FINAL REPORT

AN ASSESSMENT OF INFORMATION DEMANDS FOR REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGIES

By

William G. Brooner
Paul M. Maughan
David A. Thibault

Submitted to the

Agency for International Development
Washington, D.C.

Contract No. PDC-1406-I-00-7070-00
Task Order: 01

February 1988

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PREFACE

The U.S. Agency for International Development, through the Office of Science and Technology's Bureau of Forestry, Environment, and Natural Resources, issued an IQC Work Order to Earth Satellite Corporation (EarthSat) on August 10, 1987, to conduct an assessment of the Third World need for new applications and technologies in remote sensing programs. The assessment includes recent developments in remote sensing and geographic information system technologies which can contribute to economic development activities in developing countries.

The report was prepared by the principal study team members, Mr. David Thibault, Mr. William Brooner, and Dr. Paul Maughan. In addition, significant contributions were provided by Mr. James Durana, Ms. Nancy Anderson, and Mr. Jim Deigan. While the principal study team members conducted the international travel interviews, the contributing members provided many of the domestic interviews for the study, as summarized below:

	Location	Dates	Organization/Function	Team Member(s)
1.	Bogota, Colombia	SEP 9-11	IGAC/CIAF, AID	Brooner
2.	Quito, Ecuador	SEP 12-20	DESFIL Workshop, CLIRSEN, AID	Brooner
3.	Rome, Italy	SEP 17-19	ESA, FAO	Thibault, Maughan
4.	Niamey, Niger	SEP 21-23	AGRHYMET, AID	Thibault, Maughan
5.	Lima, Peru	SEP 21-24	ONERN, APODESA, AID	Brooner
6.	Abidjan, Ivory Coast	SEP 24-27	AID	Thibault, Maughan
7.	Sao Jose dos Campos & Cach. Paulista Brazil	SEP 25-28	INPE	Brooner
8.	Nairobi, Kenya	SEP 28-30	RCSSMRS, KREMU, UNEP/GEMS	Thibault, Maughan
9.	Brighton, England	OCT 10-17	Congress of the Int'l Astronautical Federation	Maughan
10.	Washington, DC	OCT 22	InterAmerican Development Bank	Brooner
11.	Ann Arbor, MI	OCT 26-30	International Symposium on Remote Sensing of Environment	Durana
12.	Dhaka, Bangladesh	OCT 27-30	SPARRSO, BSS, BARC, AID	Brooner

13. Bangkok, Thailand	OCT 30 - NOV 3	NRC, AIT, TDRI, UNDP/ESCAP, AID	Brooner/Thibault
14. Galveston, TX	NOV 2-4	Corps of Engineers 6th Remote Sensing Sym.	Deigan
15. Tokyo, Japan	NOV 4-9	Tokai U., ERSDAC, RESTEC, JICA, JAPEX, PASCO, etc.	Brooner/Thibault
16. Washington, DC	NOV 15-18	International Geographic Information Systems Sym.	Anderson
17. Bogota, Colombia	NOV 16-21	2nd Latin American Remote Sensing Symposium	Brooner
18. New York, NY	DEC 16	UN/DTCD	Brooner
19. Washington, DC	DEC 23	World Bank	Brooner

1.0 EXECUTIVE SUMMARY

In the Fall of 1987, Earth Satellite Corporation (EarthSat) under contract to the United States Agency for International Development (USAID) completed a research assessment of the potential benefits to the Third World of new applications of remote sensing and geographic based information systems (GIS) technologies. This report presents the findings, conclusions, and recommendations of that assessment. The assessment required travel to five continents and the review of numerous projects, programs and technologies. Time constraints made it impossible to view first hand all, or even a majority, of the activities relevant to this study being conducted throughout the world. To meet this constraint the authors drew upon personal experience, acquaintances in the field and the published record of both the information requirements of the developing countries and the available technologies of industrial countries.

1.1 Findings - Information Demand

- The principal need in the developing countries is for information which will support the production of food and fiber. This demand includes information on natural resources, soils, water, vegetation, climate; and on culture, infrastructure, population, and growth.

- Information on current food and fiber production, and near-term forecasts, is essential if nations are to avoid the impact of catastrophic shortages.

- There is an increasing recognition by Third World countries that critical biological resources are threatened by uncontrolled development and that the long-term consequences of this process may irreversibly impact both the local and world environment. Understanding and managing these resources requires regular information on their extent and condition.

- Effective development planning requires basic maps of the physical environment, including planimetric base maps, current and potential land use, demography, current and planned infrastructure.

1.2 Information Supply

- Landsat was the world's first civilian remote sensing program, and for 14 years remained the sole source of high resolution, multispectral satellite imagery. Its success, and the anticipated growth of the remote sensing industry, have led many countries to develop their own remote sensing systems.

- A variety of satellite data are available for the entire world, on a continuing basis, and at low cost (when compared to conventional data collection methods).

- Availability, cost and format of satellite products are principal concerns to Third World users of remote sensing data.

- The development of resource information from remote sensing data may include both manual and computer aided techniques.

- Many computer aided techniques have not advanced beyond research or demonstration (feasibility testing) to operational uses. These techniques may employ aerial photographs, land satellite data as well as daily weather satellite data. Fortunately, this situation is rapidly changing.

- An increasing percentage of satellite image users are working with digital data rather than relying on traditional photointerpretation techniques.

- In the future the principal impediments to the use of remote sensing and GIS technologies are likely to be institutional, not technological.

1.3 Managing Information: Institutional Findings

- The continued training of scientists, technicians, and public officials in the operational use of these technologies is essential to their adoption and effective use.

- Regional centers have been and can continue to be effective means of providing the concentrations of critical capital and human resources essential for the dissemination of these technologies.

- National service centers located close to the budgetary or development planning authority are institutionally most likely to make effective use of these technologies.

- The emphasis of remote sensing and GIS programs must be on the current information needs of operational programs, and not on research.

1.4 Technology Supply

- Development of user-friendly, higher storage capacity, low cost image processing hardware and software systems, and the growth of GIS as a discipline, have expanded the capabilities of remote sensing specialists.

- Computer systems for image processing and image analysis are available from numerous manufacturers. The operational use of these systems in developing country environments is increasing, and the promise is good that they will contribute to meeting information needs. Image processing capabilities must include the production of hard copy outputs.

- Geographic information systems technology, also widely available, can dramatically increase the utility of existing data and broaden their use.

- Hardware and software are useless without a long-term commitment of recipients, vendors, and donors to system support and maintenance and to training.

- Training must be local, must deal with local data, and must survive the initial period of enthusiasm over the new system. It must include:

    - Applications training for local scientists and technicians on local information needs;

    - Hardware system support training for local technicians, including basic diagnostics, and minor repairs - replacing circuit boards, for example; and

    - Orientation for managers and resource scientists so they may know the potential of the tools available to them through their staff and colleagues.

- A worldwide service industry made up of hardware, software, processing and interpretation professionals is well established and growing.

1.5 Conclusions

The continued emphasis in AID projects on remote sensing techniques as an important tool in the development of agricultural, natural resource and environmental data bases is appropriate, and can provide cost savings and increase program effectiveness.

Geographic Information System (GIS) technology can contribute to the development process in project selection, planning, implementation, and evaluation. At present, some developing countries are employing this technology, others are capable or could be.

Adoption, however, may involve more political than technological problems because GIS requires the accumulation of large amounts of data covering the activities of many ministries in a single place. That repository must therefore have the strongest of political support.

The developing countries have demonstrated the capacity and desire to incorporate these technologies in their operational programs.

GIS may also have a place in the AID Mission or Regional Economic Development Services Offices to plan and monitor AID and other donor support projects.

1.6 Recommendations

The mechanisms for encouraging the timely adoption and assimilation of remote sensing and geographic information systems technologies differ in many respects from those used for the transfer of other high technologies to the developing countries. The transfer of these other technologies, such as medical, manufacturing or food processing technology, requires the training of local scientists, engineers and technicians. If the benefits of the new technology are clear, the convincing of administrative or local officials on its use is generally not an obstacle to technology transfer.

Because remote sensing and geographic information systems technologies can serve and effect every public program, and provide valuable information to competing ministries, agencies, and programs, efforts to transfer these technologies must survive the closest political scrutiny, interagency competition, and mistrust. Furthermore, the potential national security implications of collecting these kinds of data and placing them in a single civilian agency is of concern to some governments.

The following recommendations take into account that these high technologies must overcome institutional as well as technical obstacles if they are to be accepted and employed. The study team has attempted to limit the scope of these recommendations to mechanisms which are compatible with AID's objectives, program and budgetary constraints.

o Specific Actions Within AID

a. Prepare and disseminate within AID two monographs, of four to six pages each, which describe in layman's terms these two technologies, their relevance to the development process, and general approaches for incorporating elements of these technologies in future AID projects. The goal is not to conduct remote sensing or GIS projects, but rather to encourage the use of these techniques or tools in every project where the benefits are compelling.

b. Prepare and disseminate within AID brief technical monographs describing specific applications of these technologies in development programs, and providing information on the costs and benefits.

c. Provide technical support to AID project planners in the preparation of technical specifications.

d. The Participant Training Program of AID offers an excellent vehicle for regional short courses, on the job training and internships at regional centers, commercial organizations, and other institutions. It is recommended that AID Missions use this program for training recipients in remote sensing and GIS.

e. AID Missions should request a remote sensing and GIS expert advisor to review their program portfolios (present and planned) to identify where and how these technologies can make significant contributions to their projects.

f. Where basic small-scale (1:100,000-1:500,000) maps are out of date or otherwise inadequate, image base maps for AID project areas should be produced from high quality satellite imagery.

g. AID should support and participate in regional associations, and apprise respective missions of activities, events, etc., in a periodic newsletter/report.

h. An AID newsletter (perhaps 3-4 issues per year) should abstract various remote sensing and GIS newsletters, and contributions to existing AID publications should be increased.

- General Actions with Other Donors and Recipients

  i. Continue to support multi-donor efforts to coordinate activities in these areas so as to minimize duplication in regional and national programs, and incompatibilities within a single country's programs.

  j. Continue to support training, particularly regional and local training which deals with local problems, local data, and local institutions.

  k. Recognizing that the effective assimilation of these technologies will take five to ten years once the process has begun in any country, initiate only those programs which recipients and donors can support to their successful conclusion. Support includes:

     - Hardware and software, and its maintenance and periodic upgrades;
     - Training on-site;
     - Adequate facilities;
     - Committed local staff;
     - Continuing expatriot scientific and technical support staff on-site;
     - Assurance that data will be available and data costs can be met; and
     - Provision of operating funds.

  l. In water deficient regions, groundwater exploration and aquifer recharge estimations should be continuing high priority projects. Small-scale surveys can be completed quickly for large areas. These will focus attention on the areas of greatest potential.

  m. ESCAP is planning a regional inventory of remote sensing and GIS equipment. Similar inventories are needed for all regions.

  n. ESCAP's Roster of Remote Sensing Scientists and Specialists should be duplicated in other regions.

- Conclusion

In 1970, USAID first examined the potential of remote sensing to meet the information needs of the developing countries. A three-day symposium at the Smithsonian Institution considered most of the same issues we are today considering. While much progress has been made in the intervening years, remote sensing is yet a young technology. Its assimilation will continue and can be stimulated by USAID and other donors. The observations and predic-

tions of the symposium participants remain sound. The advise of one, O.C. Herfindahl, is most consistent with the authors' conclusions.

> *"Any program of technical assistance to aid in the determination of needs for resource information and of the appropriate way for using remote sensors to generate this information should be formulated and executed with great care, for the opportunities for serious error are considerable. There is no standard set of data that a country should have by a certain date. Since the amount of money and technical talent a country can afford to devote to the generation of data, with or without help, is always limited, the data to be generated next year should depend on what data already are available and on the prospective demand for data in succeeding years.*
>
> *Data demands from both governmental and private users are highly dependent on the capacity to use data. Demands cannot be determined from the existing body of data and the physical situation in the various resource sectors of the public and private parts of the economy. Rather, the capacity to use data and demands for data are intimately bound up with the political and bureaucratic processes by which the various governmental programs that are potential data users are determined and executed. The extension of technical assistance touching closely on these matters is delicate, and has distinct limits"* (Herfindahl, 1970).

2.0 INTRODUCTION AND BACKGROUND

Remote sensing is a term which covers a wide range of data collection techniques. For purposes of this assessment, only air and space borne sensors are considered. The simplest of sensing devices, the hand-held camera, is used in low flying aircraft to conduct wildlife counts, to monitor crop conditions, and to verify data gathered by other sensors or techniques. Larger cameras are used for regional resource surveys, and the production of thematic and topographic maps. Space borne remote sensing instruments can provide similar kinds of data, but for larger areas, on a one to three week repetitive basis, at a lower cost per square kilometer but also a lower level of ground detail. Remote sensing instruments provide data which must be processed and analyzed to extract the information required by those concerned with agricultural development, natural resources assessments and the environmental analyses. This study considers the kinds and availability of remote sensing data, as well as the existing techniques for processing and analyzing those data.

Geographic Information Systems (GIS) technology is a rapidly developing information handling science which uses computers to record and analyze data on a variety of themes with a common geographic reference. For example, the GIS database may include data on soils, topography, and surface hydrology and the ability to effectively overlay, model, and manipulate these data to meet given analytical objectives. The value of the system is that it enables the scientist to consider, with the aid of the computer, combinations of these data sets in project planning, implementation and monitoring. For example, he may exclude from consideration for cultivation areas containing certain soils, on specified slopes. The number of themes (i.e., geographic descriptions) included in the data base may be increased without limit, though generally the number is between five and fifteen; each may have lengthy attributes. Additional categories may include: land use, vegetation cover, population, transportation networks, geology, political boundaries, critical habitats, rainfall, etc. Many of these data already exist in the developing countries in map or statistical form though their quality varies greatly.

However, to be used in a GIS, data must first be converted into a computer compatible form. Usually the process used is an electro mechanical one called "digitizing." The conversion of analog data, maps and statistics, to digital form is labor intensive, requiring a skilled technician several hours to several days per map. In a regional project area, hundreds of maps may be involved. GIS as an operational technology has only recently arrived in the industralized countries; although initial developments began in the 1960's and several commercial systems were introduced in the 1970's, major hardware and software advances and acceptance by a broad user base has been most greatly realized in the present decade. The extractive and forest products industries are the principal private sector users, while state and local governments lead the public sector. University research is intensive,

and the available systems numerous. Both the United Nations Environmental Programme (UNEP) and the World Bank have initiated significant programs in applying GIS technology in the developing world.

2.1 Information Demand - The Needs of the Developing Countries

The information requirements of the developing countries may vary in form, or emphasis, but basic needs are common. Remote sensing can significantly contribute to meeting each of these needs, though it is a tool which must be used in conjunction with conventional survey and data collection techniques. While remote sensing is not a panacea, in the developing world where resource data are scarce and time and funding constraints severe, it is widely acknowledged as a valuable tool for filling the information gap. The following are the principal information requirements related to agriculture, natural resources and the environment which the investigators found in their discussions with local officials and donor organizations:

- Weather and Climatology
- Soils
- Hydrology
- Topography
- Geology
- Land Use and Change
  - Population and population change
  - Infrastructure
  - Political divisions
  - Housing
  - National parks, critical habitats, etc.
- Land Cover and Change
  - Cropland
  - Grasslands
  - Forests
  - Deserts
  - Fragile lands

The detail at which these data are gathered and the scale at which they are presented varies from country-to-country and project-to-project. Section 3.0 reviews the general information requirements and parameters in more detail. Useful information derived from existing data covering an entire country can be quickly extracted from a GIS provided that the system is well tested, the objectives reasonable, and the technical assistance sufficient.

The Uganda Case Study conducted by the United Nations Environment Programme and the Government of Uganda is an example of such a project (UNEP, 1987). While most of the basic data were presented on small or national scale maps (i.e., 1:1.5 million), derivative information on soil erosion risk, population pressure, land use

pressure, etc., were extracted. This information is being used to identify sites for more detailed data collection and analysis. The GRID Uganda Case Study was completed in just five months.

Reliance on existing data for the initiation of a GIS can provide quick access to the technology, even where data are incomplete or of lower than desired quality. Improving data bases is a longer process which can be carried on simultaneously with the transfer and assimilation of the GIS technology.

2.2 Resource Information Management Needs

Most existing resource information, including that listed in Section 2.1 above, is presented on maps. Mapped information is of great value in project planning and implementation. Seldom does a development project go forward without a map. These maps may vary from detailed surveys to simple sketch maps, and they may contain a wide variety of data. If this mapped information were generally available (and often it is not available beyond the offices of the originator) and compatible with other mapped or statistical data, many projects and many users could benefit from its existence. Compatibility assures that the resource scientist or development planner, for example, may use different data sets simultaneously without making mechanical or mental adjustments for differences in scale or area of coverage.

Both the industralized and developing countries are increasingly turning to GIS technology as means of dramatically increasing the utility of mapped or spatial data. However, the benefits of GIS technology are likely to be far greater in the developing world. This, we believe, will result from a convergence of this technology with the rapidly increasing need to manage the large volumes of data being acquired in the development process. This need is well recognized by recipients and donors alike. Past duplication of efforts and problems with data access and compatibility motivate the broad interest in this technology. The study team were told that six different Thai Ministries are considering GIS for their programs; while the needs and potential benefits are clear, the mechanisms which will assure the successful adoption of this technology are far less so. This subject is considered in more detail in Section 3.0.

2.3 The Supply of Remote Sensing Data and Technology

Aircraft data acquisition is technically possible throughout the world, though costs will vary greatly. Aerial photographs are far more expensive for large areas than land satellite data. However, in some cases the level of detail required may only be achieved using aerial data. For small project areas, aerial data acquisition may be the more cost-effective approach.

Satellite data are available routinely from worldwide weather satellites at a nominal cost, and from two commercial land sensing satellites, Landsat and SPOT. Japan, India, Canada, Europe and the Soviet Union are also in the process of initiating satellite data acquisition programs. All will be providing data in the next decade.

Worldwide interest in the Landsat and SPOT programs has drawn users from over 100 nations, and 15 countries have the facilities to receive, process and distribute data products. An increasing percentage of over 10,000 users of Landsat and SPOT information are working with digital data instead of relying on traditional photo-interpretation techniques. A demand for higher quality, faster digital processing and hardware/software packages has evolved, creating a growing and valuable international service industry.

Numerous computer based systems for processing and analyzing remotely sensed data are available. The systems range in price from $20,000 to more than $1,000,000, and the range in capabilities is at least as great. Reliability and detail of documentation in a developing country environment are key factors in selecting from among technically similar systems. Both mini and personal computer based systems were considered for image processing and analysis hardware and software. Extended discussion of remote sensing's potential contributions to meeting the information needs of the developing countries is presented in Section 4.0.

2.4 The Supply of Geographic Information Systems Technology

Recent developments of user-friendly, higher storage capacity, low cost integrated image processing and geographic information system hardware and software systems, and the growth of GIS as a technical discipline, has expanded the potential of remote sensing and the applications of these technologies.

While dozens of systems, both PC and mini computer based, are available there are few which have been proven in operational environments and fewer still which could be expected to withstand the rigors of installations far removed from customer service and software support. However, this situation is changing and the options available to the developing countries in the next five years should be extensive. Section 4.3 contains an expanded discussion of available GIS technologies.

2.5 USAID Involvement in Remote Sensing Programs

As early as 1970, remote sensing was recognized as having potential for significant impact on the development process. USAID's Office of Science and Technology assumed an early lead in funding projects to transfer remote sensing technology to devel-

oping countries. Project funding included technical assistance, training, data and equipment procurements, and establishment of over a dozen national and three regional remote sensing centers.

During the early 1970's, NASA, through its Principal Investigator program, funded developing country scientists to evaluate Landsat data for natural resources assessments and environmental monitoring. AID concentrated its efforts, through workshops and seminars, on sensitizing developing country officials to the potential applications of remote sensing for development.

AID's Remote Sensing Grant Program, initiated in 1974-75, awarded ten grants for developing country demonstration projects in agriculture, geology, forestry, coastal development and regional planning. The AID/NASA "AIDSAT for Space Age Technologies," demonstrated worldwide benefits of space technologies. Together, these projects furthered recognition of remote sensing's role in ongoing development activities.

