development project
- Consultation visits by experts for specialized uses of remote sensing projects.

A pilot project along the lines proposed could also be mounted to serve a group of smaller countries from a single operating point. With modest equipment for photoprocessing and interpretation and a small staff of resident and

traveling specialists, a multicountry facility could fill several functions: provide brief informational seminars and training courses; offer help in photo interpretation; advise planning boards and ministries on their organizational, equipment, and training needs; and generally serve as a focal point for the transfer of the technology to the countries concerned and for liaison with international agencies that can provide supplementary assistance. AID is presently considering a proposal for one such service in Africa.

Sectoral Demonstration Projects

The NASA directed investigations program and much other work with remote sensing products to date have been essentially experimental: to assay the capabilities of the LANDSAT sensors and the value of the information that can be derived from their data. Though practical applications in developing countries are accumulating, they are for the most part still simple and fragmentary undertakings well short of an operational scale. What developing countries now need is a body of experience with remote sensing surveying and environmental monitoring that provides proven methodology for application to resource management and development.

AID should initiate and support a series of demonstration projects that would take satellite data applicable to a particular resource sector problem through the continuum of processing and analysis, to incorporation in planning and decision, and finally to implementation in management and development action.

Subject areas that might be appropriate for such projects include:

- Identification of underutilized tracts of land in heavily populated regions
- Land use mapping to assist planners in allocation of investment funds for agricultural or other development
- Topographic and geologic mapping to help in siting of reservoirs, dams, and transport routes
- Monitoring of land clearing in forest areas
- Identification of unmapped rural settlements
- Recognition of geological formations or structural features indicating likely areas for mineral or ground water exploration
- Survey of coastal waters and coastlines to detect sedimentation, erosion, or pollution in streams requiring attention, or natural oil seepage suggesting advisability of offshore oil exploration.

Planners and resource managers of developing countries are usually better able to recognize the applicability of the technology to their own needs when

able to observe its workings in a familiar environment. AID should help and encourage participation in these demonstration projects of resource and other specialists from neighboring countries.

Equipment

Because of the growing range and the unfamiliarity of the equipment becoming available to process, analyze, display, and reproduce satellite data, many countries need help in deciding what their requirements in this respect should be. AID, with assistance from NASA, can perform a useful first function by disseminating authoritative comparative descriptions of processing equipment, display units and software, including their capabilities, performance characteristics, costs, and compatibility with existing national computer programs. Advisory assistance could also be given by AID-supplied experts attached to pilot programs or by specialists sent from the United States on special missions until trained indigenous personnel can provide the needed expertise and skill.

For individual countries or regional groupings certifiably in need of certain items of equipment for a regional receiving and processing station or a national data analysis center, but lacking foreign exchange for direct purchase, AID should consider the use of loans or grants to facilitate the needed procurement.

Information and Training

The long-term needs of developing countries for manpower trained in remote sensing are considerable. AID can make a major contribution toward meeting these requirements by supporting a range of information and training activities at three different levels:

1 Creating awareness In many nations some appreciation of the value of remote sensing technology can be found in limited scientific and technical circles. But government planners, administrators, and decision makers have not yet had sufficient exposure to and familiarity with the technology to make sound decisions with regard to its incorporation into the national program for resource management and environmental monitoring. In concert with other agencies similarly engaged, AID should continue for some time to support a program of workshops and seminars intended to familiarize senior government executives and resource agency administrators with the general nature of the technology, its benefits and limitations with respect to various sectors of application, the availability and costs of the data, and the organizational and other steps that countries will need to take to utilize and profit from the

technology. To the greatest extent possible, such activity should be pursued in the developing countries or at regional centers.

2 Short-term training Most developing countries are in need of a nucleus of resource specialists sufficiently familiar with the handling of remote sensing data to be able to advise their governments regarding the relevance of the new technology for meeting their countries' resource and monitoring requirements. For specialists in fields such as agriculture, forestry, geology, land use, hydrology, and cartography, AID should support the organization of intensive courses of about four months duration to furnish a basic grounding in the characteristics and treatment of remote sensing data. Such courses will not produce remote sensing experts, but will enable resource specialists—agriculturists, foresters, hydrologists—to determine the applicability of the technology to their respective fields, to interact effectively with remote sensing technicians, and to begin to employ the data in their work. Courses should cover such subject matter as:

- Specific user requirements for earth resource information
- Basic matter and energy relationships
- Remote sensing capabilities in various parts of the electromagnetic spectrum
- Multistage sampling techniques including techniques for the acquisition of ground truth
- Photo interpretation equipment and techniques
- Image enhancement techniques
- Data extraction techniques
- LANDSAT capabilities to date
- Techniques for optimizing the interaction between those who provide earth resource information and those who use it in the management of earth resources.