In 1977, the National Academy of Science recommended *"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"* (National Academy of Sciences, 1977).

AID's funding for remote sensing technology transfer peaked in 1979. A major agricultural project to assist eleven developing countries to assess crop production and establishment of regional remote sensing centers in Africa and Asia were initiated.

During the present decade, remote sensing has continued to contribute to AID programs, principally natural resources and environmental activities through mission designed projects focused on agriculture and forestry, geology and geography, and hydrology. As more emphasis has been placed on food security, a major AID initiative (in collaboration with other Economic Summit states) is development of an early warning and crop reporting system for Africa. Food security for Africa and other food deficit regions will remain for the next decade the most important requirement in AID for remote sensing technology.

In addition, two other program thrusts, prompted by recent legislation, are expected to require investments by AID:

a. Monitoring of Tropical Forests; the ability to monitor the extent and changes of deforestation using satellite remote sensing has been clearly demonstrated, and information can be provided to developing country decision-makers who must establish policies sustaining the wise use of tropical forests. At the AID sponsored "International Conference on Fragile Lands: Sustainable Uses of Steep Slopes" held in Ecuador in September 1987,

workshop participants reported that the interpretation of satellite imagery and aerial photography represents a modern and rapid method to determine impacts and effects of deforestation, and recommended that their utilization should be increased.

b. Conservation of Biological Diversity; as greater attention is focused toward biological inventories and Conservation Data Center's field surveys, the demonstrated application of remote sensing to stratify and classify land cover, and to direct and guide field collection of biological data will be of value. In addition, the integrated role of Geographic Information Systems can be an important technology for developing National Conservation Strategies.

Increasingly, AID's investments in remote sensing and GIS technologies have moved beyond the stimulation phase of demonstration projects. Essentially all funding for remote sensing projects is now through mission and regional bureau activities. Seen as a "tool" for providing essential natural resource and environmental information, remote sensing and GIS technologies are becoming more operational in the context of ongoing development projects. There is no lack of good applications, from environmental monitoring and profiling, to planimetric mapping and infrastructure planning. Much of the technology is "appropriate," and both daily environmental satellite data (NOAA AVHRR, GOES, GMS, etc.), and land resources satellite data (Landsat, SPOT, MOS-1) are greatly underutilized. The increasing availability of PC-based image processing and GIS systems have motivated developing countries private sector and NGOs to make necessary investments (often with USAID assistance).

The primary limitations to effectively using remote sensing and GIS technologies are generally not technical, and AID also recognizes the continued need for institutional and training assistance.

o Key Thrusts and Sub-Elements (1981-1985)

"During the period 1981-1985, environmental and natural resources activity of AID totaled $815,995,000 of which $33,323,113 was spent on space-related remote sensing activities. Land processes projects focused on agriculture and forestry, geology and geography, and hydrology. (While some projects were oriented to only one of these categories, most projects were oriented toward all three categories.) For example, during this five-year period $6,340,090 was spent in the area of agriculture and forestry; $1,050,000 was spent on geology and geography; and $4,104,400 was spend on hydrology related projects. However, $9,516,450 was spent on projects that touched all three areas of natural resources development mentioned above."

"While institution building is a function of many remote sensing projects, the building of indigenous capacity is especially significant in the activities of three regional remote sensing centers funded over the period 1981-1985 in East Africa, West Africa, and Asia. The total expenditures on these three centers over this period totaled $6,772,000."

"Atmospheric remote sensing related to land processes accounted for expenditures of $5,140,173. A total of $400,000 was spent on onchocerciasis control. In addition, the AID Office of U.S. Foreign Disaster Assistance funded the Global Climatic Impact Assessment project totaling $2.1 million during the period 1983-1985."[1/]

2.6 Current Activities and Programs - Selected Examples

Remote sensing and GIS programs and operational uses are numerous and geographically widespread. The following are brief summaries of the current activities of the other major donors to programs involving these technologies, and six specific programs which the study team visited. In addition, specific projects are discussed in Section 3.0.

2.6.1 **World Bank**

The World Bank has been actively involved in the use of remote sensing since reconstruction and development work was begun by the Bank shortly after World War II. Aerial photography was used primarily to provide civil engineering and agricultural development information. The World Bank's activity in remote sensing increased in 1972, and over the ensuing years the primary Bank unit involved in use and promotion of remote sensing technologies, the Resource Planning Unit in the Bank's Agricultural and Rural Development Department, provided support to projects, including the carrying out of a number of mapping projects using Landsat as a base (e.g., Orissa, India; Nepal; Peru). The Unit was also involved in technology transfer to developing countries, e.g., Indonesia, Nepal and others. The Cartography Division prepared the *Landsat Index Atlas of the Developing Countries of the World* (1976), and began in 1980 to develop Geographic Information Systems (GIS) capabilities. In 1984, the Cartographic Division completed a project on Thailand: "Geographical Information System for Land Policy Analysis."

1/ The material presented was contained in a white paper entitled "National Plan for Remote Sensing Research and Development" prepared by USAID 3/15/85.

The Banks remote sensing and GIS functions were recently reorganized and presently the Center for Earth Resources Analysis functions as a program activity in the Operations and Strategy Division of the Environmental Department. The program has three major areas of responsibility:

a. Collaborate in case studies under new environmental initiatives on the economics of natural resource management and assessments;

b. Provide advice and assistance to the Bank's operational departments in designing projects and programs within which GIS and remote sensing activities are being financed; and

c. Coordinate with other institutions with similar interests.

o **Economics of Natural Resource Management**

The stated goal of the World Bank's recent initiatives on the economics of natural resource management is to incorporate environmental and natural resource concerns systematically into the Bank's country macro-economic development activities in order to improve the country's capability to address environmental problems at the country development strategy and policy levels. The aim is to develop means to integrate the environmental and natural resource dimensions directly into country economic and social policy work, in an effort to achieve sustainable development. Geo-based systems assistance is provided in the form of several country case studies, examining the existing natural and human resource base (e.g., the capability of the resource base to sustain development, the actual use to which the resources are being put, the degree and extent of degradation that has already occurred); the nature, causes and severity of natural resource degradation in light of prevailing socioeconomic criteria (including the welfare of vulnerable societal groups and future generations); trends and patterns in resource utilization; and prospects for the future under various scenarios of economic growth. Approaches and methodologies are being developed to make this information useful more generally to Bank staff and developing country planners formulating policy and project strategies aimed at sustainable development. Remote sensing and geographic information system technologies are central to the support of this initiative.

o Support to Bank Financed Projects

The Center's greatest involvement in the Bank's project cycle is in identification, preparation and implementation/supervision. Work commences early in the project cycle at which time issues requiring a technical evaluation by staff surface. Common examples

of such issues are the need for and an evaluation of proposed aerial surveys in support of resource assessment or cadastral mapping, the need for a GIS component in a project, and a survey and mapping institution building component of a project. Recent examples of project support activities include:

Brazil: Northeast Region Land Tenure Improvement Project. Review progress of project implementation, review the status of bid document preparation for aerial photogrammetry and mapping under international competitive bidding, and review the status of mapping cadastral areas covering 450,000 km^2 in ten northeast states.

Brazil: Northwest I, II, and III Rural Development Projects. Monitoring of deforestation in Mato Grosso and Rondonia States, and assessment of soil fertility in colonization areas.

Nepal: 1) Review and evaluate the National Remote Sensing Center's Digital Image Processing and Geographic Information System facilities with a view to recommending guidelines for future projects of this nature, and 2) complete a mapping project of Nepal at the scale of 1:250,000 based on Landsat.

Colombia: INDERENA - Evaluation of a proposal for systematic geographic data collection, storage, analysis, and distribution.

India: 1) Preparation of a component of the Narmada River Development Project to develop a geographic information/land resource data base for the Narmada Valley Development Authority, and 2) review technical and institutional aspects of GIS needs of the National Wastelands Development Board as part of a World Bank Forestry Sub-Sector Review. The use of SPOT imagery to update 1:50,000 land use maps was considered.

o Technology Transfer

While much of the work in support of Bank-financed projects deals with technology transfer, queries are routinely received concerning GIS and remote sensing technologies that are not part of any Bank project or sector study. Such inquiries typically are to evaluate the merits of consultants' proposals to governments or other multilateral finance development institutions, with regard to the development or enhancement of GIS, or remote sensing capabilities.

Presently, the most important remote sensing and GIS technology transfer activity of the Bank is a collaborative program with UNDP for "Strengthening Natural Resource Management Capabilities in Africa," initiated in June 1987 with initial fund-

ing commitments of over $3 million. The immediate objectives of the program involve training for and transfer of image analysis capabilities and geo-based information system hardware and software to remote sensing centers in Africa; and the application of computer-implemented remote sensing and geo-based information system technology to natural resource assessment and management in African countries.

The World Bank and UNDP are currently completing a four-month "Preparatory Assistance for Strengthening the Regional Remote Sensing Centre in West Africa (CRTO)." The objectives of this effort are to improve the capabilities of the CRTO in Ouagadougou, and the effort involves reviews and evaluations of existing management, administrative, and financial procedures (including a complete audit of the Centre finances), and franco- and anglophone curricula. In addition, inventories of goods and services has been undertaken for the photo lab, library and archives, as well as an evaluation of the effectiveness of the technical outreach program and user assistance program.

This current review and evaluation of the CRTO is a result of Donors Meetings in Paris in March 1987. A report of findings and specific recommendations to the CRTO's Director for improving the centers efficiency on day-to-day activities, financial practices and procedures, management and other recommendations for improvements will be issued shortly. The CRTO's implementation of the recommendations, as well as those made at the Donors Meeting in Paris, are prerequisite to the CRTO's participation in the UNPD's/World Bank's three-year program for "Strengthening Natural Resource Management Capabilities in Africa."

The objectives of the UNDP/World Bank initiative in Africa are similar to UNEP's GRID program, are linked by a common aim, and upon implementation should increase the effectiveness of the GRID project. The UNDP/World Bank project also complements other collaborative donor activities, and seeks to develop a broadly applicable, practical methodology for policy analysis of environmentally sound and economically efficient management of natural resources.

The activities of the Natural Resources Management project will be divided into three types:

a. Training and technical assistance for improved resource data management and analysis. Training in project operation and management will also form an essential part of the course.

b. Outreach seminars to provide for a widespread understanding of these methods by policy makers.

c. Demonstration projects which will provide trainees and policy makers with a clear understanding of how modern resource management systems are implemented and how they

can be used in defining policy goals, assist in resource planning and provide objective information which will allow policy makers to emplace the necessary incentives for improved macro-economic development.

The project will be located in East Africa at the Regional Centre for Services in Surveying Mapping and Remote Sensing in Nairobi, Kenya, and in West Africa at the Regional Remote Sensing Center (CRTO) in Ouagadougou, Burkino Faso.

2.6.2 Food and Agriculture Organization of the United Nations

The FAO Remote Sensing Centre was established in 1980, and has played a major role in technical assistance and technology transfer of remote sensing technology. The Centre, based in Rome, consists of three groups of activities: Assistance in project development and implementation for agricultural, forestry and fisheries sectors; training and technology transfer; and technical support for environmental monitoring.

o Technical Support

The FAO Remote Sensing Centre provides a wide range of support services to member states and FAO field projects, including:

- Selection, procurement and analysis of satellite imagery

- Planning of aerial photography and analysis.

A primary activity involves monitoring agricultural drought conditions in Africa and data compilation for the FAO Global Information and Early Warning System. METEOSAT data, for example, are used to assess precipitation, reported in 10-day intervals, and to forecast agricultural drought. Vegetation index analyses of NOAA AVHRR data are used to identify and assess desert locust breeding areas and outbreak incidences.

Technical support facilities include a browse system for archival of satellite imagery, indices, and listings; a World Aerial Photographic Index (WAPI) for country-based indexing of the location, type and availability of aerial photographs; analog and digital imagery analysis systems; photographic laboratory for black-and-white and color processing and printing; cartography systems; and a remote sensing reference library. A GIS system is being developed and will be installed next year. Program funding is primarily provided by Dutch, Japanese, French and Swedish trust funds, as well as UNEP.

o Training and Technology Transfer

FAO views training as an essential link in the process by which remote sensing technology is being transferred to developing countries, and approximately ten training courses are provided annually at FAO headquarters, each for three to four weeks duration. In addition, regional and national seminars and workshops emphasize technical cooperation between developing countries, and on-the-job specialized training is selectively provided to experienced participants.

FAO's experience in short-course training has shown that developing countries requirements far exceeds current capacities to fulfill these needs. The number of participants that can be accepted is about 25% of the total applications; generally 65%-90% have qualifications and experience which make them basically acceptable. In a recent forestry course, for example, 24 participants were selected from a field of 150 applicants.

o Project Development and Implementation Assistance

Staff of the Remote Sensing Centre assist in the application of remote sensing in many renewable resource disciplinary areas including soils, land use, water resources, forestry, fisheries, livestock and rangeland surveys. They provide backstopping support and field support for establishing national remote sensing centers and programs. Continuing assistance is not a goal; the FAO objective is to start programs and insure that a national capability is developed to maintain the program. FAO has assisted in the establishment or augmentation of national centers in Argentina, Bangladesh, India, Peoples Republic of China, Vietnam and others.

The Centre undertakes advisory services and consultancies as needed for project identification or feasibility missions, economic assessments, and preparation of project documents. Advisory visits are intended to assist national or project staff who lack specialized knowledge necessary for technical decisions in remote sensing applications.

o Worldwide Indexes of Aerial Photography and Space Imagery

To many, it has long been apparent that large amounts of aerial photography and space imagery are available for the developing world, but the location and attributes of those data have been generally unknown to all but a few of their potential users. The agency which collected the data, the donor, and perhaps a few others knew of their existence. In 1981, The Remote Sensing Centre of FAO convened a panel of experts to examine means of creating a worldwide data base on existing space and airborne imagery. The goal is not to gather the data, but rather to identify its repository and describe its general parameters (i.e., area of coverage,

scale, instrument, date, etc.). The experts recommended the establishment of an automated data base in Rome which would be accessible from anywhere in the world. That system exists and is fully functioning. To build the data base, FAO employed the staff of the Centre as well as consultants. Considerable progress has been made. SPOT and Landsat coverages are included as well as detailed surveys of existing air photo coverage for much of Africa.

- ARTEMIS (Africa Real-Time Environmental Monitoring Using Imaging Satellites)

The Remote Sensing Centre has developed an operational satellite-based early warning system with support from The Netherlands. It will provide timely information to the UN's global information and early warning systems, as well as other programs in FAO, UN sister organizations, as well as national and international programs and agencies. It will operate in close cooperation with NASA Goddard Space Flight Center, the University of Reading (U.K.), and the National Aerospace Laboratory of The Netherlands. The program will make use of automated databases of geographic features, agroclimatology, METEOSAT rainfall estimates, AVHRR vegetative index-value and the Desert Locust Habitat database. Ultimately, a distribution system is envisioned with centers in West Africa (AGRHYMET) and East Africa.

2.6.3 United Nations System

Within the system of United Nations bodies and agencies, the political coordinating role in remote sensing is played by the UN Committee on the Peaceful Uses of Outer Space (COPUS) supported by the UN Outer Space Affairs Division.

The Division, based in New York, has responsibility for implementing recommendations of the Committee related to the promotion of international cooperation and peaceful uses of outer space. Through its Programme on Space Applications, the Outer Space Affairs Division organizes, sponsors, and conducts seminars, panels, and workshops, usually in cooperation with other UN bodies, including FAO and the Department of Technical Cooperation for Development (TCD).

Of increasing importance are the regional economic commissions of the United Nations for promoting and facilitating the regional use of remote sensing technologies to accelerate economic development. These include the Economic Commission for Africa (ECA), the Economic Commission for Latin America (ECLA), the Economic and Social Commission for Asia and the Pacific (ESCAP), and the Economic Commission for Western Asia (ECWA). ESCAP, for example, has initiated a very successful Asian Regional Remote Sensing Programme.

o Department of Technical Cooperation for Development (TCD)

As part of the Secretariate of the United Nations, the Department of Technical Cooperation for Development provides technical advisory services and assistance for a variety of activities including natural resources exploration and remote sensing. The Infrastructure Branch, as part of the Natural Resources and Energy Division of the TCD, provides technical assistance in the planning, construction, maintenance and operation of a large variety of public works. Cartography (surveying and mapping) and remote sensing are considered vital tools in the planning and operation of these activities and are therefore part of the functions of the Branch.

Activities in remote sensing include preparation of projects and establishment of remote sensing centers at national and regional levels. Projects provide technical assistance, including training fellowships and interpretation/analysis equipment. Assistance in the use of remote sensing for resources development is also provided.

As of 1987, about 30 countries have received technical assistance and advisory services which resulted in project designs for further implementation either on a multinational or bilateral assistance level. The range of technical assistance has covered simple processing of remote sensing data to establishing the infrastructure of a fully developed remote sensing center.

The TCD is also instrumental in initiating regional remote sensing programs, a process that is considerably more complex and difficult than national programs, but which also provides significant potential for interregional technical cooperation and benefit. Regional programs also facilitate the use of remote sensing technologies as appropriate to address problems of regional concern.

TCD's first regional program was initiated nine years ago, with UNDP, and involved nine countries in the ESCAP region. The program was subsequently transferred from TCD to ESCAP, and continues with UNDP funding.

A similar regional effort is in the preparatory stage involving eight countries in Latin America. Although it is moving slowly, the program has a strong technical focus, led by CNIE (Argentina), and is included in the UNDP pipeline. The Project Document has been approved by Argentina and endorsed by the participating Latin American countries.

Also in the preparatory stage is a regional remote sensing program among Arab States. National technical representatives met in Tunis in 1986; a follow-up assessment of regional needs and

requirements at the national planning level covering 14 countries was completed in June 1987. A regional program Project Document has been formulated.

Examples of ongoing remote sensing related projects at TCD include:

China:	Establishment of a National Remote Sensing Centre
Ethiopia:	Development of National Scientific and Technological Capacity in Natural Resources in Remote Sensing
Jordan:	Development and Training for a Modern Integrated Mapping System
Madagascar:	Assistance to the National Institute of Geodesy and Cartography
	Aerial photography and topographic studies for the Canal des Pan Galanes
Zaire:	Remote Sensing Training, ERS Center in Zaire
Regional Latin America:	Technical Cooperation for Satellite Observation of Natural Resources

In addition, current "pipeline projects" involving remote sensing activities are at various stages, and include new or expanded activities in China, Ethiopia, Iraq, Jamaica, Peru, Philippines, Regional Arab States, and Regional Latin America.

2.6.4 The Economic Summit

The Economic Summit in Versailles in 1982 established a Working Group on Technology, Growth and Employment whose goal is to analyze the influence of modern technology on economic growth and employment.

While this Group's activities were originally restricted to the study of these effects on the economies of Economic Summit members, lines of cooperation have since been established with other countries, and in the areas of remote sensing in particular with the developing countries.

The Summit recognized that satellite-assisted remote sensing is a field in which modern technology is playing an increasingly important role. Data cover many sectors of the economy and present the developing countries with a cost-effective method of establishing more accurate data bases for planning.

Member countries of the Economic Summit convened a panel of experts in Berlin in 1986 to consider the potential of these technologies for meeting the information requirements of the developing countries. More than 50 experts from the industrial and developing countries and international organizations participated. Both recipients and donors discussed information needs and solutions. The discussions were extensive and the comments of participants unrestrained.

Conclusions of the 1986 Conference included:

- The developing countries have long been convinced of the potential of remote sensing but they lack the training opportunities and the resources to acquire and use this technology.

- There is a serious gap in the coverage of Africa by a satellite receiving station and so the urgent need of cooperation from the industrial countries to support the installation of receiving stations and their operation on this continent.

- The enormous capacity of aerial photographs already existing and photointerpretation are under valued.

- Other major needs of information derived from remote sensing are linked to the following areas of applications:

    - base maps at small and medium scales;

    - natural resource inventory and monitoring;

    - meteorological information related to natural catastrophies (tornado and drought warning, flood monitoring, etc.);

    - forest inventory and deforestation monitoring;

    - monitoring of waterlogging and salinity of soils;

    - food and crop inventory;

    - land use mapping;

- geological (structural and lithological) information for hydrogeology, mineral and oil exploration, seismic activity.

- Developing countries needs also include availability of satellite remote sensing data. In this regard, the industrial countries should establish policies to ensure availability of data, price stability of raw data, and timely dissemination of these data to developing countries.

- In spite of the economic constraints that face many developing countries, most of them have created remote sensing centers or coordinating agencies, and have defined national policy and program to support activities in this field.

- There is a serious lack of training material on digital image processing and geographic information systems in most of the developing countries, and even within the regional centers. A major support from industrial countries is requested in this regard.

- GIS are also in a state of development, but it would be of great importance to develop such tools in order to optimize the use of multisource data, including remote sensing data, adequate extraction of valuable information and its dissemination in a faster and more efficient manner.

2.6.5 GRID: United Nations Environmental Program, Global Environmental Monitoring System

GRID (Global Resource Information Data Base) is an activity of the United Nations Environment Programme which was established as part of UNEP's Global Environmental Monitoring System (GEMS) in 1985.

GRID uses spatial data in the form of maps, images, and information acquired by ground surveys, and information derived through the interpretation of remote sensing data. These data and derivative information are processed and stored in a geographic information system, thus making them easily accessible. The GRID GIS also enables data users to compare, or overlay one data set with another.

At present GRID is in a pilot phase:

Pilot Phase (1985-87) - testing data-handling technology; collation of global data sets; initial data supply; demonstration case studies; and training.

Implementation Phase (1988-90) - system specification; dataset expansion and refinement; contribution to global assessments; establishment of regional nodes; linkage to agencies; completed case studies; and training.

Operation Phase (1990-On) - establishment of national nodes; global application of resources; information technology; and training.

The goal of GRID is to provide scientists and planners access to integrated environmental data sets and data management technology, using common formats and systems of storage and retrieval.

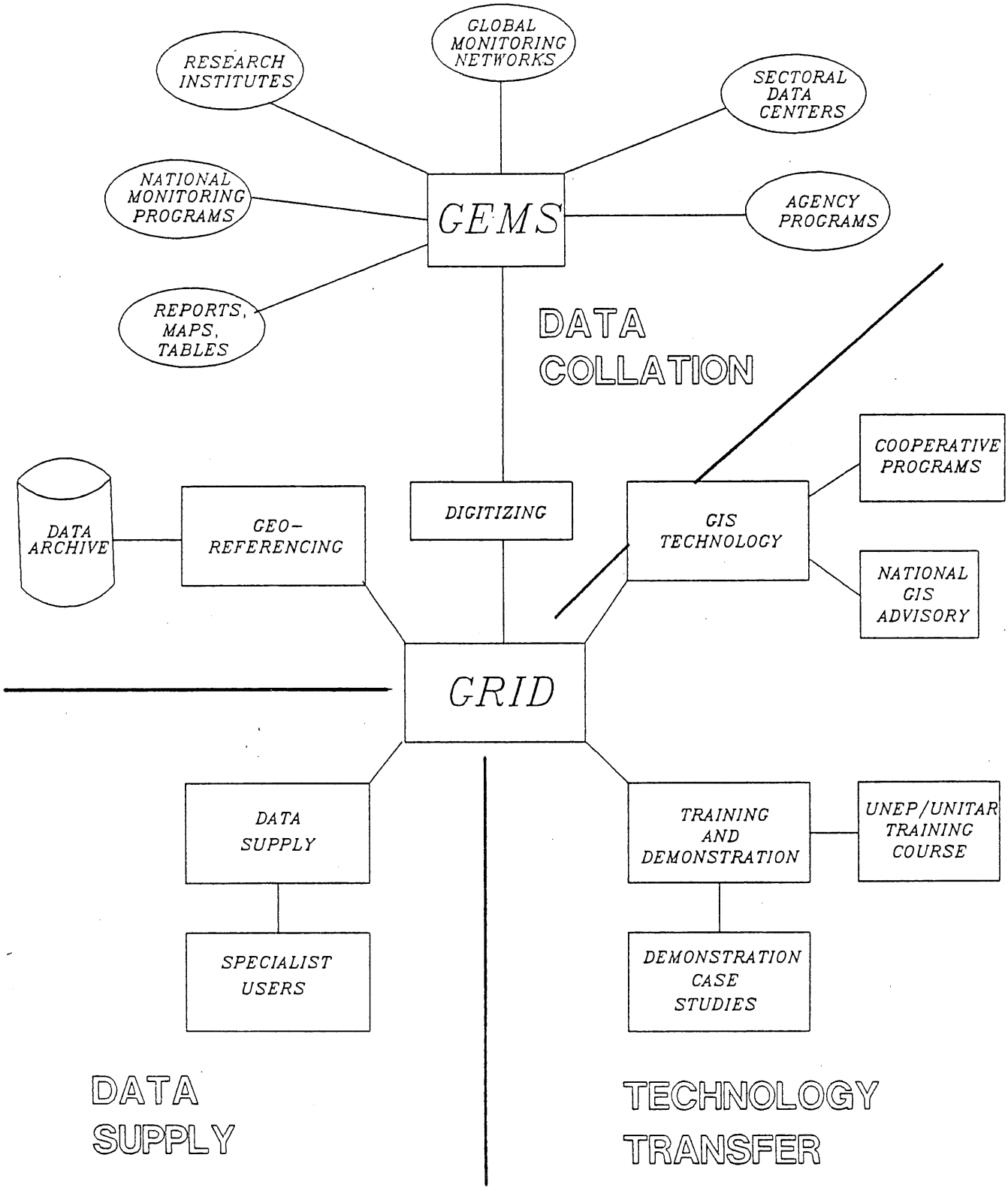
Harmonizing new information with existing data sets can help decision makers identify areas of environmental stress, and focus effective remedial action. Rather than analyzing a problem in isolation, GRID provides an opportunity to examine problems in a global, continental, or national context. GRID serves as a switchboard that can process, and make the appropriate connections between, the diverse sets of information that are gathered by GEMS and other national and international programs.

A typical example is the approach being planned to assess the likely impacts to coastal zones of sea-level rise caused by global warming. A national or regional planner needs to know what land use types (such as agriculture, recreation areas, urban centers) together with the people and their infrastructure, which would be effected by a range of sea-level rise scenarios.

GRID's importance to developing countries goes beyond the establishment of a series of macro scale worldwide or continental data bases which can be manipulated using state-of-the-art GIS technology (*Figure 1*). Techniques which work at global and continental scales are equally useful at national and provincial levels. Indeed the GRID GIS software (ARC/INFO) is used by many local and regional government agencies in the United States. Cooperating governments may acquire GRID GIS application expertise through training at GRID headquarters in Geneva. In addition, pilot projects conducted by GRID and cooperating governments offer the opportunity to acquire the technology, and the necessary training through first hand experience using local data, addressing local problems. The Uganda Pilot Study referred to in Section 2.1 is an example of such a project.

FIGURE 1: How GRID works

GRID works in three main areas: data collection, data supply and technology transfer



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2.6.6 ESCAP/UNDP Regional Remote Sensing Programme

The Regional Remote Sensing Programme, initiated in March 1983, is a project of the governments of Asia and the Pacific, with the United Nations Development Programme providing financial support to the project. National agencies for remote sensing and related ministries in the region are the coordinating agencies for the Regional Remote Sensing Programme (RRSP), while the Economic and Social Commission for Asia and the Pacific (ESCAP) is the executing agency, in association with the United Nations Food and Agriculture Organization and the United Nations Department of Technical Cooperation for Development.

In 1986, the Regional Remote Sensing Programme was extended for five more years, through 1991. This illustrates the success of the program which has established a close network throughout the remote sensing community of the ESCAP region.

The program has successfully assisted regional coordination and the exchange and dissemination of information to member countries. It organizes regular meetings of the Directors of the National Remote Sensing Centers/Programs, as well as technical working groups such as the Expert Group on Remote Sensing Education and Training in the ESCAP Region. It recently published a "Roster of Remote Sensing Scientists and Specialists in the ESCAP Region," and is presently initiating an inventory of remote sensing, photogrammetric, and GIS equipment in the region.

2.6.7 The Regional Centre for Services in Surveying, Mapping, and Remote Sensing (RCSSMRS)

The Regional Centre at Nairobi was established in 1975 to provide surveying and mapping services to the nations of East and Southern Africa. In 1977 remote sensing services were added. The Centre is located in new facilities outside of Nairobi and has departments in cartography, geodesy, engineering, and remote sensing. Training and technical services are offered in each of these areas. Member states which comprise the governing body include Comoros, Kenya, Lesotho, Malawi, Somalia, The Sudan, Tanzania, Uganda and Zambia. The members and international donor agencies provide the financial support for the Centre. *"In remote sensing, the Centre's support includes training courses, user services and project design and implementation support. Each of these areas of activity shows a continuing demand and offers services on a regional basis. Participation in these activities by individual countries is a function of existing facilities and national programmes. Zimbabwe has a well developed activity in remote sensing making use of digital processing capability in the University and the Institute of Mining Research. Tanzania has optical image analysis equipment in the Institute for Resource Analysis and The Sudan has a national remote sensing center currently receiving direct assistance from USAID through a contract with the RCSSMRS.*

Other countries in the subregion have developed remote sensing to varying levels. However, there is no operational receiving station for SPOT or Landsat data in the subregion and the Landsat receiving station near Pretoria has a coverage circle reaching only as far north as central Tanzania. Not mentioning the fact that most of the African countries will not and cannot use information from that station" (Hassan and Falconer, 1986).

The Nairobi Regional Centre represents a clear success story in the establishment of a mechanism for transferring an advanced technology to developing countries. The elements of that success are based upon several principles which we believe are applicable in other developing regions:

- The Centre serves a region which is large enough to justify the financial support necessary to acquire, operate and maintain high technology equipment.

- The Centre's service area contains many resource management problems which are common to all of the member states.

- Training of local scientists and technician's emphasizes hands on practical uses of the technology. Training exercises involve data, and problems from the trainees own countries and ministries.

- When the trainee returns home, he continues to receive support from the Centre in the form of data, materials, and technical advise.

- Donor support has been long-term with expatriot experts on site for more than a decade. The transfer to full African direction and operation is now in the final stage.

- The Centre is accountable to donors and its governing board.

Dr. Hassan Hassan, Director of the Remote Sensing Department commented that whereas the U.S. uses remote sensing mostly for research, Africans use remote sensing for operational programs. Thus, remote sensing becomes an absolutely necessary tool for resource management and plays a crucial role in decision processes for many resource issues.

A second point made by Dr. Hassan was that effective use of remote sensing data and translation into information products can only be done through a centralized group, that is a place where there is a critical mass of equipment scientists and technicians, etc., that can interchange and exchange information and capabilities to keep a facility within grasp of the rapidly changing technology.

The philosophy of the Regional Remote Sensing Centre is to work with people, not for people, and therefore their projects take on a somewhat different connotation as they are reviewed and evaluated. In this context, the map maker at this Regional Centre becomes only an intermediate user. The end user becomes the particular country with which the Regional Centre works. An interesting consequence of the development of GIS capability is that a fully operating GIS could allow the end user to bypass the intermediate map maker. This is an extremely important point in considering the utility of GIS systems in Third World development.

The Nairobi Regional Centre considers one of its main roles as communicating the status of remote sensing technologies and providing information on its usage. They would very much like to put together a useful inexpensive package ($2,000-$3,000, or as costly as $20,000-$30,000 incorporating a PC-based image processing/GIS system) that each trainee would carry home after completing the training course. Such packages would contain basic supplies and materials that would allow the trainees to do image overlays, etc. Trainees often find very desperate situations when they return to their home because they cannot get even the most fundamental tools in their own country setting to carry out what they have learned during their training.

The study team had the opportunity to walk through the digital image processing and photo labs and were quite impressed with the expertise demonstrated in producing digital products and multispectral images.

In response to questions about the construction of a direct receiving facility for Landsat/SPOT and other satellite remote sensing systems, Dr. Hassan responded that there is currently a nine-month, three nation funded (French/German/Italian), feasibility study to determine the requirements and funding mechanisms for such a ground receiving station. It appears that the Italians want to use the hardware from their station at Mas Palomas rather than purchase new hardware for an east African receiving station. However, it is generally believed that the study will recommend a new ground station be put in place in Nairobi as funds can be made available. It will take three to five years for such a station to become operational.

2.6.8 Asia Institute of Technology

In 1979, USAID authorized a program to develop a regional training center for southeast Asia. The Asian Regional Remote Sensing Training Center (ARRSTC) was established at the Asian Institute of Technology (AIT), a multilaterally supported autonomous international institution for post-graduate education, principally in the engineering-related sciences. The location,

near Bangkok, took advantage to proximity of the Thailand receiving station, and AIT's facilities provided an attractive environment for transferring remote sensing to developing countries of Asia.

In 1982, ARRSTC initiated its first training course. From 1982-1986 AID provided seconded faculty, under personal services contracts, as well as building and equipment facilities.

In addition, UN/ESCAP and agencies of the French and German governments have provided support in the forms of seconded faculty to teach and work on research and development projects, equipment grants, and scholarship support for academic participants.

As the ARRSTC program developed and expanded, appropriate equipment and facilities were acquired to provide both visual and digital analyses, as well as GIS applications. The curriculum has been expanded and integrated with other programs at AIT, as well as improvements in courses, laboratory and field exercises. In the 6th Year Evaluation Report prepared for AID in 1986, major achievements of ARRSTC were summarized as follows:

a. Out of an original goal of 300 trainees, 290 from 12 countries have been trained. Of these, 86% are using their training, 65% have received promotions following their training, and 39% are in teaching or research.

b. The course program has been fully integrated into the AIT pattern with five initial courses; and in the current term, 39% of the students are from other AIT Divisions.

c. The curriculum is strong with substance and depth, even though four deficiencies were identified, all of which are easily correctable.

d. President North has recently taken steps to put ARRSTC management under the AIT administrative framework.

e. The ARRSTC program has completed two demonstration projects, has one nearing completion and two new projects have been initiated.

f. The AIT Faculty Senate has "approved in principle" an Integrated Natural Resources and Development Program on which design and planning is continuing. This is an outgrowth of ARRSTC thinking and leadership.

2.6.9 Instituto Geografico "Augustin Cadazzi," Bogota, Colombia

The study team met with Dr. Carlos Molinas (Subdirector) and Professor Myriam Ardila (Remote Sensing and GIS Department) at the Centro InterAmericano de Fotointerpretacion/Instituto Geografico "Augustin Cadazzi" (IGAC/CIAF) in Bogota, Colombia. In addition,

IGAC/CIAF co-hosted the Second Latin American Remote Sensing Symposium in November. The symposium was held in conjunction with the VII Plenary Meeting of SELPER (Society of Latin American Remote Sensing Specialists), the III Symposium of Colombian Remote Sensing Specialists, an International SPOT Colloquium, and the Second meeting of JOBRESA (Joint Board for Remote Sensing Activities). The symposium was attended by over 330 registrants from 22 countries and 15 international organizations, including a study team member.

CIAF is a well respected post-graduate training and research center, originally established in the late - 1960's with assistance of the Dutch Government and cooperation with the International Training Center (ITC) at Enschedde, The Netherlands. Between 1968 and 1987, a total of 718 students from over 20 Latin American and Caribbean countries (65% non-Colombian) have participated in CIAF academic programs. Dr. Molinas explained that the program's need and interest exceeds capacity, and acceptance criteria and standards are high; applicants must have an undergraduate degree, minimum of two years relevant employment experience, and requisite funding (tuition is about $6K/yr). Over the past 19 years, 39% of the applicants have been accepted.

Academic programs include soils and land use, geology and geomorphology, forestry and ecology, civil engineering and photogrammetry, regional development, and remote sensing. In addition, short courses, ranging from 2-16 weeks, have included over 1750 participants. The teaching/research faculty includes over 30 members, all with graduate training and most with advanced degrees from the U.S. or Europe.

In addition, CIAF's activities include:

a. Research, often in collaboration with national institutions

b. Consultancies - over 50 projects related to natural resources

c. Publications - including a quarterly scientific journal

d. Seminars and Symposiums - over a dozen examples.

In January 1987, CIAF was reorganized under the Instituto Geografico "Agustin Cadazzi" (IGAC); it is now a division of IGAC, known as the Subdirectorate de Docencia e Investigacion.

In March 1987, IGAC entered a new five-year agreement with the Dutch Government for 10 million Guilders (about U.S. $4 million), including fellowships, materials and equipment, and faculty exchanges. Through this agreement, close cooperation between the Subdirectorate and the ITC International Institute for Aerial Survey and Earth Science continues.

Traditionally, CIAF methodologies have focused principally on aerial photointerpretation and photogrammetry, and SLAR interpretation. In recent years, a remote sensing group has been very active, developing both teaching and research programs involving Landsat and SPOT digital processing and GIS applications and technology development.

In September 1987, the InterAmerican Development Bank (IDB) initiated a three-year technical cooperation agreement with IGAC which will significantly upgrade the subdirectorate's equipment, facilities and training programs in remote sensing and geographic information systems. The $2 million IDB grant will enable acquisition and development of advanced digital image processing systems, an integrated GIS facility, advanced training for remote sensing and GIS faculty, new photographic laboratory facilities, and on-site technical assistance for systems development, integration and implementation. Both minicomputer and PC-computer based system procurements are underway.

IGAC/CIAF clearly provides an established, effective, regional center committed to the transfer of remote sensing and GIS technologies. USAID missions in the Latin American and Caribbean regions are encouraged to participate by supporting qualified local participants for both available certificate and short courses, as well as benefit from IGAC/CIAF's research and consultancy capabilities and experience.

2.6.10 Brazil's Instituto de Pesquisas Espaciais (INPE)

Remote sensing activities and programs in Brazil began in 1968. In the subsequent 20 years, Brazil has become a major participant in international remote sensing applications, development of new technologies, and supplier of data. Throughout this history, and leading current and future programs and developments, the focal organization has been the Brazilian Instituto de Pesquisas Espaciais (INPE), headquartered at Sao Jose dos Campos, SP.

In the early 1970's, Brazilian remote sensing activities focused on three programs:

1. Participation in NASA's ERTS-1 program and the construction of a Landsat receiving station at Cuiaba;

2. Training of Brazilian scientists in Landsat applications and analysis, and

3. Projeto RADAM, an integrated natural resources survey of the Amazon Basin, using Side-Looking Airborne Radar (SLAR), conducted through the Ministry of Mines and Energy (IBGE).

In the mid-1970's, the satellite remote sensing program at INPE began receiving Landsat data, and applications programs were developed. Also during this period, Projeto RADAM BRASIL expanded to include an integrated natural resources survey of the entire country using airborne SLAR imagery.

As the Brazilian remote sensing programs evolved into the 1980's, the Projeto RADAM BRASIL was fully integrated into IBGE, and resource maps and studies were concluded for the entire country. At INPE, Landsat reception, processing, archiving and distribution activities grew (image distribution of photo products peaked in 1979). Application methodologies and technology transfer programs were developed, personnel training became more highly specialized, and systems and instrumentation programs were developed.

The study team met with Marcio N. Barbosa, Director of Remote Sensing at INPE, and senior members of his staff at both INPE Headquarters, at Sao Jose dos Campos, and the INPE Data Processing Facility, at Cachoiera Paulista. In recent years INPE's remote sensing program has been reorganized and substantially expanded, discussed in the following. In addition INPE is developing Brazil's earth resources satellite program, summarized in Section 4.1.

New objectives and goals emerging from INPE's remote sensing program reorganization included:

- Expand the capacity to receive, processes, archive and distribute current and new satellite data. INPE has received GOES since 1969, Tiros-N and Landsat since 1973, as well as NOAA 8 and 9 AVHRR, and SPOT reception began in September 1987; future plans include Europe ERS in 1991 and Radarsat in 1994;

- Expand external training programs and facilities;

- Establish new regional remote sensing laboratories and university affiliations. Regional remote sensing laboratories are already in operation at three locations in Brazil;

Today, INPE is organized under the Ministry of Science and Technology; remote sensing programs and Brazil's developing space program receive high visibility and strong Ministry support, from which INPE's Directory of Remote Sensing currently receives a program support budget in excess of $1.5 M per year (not including salaries and revenues from data sales and contract services). Donor assistance programs contribute an additional $800K.

In recent years INPE has been developing a family of image processing systems based on Brazilian microcomputers (SITIM System for Digital Image Processing). After development and testing, equipment and systems are transferred to national industries for production and commercialization. INPE staff reported that there are, at present, fifteen digital image processing systems in Brazil (types and manufactures unknown).