The emphasis of the courses should be on the acquisition of basic skills for the analysis and interpretation of remote sensing data. Wherever possible, such courses should be organized at educational institutions or regional remote sensing processing and distribution centers within the developing countries, where opportunity for interaction among specialists of different disciplines and different countries would be maximized.

3 University education Countries actively engaging in remote sensing utilization, and developing the institutional infrastructure to serve the needs of a widening user community, will need high-level indigenous expertise with substantial mastery of the scientific and technical foundations underlying all categories and aspects of remote sensing including their relationship to

various sectors of application. AID should assist in providing opportunities for undergraduate and graduate study at U.S. universities offering specialized programs in remote sensing.

In stepping up its training and education activities over the next few years, AID will have to cope with one limiting factor. Because of the newness of the technology and the mushrooming demand for training in its use in the United States and elsewhere, institutional capacity, instructors, and other requisite aids will all be in short supply. Together with interested institutions at home and other bilateral and multilateral aid agencies, AID should seek to expand institutional capacity for high-level training both in the United States and other countries. Two initiatives warrant consideration in this regard: (1) the establishment of a remote sensing center at a U.S. university to create a significant U.S. capability in remote sensing oriented to the needs of developing countries, including provision of advanced training; (2) assistance to selected universities in developing countries to include courses or programs in remote sensing in their curricula with a view to their ultimately satisfying local or regional training and education needs.

4 Published materials The flow of published reports of remote sensing investigations and other studies of sensing techniques and applications has now reached such a volume that full-time specialists cannot keep abreast of it. The primary literature not only has become unmanageable, but it is only partially available to practitioners in the developing countries.

There is a growing need for consolidated presentations of the current state of experience with applications of satellite data, as well as of advances in processing and analytical techniques. Together with NASA and other organizations concerned with this problem, AID should encourage the preparation of literature review and synthesis studies not only to serve technical assistance purposes but for use in university instruction in the United States and in other countries.

There is also a need for specially prepared materials, at a more generalized level, to acquaint planners, administrators, resource managers, and political leaders with what remote sensing can and cannot do for resource management and environmental monitoring. This documentation should offer more detailed information for each sector of application than is currently provided in the brief summary pamphlets available for this important purpose.

Research

Several areas of research could be profitably underwritten by AID in its effort to advance the utilization of the technology for development and resource management.

Tropical, arid and other conditions special to the developing world, as well as area-specific data requirements, create problems for remote sensing use that require basic investigation. AID is already engaged, by means of a small grants award scheme, in assisting promising research projects proposed by developing country investigators. AID should continue to support such investigations. Important problem areas deserving research attention include the following:

- *Agriculture*—Examination of the particular options for, and constraints upon, improved crop production forecasting in the wet tropics and the wet-dry savannahs. These areas face unique problems not observed in the middle latitudes.
- Mapping and monitoring rate of *soil deterioration* caused by desertification, water erosion, wind erosion, water logging, salinization, and subsidence.
- Estimation of *water consumption* by crop and of regional water balances by use of LANDSAT and meteorological satellite data to aid in resolving water management problems.
- Exploration for *ground water* in subhumid or arid areas.
- *Rangeland*—Reconnaissance to evaluate land and soil for rural development, especially in stock and range improvement programs; monitoring of pasture and range condition with the aid of LANDSAT and GOES data to assist in rangeland management.
- *Public Health*—Identification of breeding grounds for disease-bearing insects with a view to eradicating the vegetation serving as their reservoirs; land use studies to help in resettlement projects.