Similarly, a geographic information system which includes satellite image processing has been in development for more than a year. This system will be based on mini and microcomputers, using Brazilian technology. It is noted that some INPE personnel are critical of this activity, believing that it is an unreasonably costly effort to duplicate presently available commercial systems on the foreign market (i.e., ERDAS and others) solely to protect Brazilian industry which is lagging in this technology.

One of the largest components of INPE's remote sensing program is technology transfer. Through user services and assistance, INPE provides advice on products, techniques, methodologies, and image analysis systems (both visual and digital) for information extraction. Training programs include short and middle term courses by a team of training specialists (MScs and Ph.Ds), catered to subject/site specific interests. At the graduate level, INPE offers a two-year Masters degree program in remote sensing. Other activities include organizing symposia, seminars, lectures, demonstrations, etc., and participation in international cooperation programs. INPE is currently the seat of SELPER, and has developed cooperative programs with more than 24 countries.

In 1986, INPE conducted a one-month training program for nine Panamanians sponsored by an IDB project, and a program for eight participants from Mexico, Dominican Republic, Peru, Argentina, and Uruguay, sponsored by UN Outer Space Affairs Division. This year (1987) INPE is conducting a nine-month training program (in English) for six participants from Ethiopia, Nigeria, and Burkino Faso, sponsored by the National Research Council (CNPQ) and ESA. Recent international projects have included a forest inventory in Uruguay, sponsored by UNDP, and a rice inventory for Corrientes Province, Argentina. INPE's interests, and current activities, clearly extend beyond Brazil.

2.6.11 Oficina Nacional de Evaluacion de Recursos Naturales (ONERN), Peru

ONERN (Oficina Nacional de Evaluacion de Recursos Naturales) is a Peruvian government institution, under the Ministry of Planning, responsible for conducting integrated studies of natural resources at the regional and national level, formulating policies for use and conservation of those natural resources, and conducting studies of the relationship between man and his environment.

Since its creation in July 1962, ONERN has been extensively involved in remote sensing and cartographic programs. Their exploitation and analysis of aerial photography is complimented by the analysis and application of satellite imagery for multiple subjects and studies. In the last 25 years, ONERN has evaluated approximately 50 percent of the Peruvian territory, produced over 95 study reports, and over 2500 thematic maps covering 26 different topics at scales ranging from 1:20,000 to 1.3 million.

In the 1970's a remote sensing division (Oficina de Percepcion Remota) was created as a focal point for satellite image processing and applications. The principal donor support was provided by the Canadian International Development Agency (CIDA), and included the provision of a DIPIX Aeries I image processing system, photolab equipment and supplies, and technical assistance under CIDA's PRECEP-I program. In the early 1980's, through World Bank support, a complete, nationwide, Landsat Photomap series (Mapa Planimetrico de Imagenes de Landsat) was prepared at 1:250,000 scale. Presently, as part of the PRECEP-II program, CIDA is providing an upgraded DIPIX Aeries III system, and the ONERN Remote Sensing Office also serves as the national distributor for SPOT data as well as a SPOT PEPS program investigator.

Under a USAID Project (No. 527-0202) initiated in 1983, ONERN received technical assistance to strengthen capabilities in land use inventories, environmental assessment, and provision of an automated GIS. In 1984, a new division was created, the Oficina de Informatica (OFIN), to organize and conduct an automated network to capture, process, and analyze natural resources and environmental information of the country in ONERN's GIS.

The ONERN-GIS can manipulate data bases with up to 25 layers, each layer with up to 127 attributes. The system is capable of compiling large, multilayered data bases, interactively analyzing and manipulating these data bases, generating and displaying resultant graphics and statistics to aid in resource management decisions. The GIS software was provided by ERIM and is a basic raster-based design providing data input, storage, manipulation and display, and output capabilities. Subsequently, a Landsat geometric correction component and data base management (DATATRIEVE) capabilities have been added.

During the survey visits and interviews with ONERN's acting director (Luis Masson M.) and the remote sensing and information division managers (Walter Danjoy and Mauro Mendoza), a variety of issues, both technical and institutional, were addressed. For many years, ONERN has relied on donor support for enhancing its capabilities and equipment. At the same time, it has recognized the need to expand its outreach to broaden its base of users/clients. In the past two years, the Oficina de Informatica has taken the

lead in this effort, publishing a 13-page capabilities and services brochure and conducting a variety of promotional meetings, seminars, and demonstrations.

While ONERN's technical facilities and staff capabilities are well advanced, several institutional problems identified in the past, e.g., the USAID project evaluation, remain. There is limited coordination and cooperation between the Oficina de Percepcion Remota and the Oficina de Informatica; the digital image processing and GIS systems are not linked and projects are often not effectively coordinated. A strong management leadership is lacking; the office of the director has been officially vacant for almost two years.[2/]

OFIN staff indicated a need and desire to link the remote sensing image processing systems with the GIS, and within the GIS to link socioeconomic information of different boundaries, i.e., incorporating relational data base capabilities. They expressed need for technical assistance to accomplish these goals.

OFIN would also like to establish a "Departamento de Capacitacion" (Training) to provide programs on how decision-makers can use information generated by the GIS. They would like to offer training programs for both private and public sector decision-makers.

Regional development corporations are public planning agencies at the Provincial Departmental (state) level, are all potential users/benefactors of ONERN's products and services, but also typically have low budgets. USAID has reportedly provided these regional development corporations (25 in total) with microcomputers (PC's), but there is a need for training and technical assistance on their uses and applications. OFIN feels they could provide this support, as well as other services.

Following completion of the recent USAID grant, no direct support is currently provided to ONERN. USAID's program was successful, establishing a solid technical capability and facility which ONERN has continued to develop and apply to multiple projects and programs. ONERN is now well positioned to provide products and services to USAID and other users on a continuing basis, and this provides USAID the opportunity to reap a return on its investment at ONERN. For this to work, ONERN must continue to improve the quality and quantity of its products and services, and USAID must be vigilant in its support by providing a continuing, and diverse, flow of project assignments requiring ONERN's products and services, and supportive of current and new USAID programs.

2/ On December 1987, Ing Cesar Calderon S. was officially appointed as Director of ONERN.

3.0 THE DEMAND FOR INFORMATION

3.1 Introduction

The quality of life a nation can afford its citizens depends on a complex interaction of geophysical, environmental, political and economic factors. How a country manages it's affairs depends not only on its own available resources (including human and natural resources), but on the information necessary to most effectively exploit those resources.

Rapid advances in information technology including data acquisition, transmission (transfer), storage (archive) and analysis offer countries struggling to get a handle on basic information needs an opportunity to develop and employ comprehensive resource data bases before the end of this century.

3.2 Meeting Information Needs

The study team examined resource information needs of nine countries and four regions with a specific focus on the utility of remote sensing technology to meet these resource information needs. The study team looked at a variety of programs and projects and discussed data requirements as well as the ability to translate data into information of value with high and mid-level managers and technicians, in both philosophical and pragmatic terms. Although findings varied from country-to-country, a set of what can be considered common information needs relevant to the developing countries was identified. These needs are described in the following section, drawing on specific observations from our discussions with scientists and officials in the countries we visited.

As a tool for meeting these information needs, remote sensing has had an unfortunate history which has made the task of encouraging the developing countries to adopt this technology difficult. In the early 1970's, resource managers and public officials were too often told by too many researchers that all of their information needs could be met by remote sensing data, that conventional aerial and field surveys were a thing of the past. This initial enthusiasm, particularly for satellite remote sensing, erred on several counts. What was theoretically possible, and could be demonstrated in the laboratory, did not necessarily work in operational programs. What worked for large regions, continents and nations, did not necessarily work at the provincial or local level. What was sufficient for research information gathering was not necessarily sufficient for the administrative and legal responsibilities of governments. When it came to meeting the day-to-day operational information needs of resource managers and other public officials, too often remote sensing failed to live up to the claims made for it.

It has taken more than a decade of practical applications of this technology to create a receptive atmosphere in the developing countries and among the donors for the consideration of this technology as one tool for meeting their information needs. Today the challenges are clearly more institutional than technical.

3.3 Summary of Information Needs

Table 1 summarizes the information needs of the developing countries as they were described to the study team. The importance of each and the parameters of the information elements varies from region-to-region and country-to-country. The level of detail and accuracy also vary depending on the application of the information. A general survey of national resources should have far less stringent requirements than a project feasibility study. Generally as the focus of the information gathering increases, i.e., the area being examined is reduced to project size, the need for detail and precision increases. The following is a general description of the resource information requirements of the countries and regions we examined.

Fortunately, for those who are or would be experts, mans' knowledge of complex problems cannot be presented in a single chart or table nor can multivariate choices be reduced to simple yes or no answers. Table 1 is intended to provide unconditioned, highly qualitative judgements on information needs. The table does not distinguish those needs based on management objectives, environmental differences, or natural, human, and fiscal constraints. Its utility is that it provides in a single place a framework which enumerates issues that must be considered in developing programs to meet resource information needs.

Resource Information Requirements

1. GEOLOGY AND SOILS

- o Basic geologic and geomorphic maps
- o Soils maps
- o Soil erosion and monitoring
- o Desertification

2. HYDROLOGY AND GEOHYDROLOGY

- o Maps of surface and groundwater and acquifer recharge zones
- o Groundwater exploration maps
- o Floodplains maps
- o Drainage maps
- o The current state of water resources

TABLE 1

Information Elements and Sub Elements	PERIOD						PRIORITY			SCALE/RESOLUTION			PRESENTATION			
	Daily	Weekly	Monthly	Semi Annually	Annually	Single Survey[1]	1st	2nd	3rd	National 1:250 K to 1:1 million	Provincial[2] 1:50 K to 1:250 K	Local[3] 1:25 K to 1:50 K	Map	Statistical Report	Narrative Report	Graphics. (Charts,etc.)[4]
GEOLOGY AND SOILS																
Basic geology and geomorphic maps						X	X			X	X		X		X	
Soils mapping						X	X				X	X	X		X	
Soil erosion monitoring					X			X				X	X			
Desertification monitoring					X			X				X	X			
HYDROLOGY AND GEOHYDROLOGY																
Maps of surface and ground-water and aquifer recharge zones						X	X	X			X	X	X			
Groundwater exploration maps						X	X				X		X		X	
Floodplains maps						X			X			X	X			
Drainage maps						X		X			X		X			
The current state of water resources					X			X			X	X	X		X	X
AGRICULTURE AND LIVESTOCK																
Climatological and historical weather data						X	X			X	X		X	X	X	X
Current soil moisture		X					X				X	X	X			
Timely weather reports and forecasts	X	X	X	X	X		X			X	X	X	X	X		X
Timely information on moisture stress, other threats to current crops		X	X				X			X	X	X	X	X		X

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TABLE 1 (cont.)

Information Elements and Sub Elements	PERIOD						PRIORITY			SCALE/RESOLUTION			PRESENTATION			
	Daily	Weekly	Monthly	Semi Annually	Annually	Single[1] Survey	1st	2nd	3rd	National 1:250 to 1:1 million	Provincial[2] 1:50 to 1:250	Local[3] 1:25 to 1:50	Map	Statistical Report	Narrative Report	Graphics,[4] (Charts,etc.)
AGRICULTURE AND LIVESTOCK (cont.)																
Frequent, regular, accurate and timely crop estimates		X					X			X	X			X		
Early warning assessments		X	X				X			X	X			X	X	X
Range forage production and grazing capacity		X	X				X			X	X		X	X		
The current state grazing lands and trends		X	X				X	X		X	X		X	X	X	
FORESTS AND WOODLOTS																
Historical distribution and species maps						X		X		X	X	X	X	X	X	
The current extent of wood resources					X			X		X	X		X	X	X	
The location, extent and rate of deforestation					X		X	X		X	X		X	X		
ECOLOGY																
Vegetation maps					X	X	X	X		X	X	X	X		X	
Habitat maps					X	X		X			X	X	X		X	
Maps of fragile lands					X	X	X	X			X	X	X		X	
Threatened biological communities					X		X	X			X	X			X	
Periodic documentation and analysis of change					X		X	X		X	X	X	X		X	
LAND PLANNING																
Historical demographic maps						X		X		X	X		X	X	X	X
Current land cover maps					X	X		X			X		X	X	X	
Land potential maps					X	X	X					X	X	X	X	
Periodic documentation and analysis of change					X	X	X	X			X		X	X	X	X

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TABLE 1 NOTES

Fortunately for those who are or would be experts, mans' knowledge of complex problems cannot be presented in a single chart or table nor can multivariate choices be reduced to simple yes or no answers. Table 1 is intended to provide unconditioned, highly qualitative judgements on information needs. The table does not distinguish those needs based on management objectives, environmental differences, or natural, human, and fiscal constraints. It's utility is that it provides in a single place a framework which enumerates issues which must be considered in developing programs to meet resource information needs.

1/ Included in the single survey column are periodic updates occurring at 5 to 10-year intervals.

2/ Local mapping is by definition for selected, small, project size areas.

3/ Graphics are commonly included in technical reports; a check mark here indicates an information need which can be fulfilled by graphic which can stand alone or perhaps a series of graphics produced by a PC.

4/ Provincial and local scale mapping need not be completed for extensive areas to be useful. If 80% of the province is climatologically constrained from agricultural development, local soils surveys for the entire province would be wasteful for agricultural development.

3. AGRICULTURE AND LIVESTOCK

- o Climatology and historical weather data
- o Current soil moisture
- o Timely weather reports and forecasts
- o Timely information on moisture stress, disease, insect and other threats to current crops
- o Frequent, regular, accurate and timely crop estimates
- o Early warning assessments
- o Range forage production and grazing capacity
- o The current state grazing lands and trends

4. FORESTS AND WOODLOTS

- o Historical distribution and species maps
- o The current extent of wood resources
- o The location, extent, and rate of deforestation

5. ECOLOGY

- o Vegetation maps
- o Habitat maps
- o Maps of fragile and threatened biological communities
- o Periodic documentation and analysis of change

6. LAND PLANNING

- o Historical demographic maps
- o Current land cover maps
- o Land potential map
- o Periodic documentation and analysis of change

3.3.1 Geology and Soils

o Geology

Basic geologic maps at small scales (1:100,000 to 1:500,000) can provide development planners with information which will assist them in identifying areas within their countries which are suitable candidates for more intensive surveys. Or perhaps more accurately, these maps may be used to eliminate from consideration areas which contain one or more major constraints to development.

Small-scale geologic maps showing structure, lithology, soil parent materials and lineaments can suggest areas where the necessary combinations of soils and groundwater for agriculture development are likely. These maps may be developed using satellite data. They may also provide information on potential geologic hazards. They will not however provide the detail necessary to

select from among alternate sites or to produce project implementation plans. Large-scale maps of 1:10,000 to 1:50,000 are needed for these purposes.

Large-scale geologic, topographic, and soils maps are essential to project planning and implementation, though the areas which must be covered by this detailed mapping are usually small. Aerial photographic interpretation and field reconnaissance are the conventional means of generating these maps. The necessary skills exist in most developing countries.

Within this category the following are the principal information elements for project planning and implementation:

Structural Geology
Lithology
Soils
Landform
Topography

In many regions of the world, geologic, topographic, and geomorphic maps are almost timeless. Change is slow, and with the exception of major geologic events, the need to update or revise maps is infrequent. Unfortunately, however, in much of the developing world the natural and man induced pressure on scarce resources has created a continuing need for information on soils and soil erosion, on deserts and desertification. These processes can critically impact a nation's ability to feed its people. Mitigation of the effects of these processes requires information on their location and rates of change. Land and meteorological satellites can provide regular data on soil erosion and desertification. The skills necessary to develop management information and recommended actions from these data exist in many of the developing countries. Access to the data and the institutional follow through are unfortunately too often lacking.

o **Soils**

Soils information is essential to agricultural development. Though the level of detail, and the classification approach are the subject of debate among experts, it is clear that without information on soils and topography, agricultural development cannot achieve consistent success. Since we did not discuss soils information needs with soils scientists *per se* we must generalize on the kinds of information for which the planners and agriculturalists with whom we met expressed a need. Small-scale (1:200,000 to 1:1,000,000) national soils and topographic maps can be used to identify candidate areas for more intensive pre-development studies, to identify areas where current land use practices will result in future problems, and to identify areas with reclamation needs and potential. The small-scale surveys will help to identify trends when used in conjunction with current land satellite data.

Broad-level soil groupings can be defined using Landsat data. The image base of wet-season and dry-season Landsat data provides an excellent map at scales of up to 1:250,000. Interpretations for regions not having dense forest canopies in the tropics are effective, with Landsat providing the synoptic coverage to interpret soil boundaries over their entire extent but yet of sufficient detail to interpret soil differences. These surveys have been implemented on a country-wide basis for many countries of the world. Landsat spectral analysis can also be used as input to soil survey at larger mapping scales. The Landsat spectral data are categorized using unsupervised approaches and are merged with slope-class maps (derived from digital terrain data), and topographic maps and photographs at 1:24,000 scale to assist in field surveys. The spectral data relates to changes in surface vegetation, soil surface color, and surface roughness.

Larger scale surveys presented on maps of 1:50,000 to 1:100,000 may simply be enlargements of the small-scale maps with no additional soils information or detail for selected areas. The value of the enlargement is limited to the additional utility the information presented may have in the larger format. Maps of greater than 1:50,000 scale may in part be derived from remote sensing data, but will rely heavily on conventional field surveys. These large-scale surveys will be limited to small areas with high project potential.

3.3.2 Hydrology and Geohydrology

As with geology and soils, small-scale maps are useful in selecting areas for more intensive surveys. Small-scale inventories of surface water, drainage, historical rainfall and evapotranspiration aid the agricultural development planners in directing resources to the most promising regions for both rain-fed and irrigated agriculture. Small-scale lineament and vegetation maps provide good indicators of likely groundwater resources. These small-scale maps of geology, rainfall, hydrology, and vegetation may be derived from satellite data supported by existing maps and surveys and modest field surveys.

The cost of such inventories will vary depending upon the amount and quality of existing data. For nationwide surveys producing 1:250,000 or smaller scale maps, typical costs are $.35 to $1.00 per square kilometer.

Medium-scale maps (1:10,000-1:50,000) are appropriate for feasibility studies, overall project planning, and regional groundwater exploration. Such maps usually cover prospective or actual project areas and their environs. They are produced from both remote sensing data, conventional photogrammetric surveys, and field studies. The specific content and level of detail depends upon the type of project. Water impoundment, irrigation ground-

water exploration, water distribution and treatment, all require different kinds of data, and different precisions. Per kilometer costs are not reliable in estimating total project cost since there are basic minimal or mobilization costs for any remote sensing survey regardless of its size. For small projects the cost to produce the kinds of hydrological data we have discussed may be less than $100,000; for projects two to three times as large, the costs may be only 10% to 20% more.

o Lineament Analysis for Groundwater Exploration

Statistically-based, regional lineament analysis using enhanced satellite images have identified large fracture systems that are controlling aquifers in Tanzania to carbonate terrains in southern Nevada. The Nevada wells producing from these fractures have extremely high yields, but nearby wells outside of the fracture zones have yielded very little water. The lineament analysis study has, first, explained the anomalously high yields of these wells and, second, defined a method for exploring for additional productive wells in these large untapped aquifers in eastern Nevada. Landsat data have also been used to separate areas of irrigated crops from dry land crops and natural vegetation. The areas of irrigation have then been used to more accurately calculate water use over several large arid and semiarid regions of western United States. Further, historical meteorological data can be used to estimate recharge rates.

Larger scale (>1:10,000) engineering maps required for detailed project planning and implementation are usually derived from field surveys, not remote sensing, and as such are outside of the scope of this study.

3.3.3 Agriculture and Livestock

Food production, population, and public health issues dominate the attention of the developing countries and international donor organizations. The interdependencies are both obvious and complex. The need for reliable information to improve and monitor food production is clear in all the regions the study team visited. Where to plant, the preferred crops and farming practices, and the current state of cultivated crops and grasslands are general information requirements. The following is a discussion of how the specific elements of these requirements are being met or can be met using remote sensing technology.

In the previous sections we have discussed the information required to determine where to plant: geology, landform, soils, and hydrology. This information along with climatological and cultural considerations will suggest preferred crops and practices.