The optimal utilization of resource and environmental information for developmental purposes should call for a close interactive working relationship between resource and physical planners on the one hand, and economic planners on the other—a relationship which at present (as discussed in Chapter II) seldom obtains. To advance the art of resource-based development planning, AID might consider supporting a research project that would seek to formulate an integrated, coherent framework of analysis permitting planners to look simultaneously at resource, locational, economic, and social planning issues. Such a project should involve an interdisciplinary group of physically and economically oriented planners, focus on some specific country or region and have perhaps a three- to five-year time horizon. In the absence of such a framework for integrating resource information with the more dominant economic planning data, the potential of remote sensing for national development planning will remain substantially unrealized even though the technical preconditions and the availability of relevant data have been met.

Resource and environmental data generally are collected in a country by many different agencies and stored in different locations in a variety of formats. As a consequence, physical planners and resource managers have difficulty combining and analyzing on an integrated basis the physical, natural, social, and other data from a multiplicity of sources pertaining to an area or thematic subject. Digitized remote sensing imagery may also constitute a major step forward as a base and integrating medium for data collected from other sources. Computerized grid cell mapping techniques are now being developed for multisource data storage retrieval and display. AID should sponsor the experimental application of these new techniques in a few developing countries to determine their suitability and the need for further research.

Use of Remote Sensing in AID-Sponsored Projects

The use of remote sensing products for project initiation, planning, and supervision is gradually penetrating international development assistance agencies. AID regional bureaus and country missions should be familiar with the technology and its potential for their program priorities. Use of remote sensing data for design and implementation of AID-sponsored projects can be an important means of strengthening the remote sensing capabilities of a recipient country, while serving AID's interest in effective project development and management.

Assistance to Regional Remote Sensing Centers

A regional remote sensing service center could advance many of the objectives discussed above and do so under multilateral sponsorship. The regional center concept has been articulated in UN studies and elsewhere, has been under detailed study by UN regional economic commissions in Asia and Africa, and has been endorsed by Arab state science ministers concerned with development.

Regional centers, associated with data receiving and processing facilities, could provide a variety of services:

- storage and retrieval of regional remote sensing data
- image review facilities for easy selection of desired imagery
- reproduction facilities for photo and digital material
- interpretation and analytical assistance for users lacking skills and facilities of their own
- distribution of remote sensing data products
- training by means of seminars, short course, and on the job learning for sensing specialists, resource managers, and others.

Wherever conditions favor their establishment, AID should join with other bilateral and multilateral aid agencies to help set up regional centers. The multilaterization of sponsorship, regional pooling of resources, and simply the economics of scale make this approach eminently deserving of a trial.

Coordination of Aid Efforts

In addition to the United States and other bilateral donors, several UN agencies and multilateral aid organizations, to which the United States is a major contributor, have begun to employ remote sensing data in their projects, to grant funds for technical assistance projects in remote sensing, and to provide processing, analysis, and interpretation services.

Assistance related to remote sensing has begun to flow through a multiplicity of channels to a growing number of countries and, in some cases, to a host of institutions within each. Generally, remote sensing assistance is provided within the context of a sectorally oriented project and through a sectorally responsible ministry or department. This approach may fail to emphasize the integrative, multidisciplinary and multipurpose value of remote sensing data and to exploit opportunities for building up a strong institutional basis in the recipient country. Donor agencies and a recipient country will find it to their common interest to coordinate their remote sensing activities so as to ensure that their efforts are complementary and serve to endow the recipient country with a permanent, institutionalized capability to apply resource sensing to its needs. AID should take the initiative in inspiring such coordination among donor agencies, and in encouraging recipient countries to structure remote sensing assistance activity in the direction indicated.

Institutions at regional or international levels concerned with remote sensing could serve as mechanisms for concerted action in the transfer of the technology. In the event such institutions come into being, technical assistance resources and programs for remote sensing could in large measure be channeled through them.

Two Dissenting Statements

Remote Sensing and Equity

IRMA ADELMAN, Professor of Economics, University of Maryland

Introduction

The purpose of this dissent is to point out a critical area of Committee discussion that is ignored in the present report except for a disclaimer in the Foreword.