Remote sensing is widely used in both the space faring and developing nations to address many of these information needs.

o Weather and Climatological Data

Information needs include the following:

- o Historical weather data
- o Basic daily weather data and forecasts
- o Early warning of climatological conditions which may cause food shortages such as El Nino, periodic droughts, cyclonic flooding, etc.

The following three sections discuss donor supported developing country programs which are directed at meeting some of these information needs:

o AGRHYMET

The recurrent famines of West Africa have motivated donor organizations to establish the means for acquiring and dissemination meteorological, and hydrological data for the subSahelean countries of Central and West Africa. The resulting program AGRHYMET is now in the third phase of a 15-year program to provide essential agro-meteorological information.

The long-term objective of the AGRHYMET program is to enable all the CILSS countries to improve food production by increasing effectiveness of investments in human, animal, chemical, and thermal energy and to provide information which will to reduce risk and loses in agricultural.

The goal of the AGRHYMET program is to collect basic data and provide information in easily usable form. Responsibility for using such information remains that of the users (local governments and institutions). The benefits deriving from using the information will primarily be seen among the users and will not easily be identified as being due to the AGRHYMET program.

The near-term objectives of the AGRHYMET program include:

- o To describe and publicize trends in weather, surface water and condition of crops which are essential in operating an early warning system for food production;
- o To use existing knowledge of regional climatology, hydrology, and of recent weather patterns to anticipate or predict major "accidents" in events liable to affect crops, forests, pastures, livestocks and farming yields;

- To advise farmers on optimum planting times and the conduct of day-to-day farming, forestry and livestock operations, using information derived from historical meteorological data and current trends.

In practice, the activities under these three objectives above are often concurrent.

The AGRHYMET program consist of three phases:

1. The creation between 1975-81 of the Niamey Regional Centre and the strengthening of national meteorological departments in the Sahel;

2. The collection of water and meteorological data between 1982 and the present and the publication of reports; and

3. The transfer between 1987-1991 of agro-meteorological technology to local agricultural ministries.

The AGRHYMET program will undoubtably become the foundation for crop monitoring for early warning in the Sahel. A high resolution picture transmission (HRPT) station using French Government funds and a computerized image processing system from the U.S. is being built. The HRPT will be able to receive imagery from the NOAA and ESA polar orbiting environmental satellites. When combined with ancillary data collected in the field, the AGRHYMET system provides valuable input for improved agricultural production and livestock system management, as well as data for private and government institutions which sets policy for the fisheries industry, transportation, forestry, and other sectors.

The AGRHYMET program is currently in its third phase and generally on schedule. Six activities have been undertaken as part of Phase 3 including:

- Define information needs and identify users,
- Selection, testing and adaption of methods to meet information needs,
- Obtaining the necessary basic data,
- Implementation of methods,
- Communications, and
- Feedback.

The EarthSat study team visited the AGRHYMET Regional Centre in Niamey and discussed the overall program status with Mr. D. Larbergeon, Director of Operations, and the research effort being sponsored with the AGRHYMET program with Mr. Delorme Pascal, Crop specialist.

The following are the key points offered by Mr. Larbergeon:

- The purpose of the AGRHYMET program is to produce information that would be useful for: 1) agriculture and 2) food production;

- The principal users of AGRHYMET information will be personnel in various Ministries of Agriculture, and projects of these Ministries;

- It is hoped that the statistics of AGRHYMET will allow the users to quantify the risks by anticipating climatic and other impacts on particular programs at the farm level;

- Several crop models are being worked on (an example cited was millet) no results are as yet available in such models;

- The most visible AGRHYMET product is a 10-day summary bulletin of meteorological conditions occurring over the CILSS region;

- In summary, remote sensing information is one of the most useful inputs to the AGRHYMET program. This is re-affirmed by France in the process of funding and installing a HRPT receive station, and the presence of the receiving station should re-enforce the objective of the AGRHYMET program.

The following are the key points from the discussion with Mr. Pascal:

- The long-term impact of the AGRHYMET program may be to restore the grazing areas in Niger because of the presence of the AGRHYMET office in Niamey. But impact on other countries in the region is unclear because there appears to be inadequate communication between the AGRHYMET Centre and other regions;

- There is a need for donors and recipients to recognize the importance of national centers for resource information collection, processing and storage. A single center can assure that the critical mass of and capital, technicans and scientists is possible.

- SPARRSO

While West and Central Africa face recurring drought, Bangladesh lies in the heartland of the south Asian monsoon region with average rainfall of about 100 inches per year, and varying between 50 and 200 inches in various regions. About 80% of the rainfall occurs between June through September; November through

February is very dry, and in some years drought conditions occur. The country is traversed by three major river systems, the Ganges, Brahmaputra, and Meghua Rivers.

Bangladesh is repeatedly impacted, often immobilized, by catastrophic ravages of tropical cyclones, norwesters, tornadoes and floods. During the past 25 years, 32 severe tropical cyclones have hit Bangladesh, many inundating over 10,000 square miles each.

Serious interest in remote sensing began more than twenty years ago. In 1967, a receiving station was installed to receive real time U.S. meteorological satellite imagery and in 1970 the Space and Remote Sensing Organization (SPARRSO) was created. In the mid-1970's, Bangladesh scientists participated in the NASA ERTS (Landsat) program and initiated a training and research project assisted by the UNDP/FAO. In the late 1970's the Bangladesh Landsat Program conducted natural resources and environmental research studies, including deforestation, lake siltation, land accretion, crop area estimations, and cyclonic storms and storm surges. In addition, the SPARRSO began supplying real-time meteorological satellite imagery to the Meteorological Department and the Water Development Board for daily weather reports and storm and flood warnings.

Two AID assistance efforts were carried out by the Office of Foreign Disaster Assistance (OFDA), and continue operational status and value. In the first phase (1978-80) the Interim Cyclone Warning System was provided in 1978 when NOAA-5 failed; an interim system provided an Automatic Picture Transmission Station (APTS) capable of accessing low resolution meteorological imagery from the Japanese GMS, the U.S. polar orbiting TIROS N, and the Soviet polar orbiting Meteor. A High Resolution Picture Terminal (HRPT) provided in 1980 by OFDA improved forecasting accuracy for cyclones, flooding, and storm surges.

In 1980, USAID initiated the Bangladesh Agro-Climatic/Environmental Project (AC/EMP) to improve planning and management of resources particularly related to agriculture and water development. AC/EMP (Phase II, 1980-1985) provided facilities and training to more comprehensively employ environmental data obtained from remote sensing technologies. Specifically, technical support from NASA/GSFC and NOAA, with subcontracts to SSAI, University of Wisconsin, LSU, ERIM and others provided an integrated advanced system for receiving both low and high resolution images from NOAA and GMS satellites, and digital image systems (VIZAR) for analyzing both meteorological and Landsat data. In addition, ten Data Collection Platforms were installed to transmit real time data on atmospheric pressure, temperature, humidity, wind direction, rainfall, etc. (nine DCP's are presently operating). The Phase II evaluation report noted that this phase generated more data and equipment than SPARRSO could utilize or institutionally absorb. Although an AVHRR antenna was installed in 1980, some computer and

related equipment did not arrive until 1985. Considerable effort was devoted to meteorological applications, for which SPARRSO provides a valuable capability and service, but inadequate attention was devoted to developing programs and requisite training in Landsat applications.

In 1985, the AC/EMP was augmented and continued with a supplementary project (Phase III, 1985-1988) for provision of additional training, technical assistance, equipment and software including a raster-based GIS capability and an I^2S image processing system for Landsat and AVHRR data installed on SPARRSO's VAX computers. Particular emphasis in the present program is on ten applications areas. Although visits to SPARRSO were too brief to permit critical evaluation, it appears that progress may be presently hindered by delays in equipment/software arrival and installations, lack of supplies, delays in applications testing, and limited involvement and linkages with user agencies (although this seems to be improving with recent efforts).

SPARRSO is currently involved in a number of programs, however, providing valuable data and information services. The SPARRSO ground station receives NOAA-9 and NOAA-10 images, up to 4 times daily, over a 4,000,000 km^2 area centering on Dhaka, and data from the Japanese GMS-3 satellite at 3-hour intervals. These data are routinely processed at SPARRSO for use by the Meteorological Department for daily weather forecasts, storm warning, daily agricultural forecasts, long-term weather outlooks and flood forecasts. SPARRSO has detected every cyclone formed in the Bay of Bengal since 1968. These data are also used operationally by the Civil Aviation Department. During the flood season, SPARRSO also routinely provides data to the Water Development Board for flood forecasting and monitoring.

In addition to meteorological uses, SPARRSO is making good and innovative investigations of NOAA-9 and NOAA-10 AVHRR imagery for monitoring both sequential flooding and agriculture. Crop vigor is being analyzed using Vegetation Index processing techniques, as well as estimates of crop damage or loss due to flooding, drought, or other hazards. Post flood Vegetation Index scenes have been found to be informative and useful at the district level. Research is currently underway with the Ministry of Agriculture, and Ministry personnel are planning field trips during the current season (it appears difficult, both logistically and institutionally, to get people into the field). The Ministry of Agriculture is a potential user of SPARRSO products and services. In October 1987, the Ministry expressed interest in a specific information requirement, winter rice crop yield forecast. SPARRSO, however, presently lacks the funds for people, vehicles, petrol, etc., to mobilize the requisite field effort, as well as operational crop yield models. There is clearly a gap between the research interests of SPARRSO and operational information needs of Ministries. Nevertheless, Dr. Khan, Director of SPARRSO, recognizes the importance of operational programs. *"Most users are*

not believers in high technology. To exist (as a High Tech Remote Sensing Research Institution) is very difficult here; if we cannot produce products that are useful, we have problems."

Landsat has been a less successful story. The AC/EMP clearly emphasized meteorological data, and it was argued that SPARRSO could get MSS data from the Thailand station. SPARRSO's need is currently expressed as "TM within one week," and they have a standing request for one-time coverage of TM data from Bangkok following completion of the station modifications to receive TM (December 1987). TM data will clearly be useful for countrywide crop monitoring, particularly estimating crop area with reasonable accuracy.

The French have installed a SPOT receiving station in Bangladesh, but it is not currently operating due principally to lack of available funding for access fee and operations. Given a similar receiving capability in both Thailand and India, for example, it is clear that an international market for generating data sale revenues is severely limited.

SPARRSO's primary data are AVHRR; they are essentially free and timely, and their use is innovative and effective. Their Landsat CCT holdings are very limited; partial coverage in 1972 and 1978, full coverage in 1984 (a digital mosaic was prepared by ERIM and serves as a base for several thematic maps) and full 1986/87 coverage has been requested. Continued follow-on programs at SPARRSO are both needed and warranted, but these programs should place less emphasis on hardware and increased emphasis on expanding practical and operational applications, a steady supply of high resolution land satellite data (i.e., TM, MOS-1, SPOT), providing training and technical assistance to develop applications focused on the agricultural information needs and the assessments of disasters on crop production in a timely manner.

o Early Warning Systems

While AGRHYMET and SPARRSO direct their efforts to the acquisition of basic weather data and research on the use of those data for estimating and improving agricultural production, the famine early warning systems have a single common objective, to avert or mitigate the effects of famine. *Table 2* generally describes a number of early warning systems in use in Africa (from Hutchinson, 1987, personal communication).

Meteorological satellite data and ground weather observations are an important component of these warning systems. Because the meteorological ground data collection network in sub-Sahara Africa is sparse, weather satellites are an essential data source. Ground calibration and verification require reliable observations through-

TABLE 2: EARLY WARNING SYSTEMS FOR AFRICA

System	Parent Organization	Sponsor	Data Used: Ground	Data Used: Satellite	Data Used: Model	Area Cover	Reporting Period
AGRHYMET		WMO; FAO; CILSS; UNDP	Rainfall; Market.	METEOSAT AVHRR		EEC & CILSS countries, U.S.	Every 10 day, monthly, annually
FEWS	USAID		Rainfall; Nutrition; yield.	AVHRR		Chad, Niger, Mali, Burkina, Mauritania, Sudan	Monthly
GIEWS	FAO		Rainfall; yield; on-site.	METEOSAT AVHRR		Chad, Senegal, Mauritania Niger, Burkina	Bi-monthly, monthly
PRE CRESAL	CILSS	Italy	Grain stocks; Roads; Transport.			Italy, CILSS Countries	
DIAPER	EDF		Rainfall; Market.			CILSS & EDF countries	Monthly
FERU	London School of Hygiene & Tropical Medicine	SCF	Market.			Mali	
OXFAM		DNAVS	Market; Rainfall; Run-off.			Mali	
SAP	European Association for Development & Health	EDF	Rainfall; Nutrition.			Chad, Mali	Monthly
ESPACE		France	Rainfall	METEOSAT	Water balance	Senegal, Mali	
ARTEMIS	FAO		Agroclimate; Locust database.	METEOSAT AVHRR			
GIMMS	GSFC	NASA	AVHRR	AVHRR			
EROS (EDC)	U.S.G.S.	USGS		AVHRR			

out the area being monitored. Unfortunately, ground observations have not yet reached minimal acceptable levels for Sub-Saharan Africa (Hutchinson).

Early warning systems require far more than weather and agricultural information if they are to succeed in meeting their objective to lessen the effects of famine. Market conditions, human nutritional status, and institutional food delivery mechanisms are essential factors in famine preparation. These information are gathered through conventional observations and field surveys. Remote sensing may contribute to relief planning - such as siting food distribution centers, but is not a contributor to meeting the market nutritional, or institutional information needs.

The Famine Early Warning System of USAID (FEWS) is the most comprehensive and the most highly regarded of the early warning systems which the study team reviewed. The objective of FEWS is to identify populations in Africa which are a risk because of food shortages. ***"Unlike other systems FEWS is based on social indicators, which often are provided earlier, more frequently, and more dependably than indicators based on physical factors measured by remote sensing techniques"*** (Hutchinson).

FEWS uses data on demography, health and nutrition, water supply, food supply, demand and cost and sociological information. FEWS uses remotely sensed data to establish the probability of famine.

During the 1985 crop harvest in Sudan, FEWS proved its capabilities when the sorghum and millet crop production was estimated for the entire country in a record 3-month time period. Landsat Multispectral Scanner (MSS) data were digitally classified for six eastern provinces to derive area estimates of the crop fields and, when multiplied by available yields, an estimate of 4,569,051 Metric Tons (MT) was made. Landsat Thematic Mapper (TM) image products were used for six provinces in the western Sudan to derive a total area planted in sorghum and millet of 3,192,365 feddan. This was far more information than was available from any other source.

Because of the urgency to derive these estimates prior to what was believed to be a disastrous harvest in Sudan, accuracies were not computed for these estimates. Since no sampling was involved in the remote sensing estimate, sampling errors traditional in field surveys were not available.

FEWS was successful in promoting its techniques and demonstrating the need for accuracy assessments in the Sudan. An area frame is being constructed for the 1986 crop season, and the African Regional Remote Sensing Centre is conducted the remote sensing operation there this year in 1987 (USAID Highlights, 1987).

o Current and Ongoing Agricultural Information Needs

In the preceding pages we have discussed examples of agro-meteorological programs which provide current weather data, estimates of food supply and demand based upon weather and other data, and early warning systems.

Whether feast or famine, managers of the agricultural sectors in every country need timely and reliable information on food production. This information supports current import and export decisions, food distribution, short and long-term planning, conservation, taxation, and numerous other public programs and policies.

The industrial countries have well established networks for agricultural information gathering. Developed in the 19th century, this networks initially relied heavily upon the direct observation of soils, field crops, and agricultural practices. Aerial photography and statistical sampling were added to information gathering methodology in the first half of the 20th century. In 1962, the first weather satellite data became available. In 1972, the first land satellite provide the means for monitoring small agricultural areas (counties) and specific crops. With these additional data agro-meteorologists began the development of computer aided inventory and forecasting techniques using multistage and area frame sampling methodologies. These computer intensive techniques show promise for the developing countries. They can make effective use of existing data collection staff for field verification and calibration (remote sensing data can also be used to evaluate the reports of field enumerators - verification has dual benefits). Increasingly these techniques are being modified to operate on minicomputers and PC's.

The following examples of operational remote sensing programs in the developing countries are clear testimony to the potential of this technology to contribute to meeting the information needs of the developing countries.

o The Kenya Range Ecology Monitoring Unit - KREMU

The study team met with Dr. Andere, Director of KREMU and his staff. KREMU was started in the mid-1970's. In response to the need for a better understanding of the dynamic nature of the Kenyan ecology and in particular the viability of the nation's resources. In addition to directly examining the resource base, KREMU also employs climatological information and related data to assist in forecasting resource consumption.

KREMU has developed a nationwide information gathering capability which includes remote sensing at three levels: ground, aerial, and satellite. Although the agency has only been in existence eleven years, the staff believes that it is beginning to gain a basic understanding of the nation's ecology. It has taken eight years to let other ministries know about remote sensing data and its utility. For the past three years, several ministries have been requesting remote sensing data and analysis, largely is result of the KREMU influence over individuals within the ministries.

Because of the success of KREMU, there is apparently some resentment by other ministries. Specifically, KREMU's attempt to create a central agency to provide remote sensing services to other ministries has meet a number of road blocks. Its present location in the Ministry of Planning and National Development places KREMU in an excellent position to positively influence data collection practices.

KREMU has completed more than 130 studies, many of which are regular assessments of agricultural production (e.g., "Long Range Maize Production in Kenya," "Inventory of Available Data in KREMU"; "Land Use Change in Uasin Gishu District": etc.).

The Remote Sensing Section is charged with responsibility of acquiring data for resource inventory through multistage data gathering techniques:

a. Through satellite, be it MSS, TM, MOMS, RBV, SPOT, metric camera, etc.;

b. Aerial photography, on total cover or sample basis; and

c. Ground.

The remote sensing section provides training in the field of remote sensing on:

- Aerial photography
  - Planning photo flight missions
  - Acquisition of data through aerial photographs
  - Handling and maintenance of camera equipment.
- Photolab management
  - Handling, planning, and ordering film and paper prints
  - Printing, processing and developing film
  - Various techniques of photo processing to enhance analysis of geobased information interpretation.

- Photointerpretation

  - Development of photointerpretation techniques for use in resource inventory and planning
  - Digital analysis of remotely sensed data.

KREMU recently developed a method of using airborne radiometers and aerial photography to forecast crop harvests. The method has been found to be fast, and cost-effective in addition to providing fairly reliable data.

The remote sensing techniques used to acquire information on animal numbers and distributions over the large, sparsely wooded, expansive rangelands of Kenya are probably the best (quick, reliable and cost-effective). An important attribute of the method used in counting animals is its ability to provide data rapidly. For example, country-wide animal censuses can now be done on a yearly basis. The animal census programme aims at:

a. Providing seasonal information on numbers, densities and distribution of livestock and wildlife species;

b. Correlating the environmental attributes that are collected at the same time as animal data to animal stocking rates and herbaceous biomass. These data are used to give an indication of carrying capacities;

c. Identifying soil erosion areas/types and conservation measures being undertaken;

d. Establishing distribution pattern of woodlots for fuelwood assessment; and

e. Predicting future trends.

KREMU's program of work for 1987 and 1988 includes aerial surveys for grain forecasting, land classification, and wildlife censuses, field surveys on soils, vegetation, wildlife, plant species and desertification; remote sensing programs for mapping and monitoring of Kenyas forests; preparing an aerial atlas of Kenya; studies of irrigation impacts, radiometric and GIS research.

o Monitoring Agricultural Developments in Brazil

Colonization and agricultural expansion into the tropical forests of the Amazon Basin has both positive and negative impacts. The economic development, expansion of food and fiber production, settlement and productive employment for an expanding population must be weighed against the increase of carbon dioxide in the atmosphere due to deforestation, and the degradation of soils and water quality.[3/]

The Amazon Basin includes about 66% of the remaining tropical forest in the world, containing about 14% of all the carbon stored in the earth's vegetation and the world's greatest remaining pool of biotic diversity; taxonomists have identified one-half million of the several million species living in this biome (Mayers, 1980). The Brazilian Government has supported programs of colonization and exploitation of the Brazilian portion of the Amazon Basin over the past two decades in attempts to integrate the isolated and undeveloped Amazon Basin into the national economy. Large forest areas along the Transamazonian Highway and in the states of Rondonia, Mato Grosso, Para and Maranhao have rapidly been cleared for agricultural settlement.

Estimates of the tropical forest area cleared in Brazilian Amazonia over recent years vary by 100%, while estimates of the annual rate of clearing vary by 1000%, from as low as 10,000 km^2 to 100,000 km^2 per year. As stated by Tucker (Tucker et al., 1984). ***"The lack of any systematic data on the subject has hampered discussion of what many scientists feel to be major ecological crisis with serious biological, climatic and political ramifications."*** Application of remote sensing technology can help narrow these differences by providing unbiased, accurate information of forest clearing area and rates of expansion.

The population of Rondonia grew 16% per year during the last decade (World Bank, 1981). The doubling time for this rate of growth is about five years. Fearnside (1982) projected that Rondonia may be completely cleared of forests by 1988 if those trends continued.

Landsat imagery over central Rondonia has been analyzed to both illustrate the expansion of colonization activities and analyze changes in forestland clearing. This work has involved several organizations, working both collectively and independently. Work by Tucker et al. (1984), for example, has reported the application of AVHRR imagery to identify an area of

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3/ The material in the following discussion is drawn from a paper by W.G. Brooner, "Remote Sensing Applications Capabilities in South America: Perspectives for the Future Based on Recent Experiences."

about 100 by 400 km in Rondonia where massive forest clearing is occurring, verified by field studies which observed large-scale colonization programs.

Landsat imagery reveals a series of linear features extending from highway BR-364 in central Rondonia. The linear features are typical of organized colonization programs involving large-scale and systematic forest clearing. Similar linear patterns can be found in other colonizing areas of the Amazon Basin, in Brazil as well as neighboring Bolivia, Peru, and Colombia. The central Rondonia example is unique, however, because of the magnitude of recent change occurring and monitored by Landsat.

Within a single Landsat scene acquired to June 1976, linear features associated with colonization along BR-364 totalled approximately 1,300 km in length, in addition to 220 km of highway BR-364. This area is immediately west of the town of Rondonia.

Comparison with a September 1981, Landsat image of the same area reveals massive expansion of land clearing and settlement; the characteristic linear features then totalled more than 3,300 km in length, a 5-year increase of 2,000 km or approximately 250%.

Field surveys in September 1982, reported by Tucker noted that the *"linear forest-disturbance features were found to be forest-clearing swaths, some more than 80 km long about 4 km apart and 600-800 m wide. The large-scale primary forest disturbance is a government-planned colonization project in which immigrants to Rondonia are sold 100 ha lots of forest to use for agriculture or pasture. Each lot has about 500 m of road frontage. Clearing on a lot begins nearest to the access road then gradually moves away as the farmer clears more land to maintain or increase agricultural production and to reach soil not yet depleted of nutrients."*

Between 1975 and 1978, the extent of primary forest clearing in Rondonia was 1,200 km^2, and 4,200 km^2, respectively, a 3-year increase of 3,000 km^2. In 1982, Tucker et al., estimated about 9,200 km^2 was cleared in areas along BR-364. All estimates appear conservative while forest clearing and colonization continue, further excellerated by improvements and paving of the arterial highway and new government sponsored colonization programs.

The Rondonia example is ideal for testing remote-sensing techniques to monitor and analyze tropical deforestation and colonization, and such work is being continued by several Brazilian and international institutions. Finer spatial resolutions, as provided by SPOT, Landsat TM and others, are needed to refine the accuracy of tropical deforestation rates and to improve the quality and quantity of analyses and applications within the colonizing agricultural areas.

Similar studies, both recent and ongoing, are assessing the extent and location of agricultural land utilization in frontier regions of Brazil, Colombia, Peru, Bolivia and others. Landsat is technically and cost-effectively suited to portions of this task, providing locational and distributional information at mapping scales up to 1:100,000.

Detailed agricultural surveys often require small parcel level analyses involving combined ground studies and large-scale aerial photographs. High-altitude aerial photography (1:50,000-1:80,000 scale) has been used to define the agricultural zones within larger regions followed by large-scale photography over selected agricultural zones and field surveys. In a land use inventory project conducted by the Servicio Nacional Aerofotogramatria de Bolivia, in 1980, for example, 1:80,000 scale aerial photography for an area of 15,000 km^2 was analyzed for the initial stratification of areas of settlement and agricultural activity. Subsequent data were acquired for parcel surveys (SNA, 1980).

Subsequently, Landsat imagery was evaluated as a potential substitute for high-altitude aerial photography. A single Landsat scene covers an area equivalent to over 100 non-overlapping 1:80,000 scale aerial photographs. Comparative acquisition and processing costs for the 15,000 km^2 area, in 1980 U.S. dollars, was \$2.55/km^2 for aerial photography and \$0.12/km^2 for a computer processed and enhanced Landsat MSS image (for comparison, current costs for Landsat TM data would be less than \$0.21/km^2).

In the comparison analysis, interpretation maps of cultivation activity areas based on Landsat MSS and on 1:80,000 photos were composited at 1:100,000 scale. The resulting areas were 1,270.6 km^2 from Landsat and 1,256.3 km^2 from aerial photos, a difference of less than 1.12%. Estimated total costs (acquisition, processing, and analysis) were \$0.44/km^2 for Landsat and \$2.63/km^2 for aerial photos. Hence, to locate and stratify areas of cultivation, Landsat images at 1:100,000 scale yield results comparable to high-altitude aerial photography results, both quickly and considerably more economically. Based on current research, Thematic Mapper imagery further improves the quality and accuracy of results, while the significant economic advantage of Landsat over aerial photography for such broad region analyses remains. It is noted however, that in either case, the state-of-the-art quality of Landsat digital image processing (MSS or TM) is critical.

o Ministry of Agriculture, Peru

USAID's Agricultural Planning and Institutional Development Project in Peru is with the statistical group at the Ministry of Agriculture. The program is focused on agricultural policy.

Area Sample Frames have been developed for most of the country, using aerial photography, SPOT, and Landsat TM (bulk prints). The project started in 1984 and is programmed until 1988. Twenty to twenty-five Ministry staff have been trained in addition to field personnel.

During 1987 seven provinces were active for sample coverage. While the project is designed for two surveys per year (March and October), this has been done in only two provinces (Piura and Tumbes). The Ministry has been unable to provide local funding to continue, no results have been published, and the Minister questions the utility of the Area Frame Sample methodology. As a result AID/Lima anticipates that this activity will soon terminate.

o Ministry of Agriculture, Ecuador

Ecuador has a functioning Area Frame Sample (2 km x 2 km sample units) at the national level. It is conducted by the National Institute of Statistics, however, and not by the Ministry of Agriculture, and as a result lacks agriculturalists as part of the program, though efforts are being made to better coordinate the program with the Ministry of Agriculture (MAG). The annual survey reports area planted, area harvested, yield, and livestock data.

Meteorological data is collected by INAMI, and reporting is fairly good. There is a good working relationship between PRONARAG (MAG) and INAMI, and daily crop weather reports are issued.

An agro-climatology activity is underway to develop the use of modeling for yield estimation. An Argentine group is working with PRONARAG on the yield models, as well as INAMI. MAG expects the models to be in place in one year, for eight crops.

3.3.4 Forests and Woodlots

The needs of the developing countries for information on their forests is motivated by both economics and environmental concern. In the humid tropics, timber represents a major resource for domestic development, manufacturing, and export. The exploitation of these resources, when properly managed, can provide continuing domestic income and foreign exchange. Unfortunately, few countries have control of the harvest of these resources, and the alarming rate of their depletion is a matter of worldwide concern. The following section which deals with ecology addresses this environmental issue. In the arid regions of the world where wood is scarce, it is an essential domestic source of energy and light construction materials. In the countries with scarce wood resources, modern sustainable yield forestry practices are being introduced and accepted.

In both cases, public officials require basic forest inventory maps showing distribution, type and extent. Periodic updates, as often as conditions dictate and resources allow, may rely heavily on remote sensing techniques.

Small-scale (1:100,000-1:250,000) vegetation or land cover maps may include a delineation of forests, mixed forests and grassland, and may be derived from satellite data with supporting data from field studies. Such maps have two values. (1) They provide an overview of a region's or nation's total forest resources which can be quickly and inexpensively updated. As with any small-scale data set generalizations for large areas are reliable. As the size of the area being examined is reduced, at these scales the chances for error increase. (2) These small-scale inventories provide a convenient and effective base for a first level stratification in a multistage sample.[4/] The following discussion of two projects illustrates the benefits of remote-sensing approaches to meeting forest information requirements.

o Forestry Land Use Planning (FLUP) Project

Resource managers throughout western Africa recognize the value of timber primarily as a fuel source. The study team was told that 80% of all cooking fuel in West and Central Africa was from indigenous wood stock. Forest management (in this case Niger's forest) by various levels of government has been largely ineffective due primarily to:

1. Lack of data on the resource base,
2. Lack of data on harvest, and
3. Lack of planning for improved yields.

The FLUP project was implemented in Niamey by USAID, in concert with local forestry officials, to examine ways to rejuvenate barren hard pan soils with simple low cost technology. The FLUP project is also examining the value of natural areas for the sustainable production of other necessities of rural and urban life. In the case of firewood, a continuous supply is necessary since Niger has little money to purchase alternative energy sources.

The EarthSat project team spoke with Dr. Steve Daus, Project Officer, FLUP project, as well as a number of technical consultants and U.S. Peace Corps volunteers. A summary of the key points of that discussion follow:

4/ Multistage sampling is a methodology developed by forest researchers to reduce the cost and increase the accuracy of forest inventories. The sampling technique minimizes the most costly aspects of the field surveys by using interpreted satellite data and aerial photographs to extrapolate from randomly selected field study sites to larger areas.

- The FLUP project is currently assembling maps showing the basic resource inventories in the Niger growing zone of approximately 330 square kilometers (800 square miles). This zone is an ideal area for a multistaged analysis approach using multi-level remote sensing data; the FLUP team used EarthSat produced MSS images and incorporated the developed previously Mali inventory procedure; they have broken out "categorization units" on a 25 square kilometer grid encompassing approximately 500 square kilometers (overlapping non-growing areas to get a composite picture of the geographic site).

- Based on Landsat reflectivity information, sites were selected for further studies; early on it was discovered that forest provided radically different ground conditions for the same reflectivities; since this study was forestry oriented only, a comprehensive study of the conditions was not carried out and therefore the reflectivity variability will not be fully understood.

- The forestry inventory incorporated 1:60,000 aerial maps that were made from photographs flown during 1975 to 1985; the mapping unit was defined through the use of the aerial photos and extrapolated to the Landsat imagery; 500 sites were selected and land units or "terrain units" were developed.

- Three groupings were attempted. The first grouping included landforms; the second grouping included soils type; and the third grouping included vegetation coverage.

- The primary driver is water availability and as a result the study divided the country into 22 natural regions and mapped it at a scale of 1:1,000,000. After developing the terrain units, stereograms were developed from aerial photography; keys are currently under development.

- The ultimate objective of this stage of the FLUP project is to produce for each political unit (or province within Niger) a map of terrain units.

- The first cut documentation will be directed at the national level (donor oriented, with the second phase documentation aimed at the local level).

- Dissemination of data to the six regional (forestry) planning centers.

3.3.5 Ecology

Basic vegetation and land cover type maps at medium and small scales (1:100,000 to 1:250,000) provide planners with information on vegetation distribution, habitat distribution, and areas of threatened biological communities or concern for fragile environments. At the regional or provincial level, these maps may assist in identifying areas which warrant more intensive surveys, and areas which should be protected from development pressures and impacts based on ecological or conservation considerations.

Small- and medium-scale vegetation maps showing plant communities and edaphic processes are an important input to land capabilities mapping. These maps may be developed using appropriately processed and analyzed satellite data.

Large-scale vegetation maps are required for specific project planning and implementation and the areas to be covered are generally limited. Aerial photographic interpretation and field surveys are the conventional means of producing these maps, but newer higher resolution satellite imagery, e.g., digitally processed Landsat TM or SPOT, for example, are useful at 1:50,000 scale. The analytical skills are extant in most developing countries; the processing capabilities are rapidly increasing with use of micro computers (Section 4.3).

Within this category the following are the principal information elements for project planning and implementation:

- Natural vegetation community types
- Hardwood distributions
- Wetlands and periodically inundated areas
- Critical habitat types
- Areas of critical environmental concern
- Fragile areas, including deforestation
- Agroforestry potential

Tropical forests are being destroyed at alarming albeit undocumented rates worldwide. Deforestation is a primary environmental concern expressed in the humid tropics. Serious national problems exist in Thailand, Jamaica, Brazil, all of the Andean countries, and Indonesia. The ability of satellite remote sensing to identify and assess the location and extent of tropical deforestation has been clearly demonstrated; high resolution Landsat TM has been operationally used to monitor temporal changes of deforestation areas as small as a few hectares, and to assess their impacts. Remote sensing provides a methodological basis for identifying these critical areas, and giving these areas relative weight for development or conservation. Because of the economic importance of the wood being harvested, and the remoteness or inaccessability of the forests, reliable data are difficult if not impossible to acquire. The contribution of deforestation effects to soil erosion and loss of productivity, and off-site effects from

uncontrolled degradation (e.g., reservoir sedimentation, loss of irrigatable lands, flooding, effects on potable water and fisheries, etc.), are increasingly recognized in project planning and operation.

Deforestation extent and impact information can be provided to decision-makers to establish policies and regulatory programs to sustain the wise use (economically and environmentally) of tropical forests. At the AID-sponsored "International Conference on Fragile Lands: Sustainable Uses of Steep Slopes" held in Ecuador in September 1987, numerous examples of both highland and lowland deforestation and their temporal monitoring were illustrated using both Landsat and aerial photography. Examples were drawn from Jamaica, Dominican Republic, Colombia, Ecuador, Peru, Bolivia, Brazil and others. Workshop participants issued a recommendation that the interpretation of satellite imagery and aerial photography represents a modern and rapid method to determine the extent, impacts and effects of deforestation. Despite recognition that costs for data and analyses may be substantial, compounded by the requirement for repetitive monitoring, the participants recommended that their utilization should be increased.

In Colombia, the state environmental agency, INDERENA, is initiating a survey of deforestation and related critical areas along the entire Andean piedmont, using satellite data to map areas as small as 1 km^2. The plan calls for monitoring and updating as often as every six months. In addition, the Fundacion Pro Sierra Nevada de Santa Marta has proposed using Landsat TM to establish an ecological baseline of the Sierra Nevada de Santa Marta National Park, and a monitoring program using remote sensing and GIS technologies to assess encroachments impacting fragile areas within this unique environment.

Conservation of biological diversity is a significant AID initiative prompted by recent legislation, and supportive of biological inventories and field surveys through the network of Conservation Data Centers. The demonstrated application of remote sensing to stratify and classify land cover, to map habitats, and to direct and guide field collection of biological data will be of value as their use increases. Landsat TM imagery, at 1:40,000 scale, for example, has been used as a base map and data source for mapping the approximately 250,000 hectare Beni Biosphere Reserve near San Borja in Bolivia. The use of Landsat TM to classify natural vegetation for wildlife habitats in Florida, provides a useful model (Wickham and Kautz, 1987), as well as programs by the U.S. Fish and Wildlife Service and National Park Service (Section 4.4). The integrated role of GIS can be an important technology for developing National Conservation Strategies.

3.3.6 Land Planning

o Current Land Cover Maps

Actual land use and land cover is one of many types of information concerning complex interrelated activities and environments needed for orderly and efficient land planning. Land use is dynamic with changes resulting from natural forces and human intervention. Knowledge of the distribution of agricultural lands, natural vegetation areas, urban lands and infrastructure, etc., as well as information on their change and rates of change are needed by planners and managers from many sectors to better determine land use policy, to project infrastructure and service demands, to identify future projects and to implement effective plans and strategies for local, regional and national development.

The variety of land use and land cover data needs is exceedingly broad; the level of information needs varies by location and environment, by time and program requirements. The data transcend numerous user groups - some of whom expressed particular needs (and programs providing information to those needs) and others who would benefit from such data when effectively presented and used.

Land use and land cover mapping was one of the earliest applications of Landsat data among numerous developing country remote sensing programs; Landsat data was well suited to producing regional/national land cover maps at small scales (1:1 million to 1:5 million). These activities followed a trend initiated in the 1960's to rapidly expand land use inventories as a result of (a) the necessity for planning and developing agricultural expansion, (b) an increased awareness and sensitivity toward proper management of natural resources and their effective development, and (c) development of data processing and remote sensing technologies which greatly facilitated cost-effective collection of land use and land cover data.

All too often, however, multiple agencies within a single region or government gather land use data independently of each other. This has often resulted in duplication or missed opportunities to improve surveys and reduce costs. This tendency is probably one the developing countries learned from the industrialized countries. Those remote sensing agencies which have routinely and continuously provided land use information have generally realized the necessity for standardized land use and land cover maps and products, developed with common methodologies, procedures, etc., by a cohesive and trained group of individuals working under common management. Standardization also includes a hierarchical legend design compatible to GIS data base requirements, and a legend design acceptable to user information needs and compatible to other land classification systems.

Increasingly, the more experienced remote sensing groups have learned that highly generalized, small-scale, land use maps compiled five to ten or more years ago do not satisfy current information needs for development activities; beyond general patterns of landscape features, they are not sufficient for project planning because they are dated and too general. Rather, "semi-detailed" (1:50,000-1:100,000) and "detailed" (1:20,000-1:50,000) maps with corresponding refinement of mapping units and legend, are required to advance programs from general planning and policy development to specific project design and implementation. These requirements can be met with appropriate processing of more recently available higher resolution satellite imagery (e.g., Landsat TM, SPOT) combined with field surveys and collateral data.

Further, timelines is increasingly important. For example, land use data were provided near the beginning of the USAID/Peru funded Pichis-Palcazu development project. The land use data base was developed by ONERN using computered processed Landsat MSS data. Today, approximately five years later, updated, comparable data are needed to assess changes, and monitor development activities, against the initial baseline. Similarly, in Colombia, the Coffee Growers Association has found that the optimal repeat cycle for comprehensive land use inventories in extensive coffee producing regions is every three to five years; the cost of aerial photography surveys is prohibitive, and procedures are being developed to satisfy most information requirements with high resolution satellite imagery.

o **Land Use Potential**

Closely related to, yet distinct from actual land use is land use potential, which is determined through an analytical process which defines the ability of resources to support various land uses at various levels of activity. The physical characteristics which are used to determine land use potential generally include soils, topography and relief, geomorphology, hydrology, vegetation, and climate. Land use potential may also include, as part of the final land use determination process, factors involving cultural influences and social consequences in the realm of economics and politics. These latter factors may include existing land use, transportation systems, goals and policies, cultural history, religion, etc.

The general concept of land use potential is founded on sustained harmony between man and nature; both are served best by a rigorous analysis of environmental alternatives, and incorporates points of factual reference: accurate biological and physical resource data. These data give the development plan, or land use potential analysis, credibility because they consist of an evaluation of the potentialities of the physical environment in which the plan or analysis is to function.

The concepts and methodologies for land use potential mapping were originally developed using aerial photographic interpretation combined with requisite field surveys and collateral data as available. Both the ITC (Holland) and CIAF (Colombia), and other institutions, have been instrumental in training scientists worldwide to apply the concepts and methodologies through subsequent activities in various national mapping centers, remote sensing institutes, Ministries of Agriculture, etc.

Land use potential maps and associated reports and statistics, including matrices of existing vs. potential land use, generally use aerial photography for detailed studies (1:20-1:50,000 scale), and increasingly SPOT and Landsat TM for semi-detailed studies (1:50,000 to 1:100,000 scale).

Another concept of land use potential, or land use capability, is based upon the Holdridge System of World Life Zones. As further developed by J. Tosi and colleagues at the Tropical Science Center in Costa Rica, the concept has been widely applied in tropical developing countries regions. The essential determinants are bioclimate, landforms and physiography, and soils and drainage; bioclimate is primordial as it effects vegetation and other biota directly as well as indirectly through its influence on geomorphology and the edaphic factors.

In 1983, Tosi applied this land capability analysis to establish an objective foundation of ecological facts concerning the comparative suitability of lands for sustainable development in the USAID/Bolivia Chapare Project area. The analysis showed that both officially-held and widely-popularized beliefs in a high agricultural potential for the Chapare were substantially in error.