It is my firm conviction that any effort to evaluate the possible effects of a new technology upon developing countries must take into account, insofar as possible, the potential impact of that technology on the poor people of those countries. The historical record of technological developments is not a favorable one from the point of view of equity, and, as a result of this record plus my own analyses, I fear greatly that exploitation of mineral resources by remote sensing and other national benefits of remote sensing technology will serve, for several generations at least, to make the poor of the developing nations even poorer—in an absolute sense, not merely relatively. Only if concrete steps are taken to reverse this process at all steps of the application of this new technology to developing nations does there appear to be a significant probability of remote sensing technology proving to be a boon to the poor, or at least neutral in its effects.

Natural Resource Abundance

There is significant reason for concern about the potential impact of remote sensing upon inter-nation and intra-nation equity. Remote sensing technology makes the discovery and pinpointing of mineral resource deposits more likely and cheaper. Natural resource exploitation has, in the past, had major impact upon the distribution of income both within and among nations.

Historically, nations which have been colonized and subjected to intense economic exploitation have been colonized primarily because of their natural resource abundance. (Countries with meager mineral resources have not been considered worth colonizing.) Information on natural resource deposits is of great value economically, but only to those with the money and know-how

required to exploit the information. Since such money and technological knowledge are concentrated, for each type of resource, in the hands of a few multinational corporations with head offices in developed countries, it is they and not the typical nationals of the host countries who have in the past been the primary beneficiaries of such discoveries. Governments of developing countries have become more aware of this problem and have become better at extracting good royalty and exploitation arrangements than they had been in the past. But even when the country does extract large royalty revenues, the benefits from the revenues tend to accrue to only a few and do not tend to benefit the masses of impoverished within developing countries.

A cross-country study of the factors affecting the distribution of income in 43 underdeveloped nations as of the 1960s (Adelman-Morris, 1973) indicates that, among the 48 economic and noneconomic influences whose effect upon distribution was examined, natural resource abundance is one of the most prominent features influencing the distribution of income. It was found that the average share of national income accruing to the poorest 60 percent of households is, on the average, 30 percent (8 percentage points) *lower* in natural resource rich countries than in natural resource poor countries. By the same token, the average share of GNP accruing to the top 55 percent of households is 42 percent (or 10 percentage points) higher in natural resource rich countries than in natural resource poor ones. In natural resource rich countries the economic status of the poor is worse in absolute as well as in relative terms: the average per capita income of the poorest 60 percent of households is about 15 percent below that in natural resource poor countries.*

The explanation for the adverse relationship between the distribution of income and the abundance of natural resources is clear. Natural resource abundance has permitted the elites in natural resource rich nations to attain a high standard of living with a very narrowly based, dualistic development pattern. In countries less well endowed with natural resources, development strategy has had to focus on the development of a broader industrial and human resource base; this has implied that in resource poor countries the benefits of development have had to be somewhat more widely dispersed, with a somewhat higher trickle down to the poor. In principle, a properly managed natural resource generated royalty fund could generate a surplus which countries could devote to development programs and strategies aimed at benefiting the poor. The past does not, however, offer much comfort on this score.

*$41 per capita, per year, in natural resource rich countries, as compared to $48 in natural resource poor countries.

Natural resource information has intergenerational distributive implications as well. Exploitation of natural resources tends to induce changes in land use patterns, environmental blight, and transformations in land quality which are largely irreversible. The effects of strip mining upon the Appalachian landscape provide a good example of the costs paid by subsequent generations for benefits derived by earlier generations because of environmentally unconstrained natural resource exploitation.

All in all, unless very stringent provisions safeguarding the interests of the poor are imposed upon potential users of natural resource data derived from remote sensing, the past suggests that the economic impact upon the poor of present generations and upon all members of future generations is likely to be negative. The imposition of such provisions is unlikely except by the most socially committed of governments, since the impact of natural resource explorations tends to benefit the current elites of developing countries, both relatively and absolutely, and since constraints may make natural resource exploitation unprofitable.

Changes in Technology

The near-term implications of those remote sensing uses which induce changes in technology (irrigation schemes, different cropping patterns, etc.) also suggest the need for extreme caution and care in project design, if they are not to injure the poor.

Past experience with major technological change suggests a set of rather gloomy generalizations. It has been found, for example, that the Green Revolution, in both the Punjab and in Mexico, has made the distribution of income less equitable, has created severe strains upon the land tenure system, has led to land consolidation and tenant and share-cropper evictions, and has increased the number of landless laborers totally dependent upon wage employment.

An examination of the impact in 23 countries of the changes in technology and in degree of commercialization which took place during the middle of the nineteenth century leads to equally discouraging conclusions (Adelman-Morris, 1976). In the first half of the nineteenth century, the spread of mechanized techniques and the spread of markets in agriculture almost invariably increased poverty among the poorest segments of society. (In some countries the worsening of the position of the poorest was, paradoxically, coincidental with rising average wages.) The extent of increased poverty depended on the nature and strength of two processes associated with structural change: first, the process of displacement of one set of economic activities by another as a result of monetization or technological change; and second, the

process of expansion associated with the introduction of the new economic activities. The impact of structural change depended upon the net balance of the two processes. During the first half of the nineteenth century the net balance of the processes of displacement and reabsorption associated with industrialization and commercialization was systematically unfavorable to the poorer strata of society. Even where average standards of living rose (as in England between 1800 and 1850), the levels of living of the poorest deteriorated. Eventually, the poor did benefit from the economic expansion associated with the Industrial Revolution. But the benefits came a full 50 years (or two generations) after the initiation of the process of technical change.

There is evidence in the growth pattern of contemporary underdeveloped countries that the nineteenth century experience is repeating itself.

Conclusions and Recommendations Regarding Equity

The Congressional mandate to AID is to frame its development assistance programs in developing countries with a view to benefit the poor people of the poor nations. It is clear from the preceding discussion that the application of remote sensing technology to the economic development of the less developed nations is most unlikely to operate in a fashion consistent with the mandate to AID. Only if specific, conscious, and determined steps are taken to ensure that the benefits of remote sensing reach the poorest portions of the populations can the Congressional objectives be met.

It is both unreasonable and impractical to cease the application of remote sensing technology to developing nations. However, provisions, institutional and otherwise, should be made for a significant portion of the benefits to accrue to those who need them most.

It is my belief that U.S. assistance to the less developed nations in remote sensing technology (and with other technologies as well) be made conditional on the development and implementation of programs which will ensure that a major portion of the benefits of the technology will be passed on to the poorest 60 percent of the population in an effective and timely manner.

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Three Issues

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I have reservations with respect to three issues treated in the report: the extent of AID's support for remote sensing in developing countries; the position taken with respect to increasing the number of earth stations; and the emphasis on regional centers.

AID Support of Remote Sensing

In view of the Committee's rather favorable assessment of the potential benefits of remote sensing, I believe it is justified in recommending support sufficient so that aid-granting agencies (AID and others) and the government agencies in developing countries will have a reasonable basis for making an assessment of its value as compared with alternatives that might involve the allocation of equivalent resources. However, since the Committee has *not* done this kind of comparative analysis, I cannot support recommendations for AID expenditures for the establishment of *operational capabilities* or, to be more general and to use the language of the report, that have as their objective "the transfer of the technology" to developing countries and/or "the assimilation" of it by them. In practice, it may be difficult to draw the line between supporting the establishment of operational capabilities and providing enough information so that others with a broader responsibility than the Committee's will be in a position to decide on priorities in the allocation of scarce resources. It may even be necessary to support some demonstration projects as part of an educational effort, but I would draw the line at our recommending such things as a broad program for providing equipment and training personnel. As an example, with respect to the latter, I can support a recommendation for "General Information" educational programs (see page ~~00~~ 131), but not one for "In-Depth Training" (page ~~00~~ 131). A decision to support the latter in the case of any given country ought to be made *after* a determination that that country's interest will be better served by investment in remote sensing than in other activities that are inadequately funded.

The Earth Segment

The Committee's support of an expanded network of earth receiving stations is inappropriate in my view, considering the following.

1. It is likely that satellite-borne tape recorders can be made to work reliably at a cost that is much less than that of building a large number of earth stations. Therefore, a system based on recording of information and later readout at those stations that are already operational may be preferable to the establishment of a number of additional stations.

2. There is the possibility of the TDRSS system. If, in fact, we are going ahead with this, it will be possible to get by without any additional earth stations (or tape recorders). There is an argument that the costs of data transmission from a receiving station in the U.S. to user countries may be great. This may be true if large amounts of data are sent by INTELSAT or other electronic means. However, it will probably not be true if *only* data that is needed on a near-real time basis is sent by such means, with the remainder (of what is to be sent at all) going by aircraft.