In Peru, the Life Zone concept is the basis for the legal Peruvian land classification and environmental planning system. As such, it is often erroneously confused with actual land use/cover. Experience in developing GIS data bases, at ONERN (Peru), has contributed to both resolving conceptual failures, as well as refining Life Zone maps using both Landsat data and the multi-parametric GIS data base.

While the study team has observed numerous successful projects in land use potential mapping, one organization is worthy of particular mention, the Center for Research and Study on Land Use Capabilities (CUMAT), a PL-480, Title III supported PVO in Bolivia. The land classification system as applied by CUMAT recognizes five general categories of major land use: annual cropping, permanent cropping, pasture, forest production, and protection (conservation) under natural cover. Within each land use category, four levels of technology are applied, from primative to mechanized. The CUMAT methodology is based, in part, on bioclimatic analysis of Life Zones, combined with edaphic and other ecological factors;

satellite and available aerial photographic interpretations and detailed studies are conducted by qualified environmental scientists and development planners.

o Demographic Maps

Demographic estimates and censuses based on conventional survey methodologies are costly and time consuming, requiring extensive planning and preparation. New applications of remote sensing and GIS technologies are being realized that contribute to the efficiency and efficacy of demographic studies.

The Bangladesh Bureau of Statistics (BBS) is presently assessing the use of GIS techniques from handling mapping needs at the field enumeration level, preparatory to the 1991 population census. Needed are small area maps to guide field enumerators, based on a variety of generally antiquated source materials. BBS estimates approximately 192,000 individual map sheets. Establishing an updated digital cartographic data base will be a monumental task, but will also facilitate maintenance, operation, and future updating and census preparations.

Development project areas are typically rural and often in relatively inaccessible areas. When the USAID/Bolivia mission needed a current population estimate of the Chapare Region for a project redesign in 1987, the best available information varied by over 250%. Existing and available digitally processed Landsat imagery, combined with existing aerial photography and a limited field sample design were used to produce acceptable rural population estimates with less than 10% variance; the project was completed in less than 90 days at a cost of less than $0.15/km^2.

o Basic Mapping

Integrating the data requirements and information needs into a useful product for resource decision-makers in a Third World setting is a major hurdle. The most common option is depicting data on a map reference. Increasingly satellite images are being used as map bases.

At every contact of the EarthSat study team, it was clear that maps were the basic development tool of the Third World and were a key input to any project that achieved success. On the negative side of this issue, the study team discovered that there is paucity of current, reliable maps in most of the study areas visited and that a continuing need for additional maps was evident.

Policy-makers and resource managers generally understand the basics of maps.

Many maps are necessarily complex, presenting many different kinds of data on a single sheet of paper. Photo maps have long been an effective means of conveying large amounts of information which all can understand, albeit at many levels of understanding. Photo maps produced from aerial photographs are costly and time consuming to produce. Satellite data offer a quick and relatively inexpensive means of producing maps of large areas.

o Satellite Image Maps and Mosaics for Improved Cartography

Many areas of the world continue to be poorly mapped. Available cartographic products are commonly of small-scale and contain significant errors of which users may not be aware. Since the first launch in 1972, Landsat has been promoted for its cartographic value, and numerous examples have documented cartographic updating applications.

Satellite Image Photomaps provide a broad geographical overview of physical resources and diverse environments for regional mapping and multiple resource applications. Landsat Photomaps, and more recently SPOT Image Maps, have provided a unique cartographic base map, particularly in areas where base maps of similar scale are unavailable; an image of the landscape for interpretation, analysis and planning; and a common reference to focus and design further analytical and cartographic products, as well as planning and development studies and programs. Landscape features and interrelationships of the physical and cultural environment may be readily seen on satellite image maps and mosaics. They provide a vital communications tool for regional mapping, geographical studies, planning and multiple resource applications.

Noteworthy among the lengthy list of Landsat photomaps and mosaics produced by many organizations is the recent program to produce planimetric Landsat photomaps, at 1:250,000 scale, of the Republic of Peru. Following a program of international competition in 1983, Institute for Applied Geosciences (IFG), West Germany, was selected and successfully completed the project which includes over 90 maps sheets. Landsat images were digitally processed, including rigid geometric registration to ground control points. On each sheet, latitude/longitude and UTM graticules, as well as toponimic information are accurately plotted. The program was funded by the World Bank and included participation of many Peruvian and international agencies, coordinated in ONERN. Previously, topographic maps of Peru were confined principally to coastal regions, covering less than 40% of Peru, and commonly many years out of date. Already, the new Peru Landsat Photomap Series is proving to be invaluable for its cartographic accuracy by providing controlled map coverage for vast areas of the nation for development planning and data base development.

Similar image maps are being routinely prepared by numerous commercial (value-added) organizations, research laboratories, remote sensing and mapping centers, etc., worldwide. For example, at SPARRSO the study team viewed a very attractive and useful series of thematic maps of Bangladesh at 1:1,000,000 scale, produced from a mosaic of fourteen Landsat MSS images. Similarly, in Thailand, a color mosaic of Landsat images, printed at both 1:1,000,000 and 1:2,000,000, was prepared by the Remote Sensing Division of the National Research Council. In Japan, the Tokai University Space Research and Information Center has published a complete set of annotated Landsat TM image maps of Japan at 1:100,000 scale, as well as a global mosaic of AVHRR imagery in the form of both a color poster and a series of globes. INPE (Brazil) recently produced a satellite image map using digitally geo-referenced Landsat TM data for the Sao Paulo map sheet, and is continuing with other areas at both 1:250,000 and 1:100,000 scales to support various mapping projects. Similar examples, of both manual and digital compilation, were viewed in every country visited during the survey.

Most Landsat photomaps and mosaics prepared to date have used the multispectral scanner imagery. Increasingly, Thematic Mapper imagery from Landsats 4 and 5 are being used for both mosaic and photomap applications because they provide image data of significantly better geometric fidelity, as well as resolution, than the MSS imagery. Welch (1985) reported research results concerning the cartographic potential of TM data;

> *"....the geodetic accuracy of the Thematic Mapper data is compatible with relatively large-scale map products, and the completeness of planimetric data are best suited for the production of image maps of 1:100,000 scale as demonstrated by the USGS maps of Dyersburg (1983), Washington, D.C. (1984), and Great Salt Lake (1985). Another potential use of the TM data is for the revision of existing maps, particularly for changes in the boundaries of urban areas and water bodies, or the relocation of major transportation features."*

Thematic Mapper data for large areas of South America are acquired through the Brazilian ground station at Cuiaba. In September 1985, four Brazilian acquired TM scenes were digitally processed and mosaicked by EarthSat, covering approximately 120,000 km^2 of northern Bolivia. The region is generally void of accurate maps or geodetic control; river courses and position of roads and water bodies are charted only at 1:1,000,000 or smaller scales. Comparison to the TM imagery reveals significant misrepresentation on these features on existing maps. The TM mosaic at 1:250,000 scale, and individual scenes at 1:100,000 and 1:50,000 scales, have provided accurate base maps, sources for cartographic revision and compilation, and a pictorial base for resource analysis and reconnaissance.

SPOT imagery has added new dimensions to image map and cartographic applications. The 10-meter panchomatic data acquired by SPOT is being used for both image base mapping at scales up to 1:25,000 as well as map updating of cultural changes. Digital image processing is often essential to make the map more "readable" at these larger scales, and to give it the metric qualities of a true map. SPOT's stereo acquisition capability enables photogrammetric relief plotting to produce topographic maps.

Any geographical data available in digital form can be combined with Landsat or SPOT imagery after conversion to the same projection and reference system. Perspective views simulating landscape relief provided by digital terrain models (DTM) can be combined with satellite imagery portraying land use and land cover.

Satellite image maps and mosaics provide an excellent base for compiling resource information as well as data for many resource interpretations. Important considerations for image maps and mosaics involving multiple scenes are dates of coverage, spectral bands appropriate to anticipated use, and sensor resolution and corrections for geometric accuracy appropriate to final map/mosaic scale and use.

4.0 TECHNOLOGY SUPPLY

It may be argued that many of the early failures or disappointments of remote sensing application to development programs were indeed technological; specifically, photographic products (commonly referred to as "bulk images") were of inferior quality by today's standards, analyses were typically made at small scales (e.g., 1:500,000-1:1,000,000), and hence highly generalized and non-specific. In most cases, advanced digital processing capabilities were not appropriate for technology transfer to developing countries in the 1970's; it was difficult enough to justify and support these high technology capabilities in industrial country laboratories.

During the present decade major advances have occurred, and are continuing in areas of data acquisition, data processing and analysis, and information management. In the following Section 4.1, the characteristics and availability of satellite remotely sensed data are reviewed. Today's data are of improved quality, higher resolution, and available from an international series of space platforms on a more timely basis. Continuity and additional systems are scheduled well into the next decade. And from a single ground receiving station in 1972, today fifteen countries are directly receiving earth resources satellite data transmissions.

Increasingly, users worldwide are analyzing remotely sensed data in digital form using a variety of sophisticated techniques. The most significant contribution has been the evolution of macro- and micro-based computers, and digital image processing has come of age on desk-top personal computers. These developments are reviewed in Section 4.2.

Access to accurate and timely information is a cornerstone in any decision-making process. With multiple, often conflicting, demands on the development and use of a resource, it is mandatory that decision-makers have the tools to analyze a variety of information in such a way that they can simulate the consequences of the array of strategies or options. Remote sensing derived data must be combined with other data sets, such as soils, topography, and socioeconomic parameters to maximize the utility of information for decision-making. Until recently, the missing element needed for success has been an efficient, readily available, method for merging and managing a number of spatially related data sets - what is currently called a "user-friendly" Geographic Information System (GIS). GIS characteristics and applications are reviewed in Section 4.3; many GIS systems are designed for personal computers, and the capabilities are impressive when viewed from the perspective that many of the capabilities were not even available on mainframe computers just a few years ago.

The current state of GIS and digital-format remote sensing technologies enables the development community to economically and efficiently utilize the array of available data, and to analyze these data in the context of planning and management decisions.

Indeed the hope and expectations of many with whom the study team met that these technologies can and will make significant contributions to development programs in the Third World seems well founded. The technological potential exists; that is clear. In the previous sections, the institutional impediments to the adoption of assimilation of these technologies have been noted. The inference however, that the tools exist and that they need only be acquired and set to the task of developing the information required errs in several respects:

Technological solutions to specific resource information requirements cannot be generic. A GIS which is appropriate in one country will not likely be suitable in another without modification, and fine tuning to the specific administrative, political, and management needs of that country. This is a technological problem which must be anticipated. While it can be easily solved, the funding and vendor commitment must be present to assure that each tool is customized to the specific task. The cost is not great (perhaps 10% to 20% of the total system cost).

Computers and other high technology tools require service, both regular preventative maintenance and repairs. This need is lessened by the advances in small computers, but not eliminated. This is a technological problem which is slowly being addressed. In late 1987 Computerland Corporation opened four franchise outlets in West Africa. In southeast Asia, IBM provides local service, and Japanese companies like Fujitsu are increasing their presence throughout the developing world.

Data supply is and will probably continue to be outside of the control of the developing countries. Civilian satellites, both private and public depend upon economic and political forces which are unpredictable. The resolve of the industrial countries to maintain non-discriminatory access to space data is a cornerstone of civilian remote sensing programs, but this commitment does not to assure that data will continue to be available, or that data will be available at an affordable price. U.S. vacillation over support of the Landsat program, and the higher data prices which are likely to be required to finance both the private Landsat and SPOT programs are factors which must be considered by the developing countries when they invest in remote sensing and GIS technologies.

Notwithstanding these concerns, the authors share the optimism for the future of these technologies in the developing world.

4.1 Remote Sensing Satellites and Sensors: A Summary of Present and Planned Systems

In March 1972, a paper by Brooner and Nichols began with the following observations -- they are equally applicable in 1987:

"In the past decade the field of remote sensing has produced increasingly sophisticated and useful tools to be applied to environmental programs and problems. Among the relatively few who have observed or participated in this development, remote sensing has effectively and efficiently demonstrated the ability to meaningfully record a multitude of phenomena in our environment. Many recently demonstrated applications have become operational." (Brooner and Nichols, 1972)

Approximately four months later, NASA launched the first Landsat type earth resources satellite. Success of Landsat-1, an experimental program, has been followed by launches of four more Landsats, program transfer to operational status administered by NOAA (1983) and commercialization by EOSAT (1985), launch of the first French commercial remote sensing satellite, SPOT-1, in 1986, and the Japanese MOS-1 satellite in 1987.

In addition, a series of geostationary environmental satellites operated by the U.S. (GOES), ESA (METEOSAT) and Japan (GMS) provide real-time meteorological observations worldwide, complimented by a series of polar-orbiting environmental satellites operated by the U.S. (NOAA AVHRR) and Soviet Union (Meteor).

Additional earth resources and environmental satellites are planned into the next decade. While the U.S. dominated the satellite remote sensing industry for 14 years, it is today a truly international initiative. International remote sensing systems reflect the growth and potential of a global industry, and open the door to international cooperation and better management of the earth's resources.

Numerous references have documented the characteristics of each satellite's sensors and performance as well as developmental and operational applications of the remotely sensed data. The following discussion, along with attached tables and figures, provides comparisons of the main features, including orbits and sensors, for the series of current and planned earth resources and environmental satellites.

The Landsat, SPOT, and MOS series of satellites are designed for regular, intermediate-to-broad area coverage of the earth's surface, providing medium-to-low resolution multispectral data at low cost per square kilometer. Significant comparative differences, however, exist among the principal sensors, e.g., Landsat's multispectral scanner and Thematic Mapper, SPOT's multispectral and panchromatic operation modes and MOS-1's multispectral scanner (MESSR) (*Table 3*).

TABLE 3: COMPARISONS OF SELECTED SATELLITE REMOTE SENSING SYSTEMS

	Landsat Multispectral Scanner (MSS)	Landsat Thematic Mapper (TM)	SPOT Multispectral (MS)	SPOT Panchrometric (Pan)	MOS-1 (MESSR)	NOAA, 8, 9 Advanced Very High Resolution Radiometer (AVHRR)	GOES (VISSR)
Spectral Bands (Micrometers)		0.45-0.52					
	0.5-0.6	0.52-0.60	0.51-0.59	0.51-0.73	0.51-0.59		
	0.6-0.7	0.63-0.74	0.61-0.68		0.61-0.70	0.58-0.68	0.54-0.70
	0.7-0.8	0.76-0.90	0.79-0.89		0.72-0.80		
	0.8-1.1				0.80-1.10	0.72-1.10	
		1.55-1.75					
		2.08-2.35					
						3.55-3.93	
		10.50-12.50				10.50-12.50	10.50-12.60
Area Coverage per Image (Square Kilometers) * Width of Swath	34,225 *185	31,450 *185	3600 *60	3600 *60	10,000 *100	*2940 (NOAA-8) *2600 (NOAA-9)	
Instantaneous Field of View (Resolution, meters)	80	30 120 (Thermal)	20	10	50	1100 (NOAA-8) 500 (NOAA-9 Visible) 1000 (NOAA-9 Thermal)	1100/4000
Repeat Cycle	16 days	16 days	5/20 days	5/20 days	17 days	12 hours	20 min./1 min.
Turnaround (time between acquisition and delivery)	4 weeks	4 weeks	4 weeks	4 weeks		2 weeks	Real time
Data Cost per sq. km (Digital Data)	$0.020	$0.105 (full scene) 0.210 (quarter scene)	$0.444	$0.444		$0.00003	
	$660	$3300 (full scene) $1650 (quarter scene)	$1600	$1600		$150	

4.1.1 Present Earth Resources Satellites

o Landsat-1, -2, -3

For purposes of this discussion, Landsat-1 launched in July 1972, Landsat-2 (March 1975) and Landsat-3 (March 1978) are treated as identical, successive systems providing continuous data until Landsat-3's retirement in September 1983. Each satellite orbited the earth at an altitude of approximately 915 kms (540 miles).

A four-channel, MSS imaged a 185 km swath, subsequently framed to produce scenes covering 185 x 185 kilometers (115 x 115 statute miles). Image acquisition time occurred at the same time of day, at approximately 9:42 a.m. local time, and the repetitive orbit provided the potential for acquiring images from a single satellite every 18 days. Unique to Landsats 1,2, and 3 was the fact that successive orbits matched successive days; this does not apply to Landsats 4, 5.

The Landsats 1,2,3 multispectral scanner acquired data in four spectral bands: 0.5-0.6 um (green), 0.6-0.7 um (red), 0.7-0.8 um (near-infrared), and 0.8-1.1 um (near-infrared). The minimum resolution element, or "pixel," provided an instantaneous-field-of-view (IFOV) of approximately 79 x 79 meters, or 0.45 hectare (1.1 acre); digital processing techniques enable data resampling to a 57 x 57 meter pixel.

o Landsat-4 and -5

Landsat's second generation of sensors were included on Landsat-4, launched in July 1982, and Landsat-5, launched in March 1984. These satellites are larger and more complex than the first generation predecessors and include, in addition to the MSS imaging system, the Thematic Mapper imaging system.

Landsat's 4 and 5 operate at a lower orbital altitude of 705 km, resulting in 16 days for entire earth coverage. Sidelap of adjacent image swaths is reduced to only 7.6 percent at the equator, compared to 14 percent for Landsats 1,2,3.

The MSS sensor on Landsat's 4 and 5 is essentially identical in image characteristics to Landsats 1,2,3, e.g., four spectral bands, 185 x 170 km (reduced from the 185 km along track image dimension of Landsat's 1-3 MSS) area coverage per scene, 59 m x 79 m ground resolution, or pixel size.

LANDSAT MSS

Advantages:

- Regional geologic/geomorphic analyses and mapping;
- Vegetation mapping and assessment;
- Repeat coverage for change analysis;
- Worldwide coverage;
- 15-year archive;
- May be enlarged up to 1:100,000 scale (1:250,000 most common);
- Low cost per km^2, cost-effective for large areas, and for monitoring programs; and
- Over 34,000 km^2/scene.

Limitations:

- Limited spectral data compared to Landsat TM;
- Low resolution (80-meter) compared to TM or SPOT;
- Cannot penetrate cloud cover; and
- Repeat coverage (revisit) of 16 days.

Introduction of the Thematic Mapper (TM) on Landsats 4 and 5 began a new generation of satellite remote sensing with refined spatial resolution and expanded spectral coverage. Ground resolution of 30 m x 30 m is provided in six spectral bands in the visible and infrared (0.45-0.52, 0.52-0.60, 0.63-0.69, 0.76-0.90, 1.55-1.75, and 2.08-2.35 micrometers) and 120 m resolution in a Thermal infrared band (10.4 to 12.5 micrometers). This increased resolution, plus additional spectral bands, provides TM with more than eight times the data contained in an MSS image.

LANDSAT TM

Advantages:

- Greater spectral data (than MSS) useful for geologic/geomorphic analyses and soils mapping;
- Greater spectral data very useful for vegetation and land cover analyses;
- Thirty-meter resolution useful for vegetation, geologic, and land use analyses;
- May be processed to scales up to 1:50,000 for small area analyses (1:100,000 most common);
- Repeat coverage for change analyses;
- Worldwide coverage potential (some limitations by ground station);
- Six-year archive potential (limited by ground stations);

- Because of spectral, resolution, and temporal characteristics, generally most preferred data source for most land resource applications;
- Over 34,000 km^2 per scene;
- Thermal capability (120 m resolution);
- Thermal infrared data.

Limitations:

- Cost per km^2 (five times MSS cost) may limit large area (multiple scene) usage;
- At small scales (1:500,000 or smaller), little difference to interpreters than MSS;
- Cannot penetrate cloud cover; and
- Repeat coverage (revisit) of 16 days.

- SPOT

SPOT-1, the first non-U.S. earth resources satellite was launched by the French on February 21, 1986, and began operational status on May 6, 1986.

SPOT-1 orbits the earth at a mean altitude of 832 km with an orbital cycle of 26 days. A significant feature, a steerable mirror, allows much more frequent revisit times. The mirror that can be tilted from side-to-side to target any area within a 950 km wide area along the satellite's path. The mirror-pointing capability means areas of interest can be imaged more frequently than once every 26 days. For example, an area at the equator can be targeted seven times during an orbit cycle, while a zone at 45 degrees latitude can be imaged eleven times during the orbital cycle. This mirror pointing capability also enables SPOT-1 to acquire stereo images by combining two images of the same area recorded during different orbits, at different viewing angles.