3. With technology changing, earth station equipment may rapidly become obsolete, and even the disposition of the stations may be inadequate. I have in mind particularly that data transmission requirements may be increased greatly with the Thematic Mapper, and if the satellite carrying it operates at a lower altitude, any pattern of stations developed for the present satellites will probably be inadequate.

4. If there is redundancy either because of overlap among a large number of stations or because there are tape recorders and/or a TDRSS system, there will be a serious problem of cost recovery for some of the earth stations. Those in Africa, for example, are not likely to be able to provide services at costs that will be competitive with, for example, the American stations. This means that those operating such stations will incur large losses or else will have to be subsidized.

It is argued that a multiplicity of earth stations is desirable because of possible concerns in some countries about assurance of service if all the data goes through U.S. receiving stations. This may be true, but to the degree it is, it will not be much mitigated as long as the satellites are under the control of one country. When the time comes to internationalize the satellites, it would not seem unduly difficult to do the same with a limited number of earth stations.

With these points in mind, it seems to me that before supporting an increase in the number of earth stations there should be a careful analysis of the comparative costs of readout involving the three alternatives: a multiplicity of earth stations, tape recording with delayed readout, and dependence on TDRSS. Such an analysis may not be a sufficient basis for a rational decision but I believe is a necessary one.

Regional Centers

I cannot go along with the report's strong endorsement of regional centers for data processing and training, and of regional earth stations. Some of my objections to the latter are given above. However, I have reservations that are more general in nature and that apply to regionalization in all its aspects.

1. The functions that might be accomplished at regional centers might better be carried out in a very limited number of international centers in relatively attractive places. Economies of scale, better access to advanced technology and possibly greater attractiveness to students, technicians and experts would suggest that this might be so.

2. There may be an advantage in agglomeration on a linguistic basis for training; for example, sending people from French speaking Africa to France, but those from English speaking countries to the United States, the U.K. or Canada.

3. In general, the bitterest disputes between nations involve those in the same region, indeed, those having common borders. Thus, cooperation on a regional basis may be exceedingly difficult. While such cooperation may serve to reduce tensions, it is by no means clear that this will happen. Even if it did, it is not clear that the advantage would be sufficient to compensate for the complications in getting nationals from hostile nations to work together and to trust each other with respect to such issues as supply and interpretation of information. The argument becomes especially doubtful when such services might alternatively be provided by national or international non-regional institutions.

I do recognize that there will likely be some advantage in regional centers in reducing travel costs and because adjacent nations may have similar problems in sensing and in data analysis.

With all this in mind, I am not necessarily opposed to regional institutions, but cannot go along with the emphasis on them in the absence of a careful weighing of their advantages and disadvantages with those of alternatives.

Glossary of Acronyms

CCT	Computer Compatible Tape
COMSAT	Communications Satellite Corporation, Washington, D.C.
CORSPERS	Committee on Remote Sensing Programs for Earth Resource Surveys, Commission on Natural Resources, National Research Council
DCS	Data Collection System
EARTHSAT	Earth Satellite Corporation, Washington, D.C.
ERIM	Environmental Research Institute of Michigan, Ann Arbor, Mich.
EROS	Earth Resources Observation Systems (Data Center at Sioux Falls, S.D.) U.S.G.S., U.S. Department of the Interior
ERTS	Earth Resources Technology Satellite (later renamed LANDSAT)
GOES	Geostationary Operating Environmental Satellite
GSFC	Goddard Space Flight Center, NASA, Greenbelt, Md.
HCMM	Heat Capacity Mapping Mission Satellite
HDDT	High Density Digital Tape
IAEA	International Atomic Energy Agency
IDAT	Interactive Data Analysis Terminal
INTELSAT	International Telecommunications Satellite Organization
IR	Infrared
LACIE	Large Area Crop Inventory Experiment
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NOAA	National Oceanographic and Atmospheric Administration
ONC	Operational Navigation Chart
Pixel	Picture element
RBV	Return Beam Vidicon
SEOS	Synchronous Earth Observation Satellite
SMS	Synchronous Meteorological Satellite
TDRSS	Tracking and Data Relay Satellite System
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey (U.S. Department of the Interior)
WMO	World Meteorological Organization
WVTR	Wideband Video Tape Recorder
WWW	World Weather Watch (a program of the WMO and the International Council of Scientific Unions)

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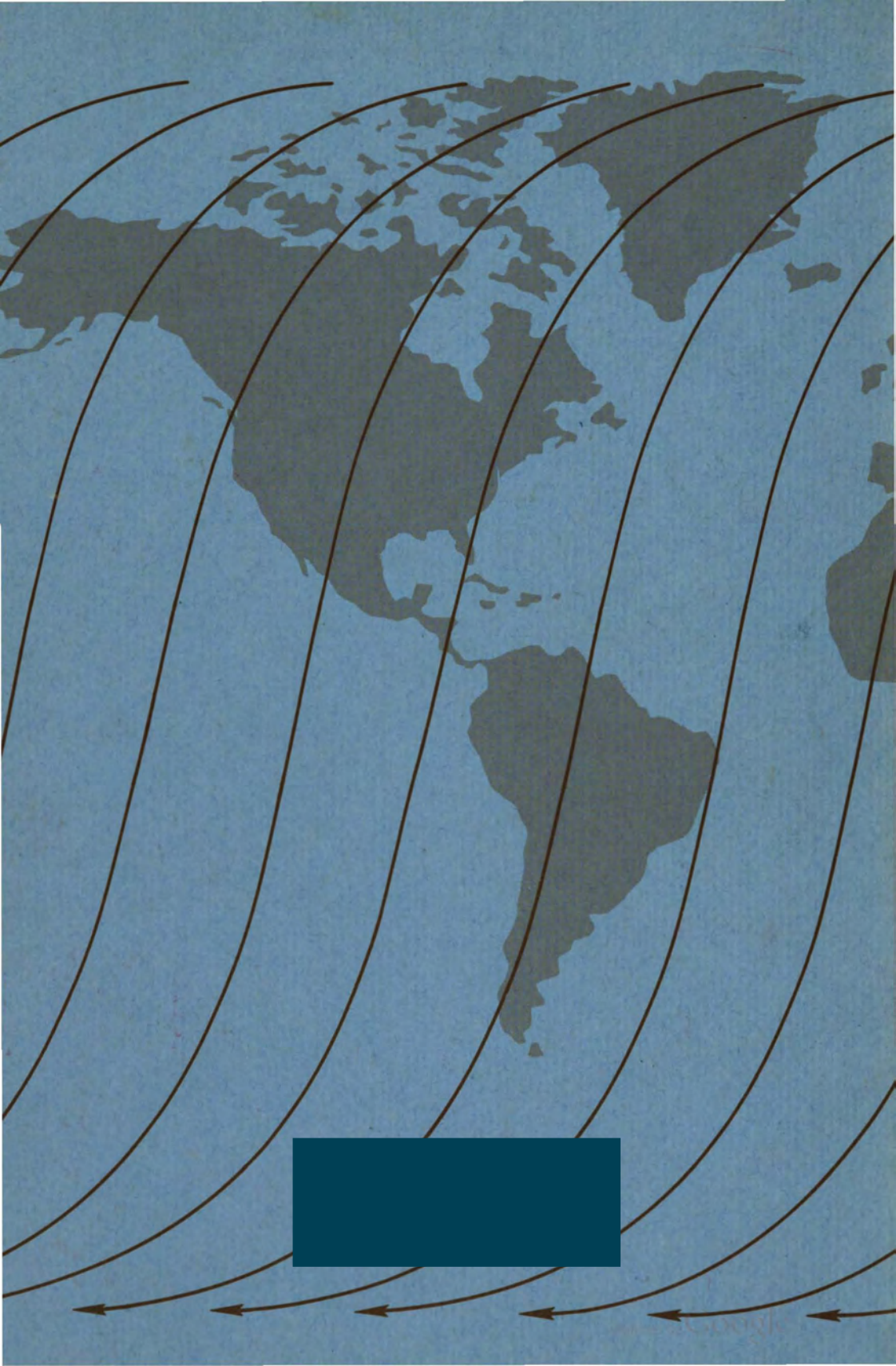
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