SPOT-1 sensors include two high resolution visible (HRV) instruments using a "push-broom" scanner to record image data. The High Resolution Visible (HRV) instrument may operate in two modes. In the multispectral mode, imagery is acquired in three spectral bands (0.50-0.59 um, 0.61-0.68 um and 0.79-0.89 um) with 20 m ground resolution. Each multispectral image covers a 60 km x 60 km ground area (nadir viewing). In the panchromatic mode, imagery is acquired in a single broad band (0.51-0.73 um) with 10 m ground resolution. Each panchromatic image also covers a 60 km x 60 km ground area (nadir viewing).

SPOT

Advantages:

- Off-nadir viewing enables more frequent repeat coverage, up to five days;
- Stereo data acquisition;
- Higher spatial resolution (20 m for multispectral, 10 m for panchromatic);
- Off-nadir viewing to "target" specific locations;
- Approximately 3600 km^2/scene (nadir);
- May be processed to scales up to 1:50,000 for MS and 1:25,000 for PAN (1:100,000 and 1:50,000 respectively are most common);
- Tape recorders allow data acquisition of any location in the world.

Limitations:

- Higher cost/km^2 compared to TM (but cost may be reduced by SPOT's ability to reduce total area to that of the purchasers interest);
- Limited archive coverage compared to TM;
- Limited multispectral data, minimal spatial resolution difference, and less area coverage compared to TM;
- No cloud penetration.

- MOS-1

On February 23, 1987, the Japanese successfully launched the Marine Observation Satellite-1 (MOS-1). The primary objectives of MOS-1 are to measure oceanographic phenomena, and at the same time provide an experimental platform for basic earth observation technology development by the Japanese remote sensing industry. MOS-1 was launched into a 909 km altitude, with complete earth coverage cycle each 17 days. In this, and additional respects, MOS-1 is very similar to the Landsat 1,2,3 series, but with 50-meter ground resolution.

MOS-1 was developed by the National Space Development Agency of Japan (NASDA), and data are distributed by the Remote Sensing Technology Center of Japan (RESTEC). MOS-1 will be followed by the planned launch of MOS-1b, scheduled for early 1989.

MOS-1 sensors include a Visible and Thermal Infrared Radiometer (VTIR), a Multispectral Electronic Self-Scanning Radiometer (MESSR), and a Microwave Scanning Radiometer (MSR).

The VTIR system uses a scanning mirror to measure a 1,500 km swath width in four spectral bands of visible light and infrared radiation: 0.5-0.7 um (green, red) with 0.9 km resolution; 6.0-7.0 um (infrared), with 2.7 km resolution; 10.5-11.5 um and 11.5-12.5 um (thermal IR), both with 2.7 km resolution. This is the primary instrument for sea surface color and temperature measurement objectives.

The MESSR system performs electronic scanning without a scanning mirror, covering a 100 km swath with four spectral bands similar to Landsat MSS: 0.51-0.59 um (green), 0.61 um (red), 0.72-0.80 um (near-IR) and 0.80-1.10 um (near-IR). Resolution of 50 meters represents a 60 percent improvement over MSS with a swath width similar to SPOT (e.g., 60 km).

The MSR system can measure microwaves emitted from the earth surface and the atmosphere at two frequencies, 24 GHz (31 km resolution) and 31 GHz (21 km resolution). The MSR is a day-night all weather system that penetrates cloud cover. The primary design objective is measurement of atmospheric liquid water content, moisture content, and sea ice and snow distribution. The recording swath width is 320 km.

MOS (MESSR, not yet fully evaluated, hence based on sensor specification information)

Advantages:

- Similar to Landsat MSS;
- Improved spatial resolution (50 m) compared to MSS;
- Anticipate low cost per km², advantageous for large, multiple scene, areas and for monitoring programs;
- Over 10,000 km area coverage; and
- Temporal coverage for change analysis - 17-day repeat (revisit) cycle.

Limitations:

- Not yet fully operational (launched in February 1987);
- Limited data available for evaluation;
- Limited coverage - see ground station map;
- Limited spectral data compared to TM;
- Cannot penetrate cloud cover.

o USSR

In July 1987, the Soviet Union launched COSMOS-1870, a polar orbiting satellite for land and ocean observations. While availability of data from this satellite has not been announced, the

Soviet Union also announced in July that Soyuzkarta, a trade association, is selling remote sensing data, including 6-meter resolution imagery.

4.1.2 Planned Earth Resources Satellites

o Landsat-6 - ETM - EOSAT

The Earth Observation Satellite Company (EOSAT) presently plans to launch Landsat 6 in the second quarter of 1991. The principal sensor will be an Enhanced Thematic Mapper (ETM) scanner. The ETM will be mechanically identical to the current TM scanners. In addition to the existing six 30-meter spectral bands, the ETM will also have a 15-meter panchromatic band with a spectral range between 0.50 and 0.90 micrometers. In addition, the ETM may also carry four multispectral thermal bands with a 60 x 60 meters ground resolution, and a 120-meter band, centered at 3.5 micrometers, replacing the present 120-meter thermal TM band at 10-12 micrometers.

In September 1987, EOSAT announced the addition of the "SeaWiFS" sensor to Landsat-6. The Sea-Viewing, Wide-Field of View Sensor (SeaWiFS) combines attributes of data gathered by the Coastal Zone Color Scanner (CZCS), which operated from 1978-1986, and the Advanced Very High Resolution Radiomater (AVHRR) which is operated on NOAA polar orbitor satellites (Section 4.2.4). The sensor will provide 4 visible, 2 near-IR, and 2 thermal IR spectral channels, near-daily local-area data with a 1.13 km resolution, daily global area coverage with a 4.5 km resolution, and a swath-width of 2400 km.

o SPOT-2 - SPOT Image

Because of the successful performance of SPOT-1, its operational life expectancy has been extended from the two years to three years, through February 1989. SPOT-2, which is identical to SPOT-1, has been constructed and is presently in storage in Toulousse, France. It is presently planned for launch in early 1989, but may be launched sooner in the event SPOT-1 develops data acquisition or transmission problems.

SPOT Image S.A. is committed to a policy of continuous data through the end of the century. SPOT-3 (also identical to SPOT-1, -2) and an upgraded SPOT-4 have been approved for construction.

While upgrade characteristics for SPOT-4 are still under study, several design consideration have been announced:

- A fourth multispectral band (20 m. resolution) will be added in the near-infrared region (1.6 u).

- On board registration of panchromatic (10 m) and multispectral (20 m) data.

- A new Vegetation Sensor, with four multispectral bands and a 2000 km field of view at 1 km resolution, for daily or bi-daily wide area coverage, designed for global vegetation/crop assessment and monitoring.

- J-ERS-1 - Japan

The Japan Earth Resources Satellite-1 (J-ERS-1) is the second series of planned Japanese satellite, to follow MOS-1 with a launch in 1992. The J-ERS-1 objectives will include earth observation data for resource investigations, forestry, agriculture and aquaculture applications, etc. J-ERS-1 is planned for a 570 km altitude orbit.

Planned J-ERS-1 sensors include a Synthetic Aperture Radar (SAR) for geologic applications, a Visible and Near-Infrared Radiometer (VNR) for vegetation/resource distribution objectives, and a Short-Wave Infrared Radiometer (SWIR) for discriminating rock types.

The SAR will be an active microwave imaging sensor which transmits pulses diagonally to the earth's surface and detects reflected waves from the surface, and will provide all-weather imaging capabilities.

The VNR will provide multispectral imaging in four bands: 0.45-0.52 um, 0.53-0.60 um, 0.63-0.69 um, and 0.76-0.90 um. In addition to vertical downward viewing, a forward-looking sensor called a three-dimensional band is planned. Combining the vertical-looking image with the forward-looking image will provide a stereo imaging capability.

The SWIR will also provide multispectral sensing with three or four bands centering on the following infrared frequencies: 1.65 um, 2.10 um, 2.20 um, and 2.35 um.

All three sensor systems on J-ERS-1 are expected to acquire image data over a 75 km swath width with a 20-meter resolution.

- MECB - Brazil

In 1980, the Brazilian government authorized the development of a series of four Brazilian satellites, collectively referred to as MECB (Missao Especial Completa Brasileira). Preliminary details were announced in 1986 by INPE which is responsible for the design, construction, and operation of the satellites.

The first two missions will provide Data Collection Satellites in an orbital altitude of 700-800 km. These satellites will collect and re-transmit meteorological and hydrological data from ground-based Data Collection Platforms distributed throughout Brazil. The first launch is planned in the early 1990's.

Subsequently, two remote sensing satellites are planned, providing multispectral imaging capabilities from an orbital altitude of 642 km. A multispectral sensor will provide data in three bands, (1) .470-.530 um, (2) .630-680 um, and (3) .830-910 um, with 40 m. resolution. Image area will be approximately 80 km x 80 km. In addition to vertical (nadir) viewing, lateral viewing of up to 15 degrees from vertical is included in the design.

o ERS-1, -2 - European Space Agency

The European Remote Sensing (ERS) satellite presently constitutes the most significant activity of the European Space Agency (ESA) in the earth observation field. The planned ERS mission is designed principally for ocean and ice monitoring. The first satellite, ERS-1, is planned for an early 1991 launch, with a three-year life time. A second model, ERS-2, is expected to be launched in 1993 to perform continuous operation until 1996.

The ERS-1 and ERS-2 spacecrafts will be polar orbiting and will contain three core instruments provided by ESA and two nationally provided instruments:

- a radar altimeter
- an active microwave instrument with a C-band wind scatterometer and a C-band synthetic aperture radar (SAR)
- a laser retroreflector
- an along-track scanning radiometer jointly provided by UK and France
- a precise range and range rate experiment provided by FR Germany.

o IRS - India

The Indian Remote Sensing Satellite System (IRS) was announced by the Indian Space Research Organization, Bangalore, in June 1986. The program is expected to consist of a series of satellites, with the first, IRS-1A originally scheduled for launch in mid-1987 (delayed, schedule uncertain).

According to Indian announcements, the IRS will be in a 904 km near circular sun-synchronous orbit with a 22-day repeat cycle. Sensors systems will consist of three Linear Imaging Self Scanning Cameras (LISS) using CCD sensors. Each camera will acquire data in four bands: 0.45-0.52 um, 0.52-0.59 um, 0.62-0.68 um, and 0.77-0.86 um. The first camera, LISS-1, will provide 73-meter resolution in a 148 km swath width. The second and third cameras, LISS-IIA and LISS-IIB, are identical systems arranged for individual swaths of 74 km on either side of the ground track, with 36.5 meter resolution.

o RADARSAT - Canada

Canada is proceeding with the RADARSAT satellite, set for launch in 1994. RADARSAT will provide SAR data for all-weather sea ice monitoring.

4.1.3 Environmental Satellites

o NOAA Polar Orbiting Satellites

For many years NOAA has operated a system of polar orbiting operational satellites, some of them crossing the equator in the morning, others crossing in the afternoon. The latest satellite of this system was launched in September 1986. NOAA intends to launch further identical satellites and to continue providing data services.

o AVHRR

The Advanced Very High Resolution Radiometer (AVHRR) is a five channel instrument designed to provide large area information on cloud systems, snow and ice cover, land and sea-surface temperature, vegetation, etc. The AVHRR instrument flies on board the polar-orbiting NOAA series of currently active satellites.

Equatorial crossings take place at 0738 and 1938 hours local time for NOAA-8, and at 0242 and 1442 hours local time for NOAA-9. Each satellite completes 14.2 orbits per day at an altitude of approximately 830 km.

The AVHRR acquires data in four spectral regions visible (0.58-0.68 um), near-infrared (0.725-0.10 um), thermal mid-infrared (3.55-3.93 um), and two thermal far-infrared (10.5-11.5 um and 11.5-12.5 um), using real-time High Resolution Picture Transmission (HRPT).

The NOAA-8 AVHRR acquires data with 1.1 km resolution in all spectral channels, over a swath width of 2,940 km. On NOAA-9, the AVHRR resolution is 0.5 km in the visible channel, and 1.0 km in

the infrared channels, with a swath width of 2,600 km. Although the orbit repeat cycle requires nine days for nadir viewing, the wide, overlapping swaths provide daily coverage.

AVHRR

Advantages:

- Large area coverage - over 2500 km per swath;
- Overlapping swaths provide daily coverage;
- Multispectral data useful for regional vegetation assessments;
- Daily data for monitoring dynamic temporal events, e.g., regional floods, fires, etc.; and
- Minimal data costs.

Limitations:

- Low resolution limits use to large regions.

o **Geostationary Meteorological Satellites**

Worldwide meteorological observations are presently performed on a global basis by geostationary operational satellites - GOES-East and GOES-West of NOAA, Meteosat of the European Space Agency, and GMS of the Japanese Meteorological Agency, provide similar data for most of the earth's surfaces on a continuous and operational basis. These systems are foreseen to continue with new, more advanced systems planned or underdevelopment. Data from geostationary spacecraft are complemented by the operational polar orbiting system of NOAA.

o NOAA - GOES

NOAA's Geostationary Operational Environmental Satellites (GOES) system has been operational for many years. The most recent unit, GOES-G, was successfully launched in March 1987.

Two geostationary operational environmental satellites monitor the Western Hemisphere their positions over the equator at 75°W and 135°W. Using the VAS (Visible Spin Scan Radiometer and Atmospheric Sounder) they can make half hourly weather observations day and night. The VISSR collects 1-8 km resolution data at 0.54-0.70 um (daytime) and 10.50-12.60 um (nighttime and daytime) thermal data for hurricane and severe storm monitoring. In the Atmospheric Sounder mode it can gather IR radiation data in 12 spectral bands for use in producing atmospheric temperature profiles and moisture measurements.

o European Space Agency (ESA) - METEOSAT

After the successful launch of two pre-operational meteorological satellites, METEOSAT 1 and 2, in 1977 and 1981 respectively, ESA is presently planning to launch the phototype P2 by early 1988. This satellite is supposed to provide continuity of data to the European Meteorological Services until the first satellite of the operational series is launched. The METEOSAT Operational Programme (MOP) will provide operational continuity until approximately 1995, with the following planned satellite launches: MOP-1 in September 1988, MOP-2 in January 1990; and MOP-3 in January 1991.

o Japan - GMS

Two geostationary meteorological satellites (GMS) have been launched to date. GMS-2, launched in 1981, operated only for six months; GMS-3, launched in 1984, is still operational with some degradation. The Japanese Meteorological Agency (JMA) plans to have a new satellite system operational by 1989.

4.1.4 Satellite Ground Receiving Stations

The early Landsat satellites contained tape recorders in order to collect data over areas beyond the receiving range of earth-based stations. Subsequent satellites, including all of the current earth resources satellites, transmit acquired data in real-time. This has led to development of a network of ground receiving stations worldwide. In addition, Landsat 4, 5 can acquire data outside of receiving station range by relaying data through a TDRSS data relay satellite; presently, one TDRSS is in geostationary position over the equator at approximately 35° West longitude, providing Landsat data acquisitions for North and South America, Europe, Africa, and the Middle East.

Fifteen countries have constructed ground systems to receive and process data directly, and other stations are in the construction or planning stages. ***Figures 2, 3, and 4*** show the location and coverage areas for the existing network of ground stations, and their data receiving capabilities (e.g., Landsats 4, 5 MSS & TM, SPOT-1 and MOS-1). Image data are processed and archived at each receiving station, and requests for data must be addressed to each respective station.

Upgrades of receiving station capabilities are both ongoing and planned. For example, in November-December 1987, the Thailand receiving station was undergoing modifications to receive Landsat TM, SPOT, and MOS-1 data; previously only Landsat MSS data were acquired. During the next year, several additional stations will be upgraded to receive SPOT and MOS-1 data, as shown on the corresponding figures.

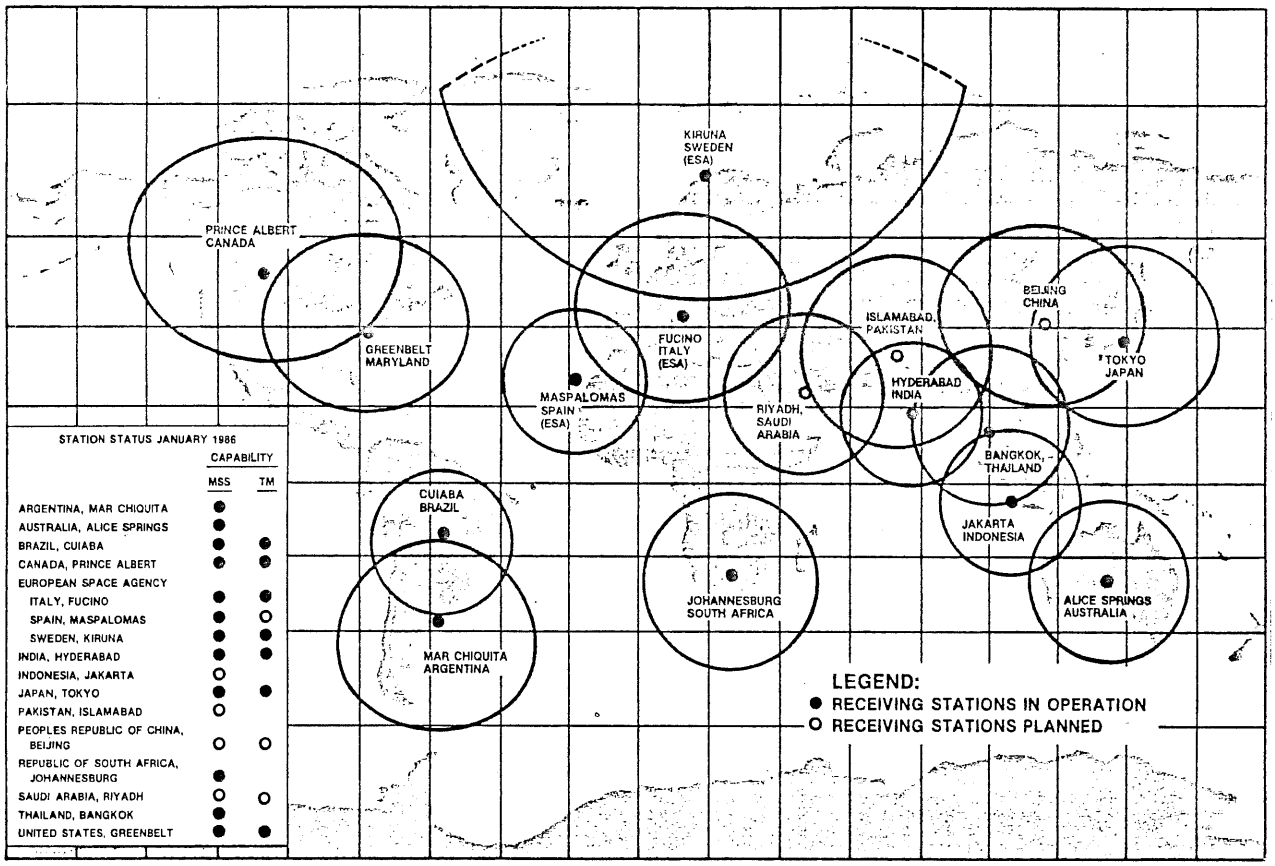

Figure 2: Landsat Receiving Station Coverage

Station	Date	Capability	Status
Argentina, Mar Chiquita	1980	MSS	Off-line
Australia, Alice Springs	1980	MSS	TM upgrade schedule for 1989
Brazil, Cuiaba	1974	MSS, TM	Operational
Canada, Prince Albert	1972	MSS, TM	Operational
European Space Agency			
Italy, Fucino	1975	MSS, TM	Operational
Sweden, Kiruna	1983	MSS, TM	Operational
Spain, Maspalomas	1984	MSS, TM	Operational
India, Hyderabad	1980	MSS, TM	Operational
Indonesia, Jakarta	1982	MSS	Off-line, TM upgrade announced
Japan, Tokyo	1979	MSS, TM	Operational
Pakistan, Islamabad	1988	MSS, TM	Scheduled for 1988
Peoples Rep. of China, Beijing	1986	MSS, TM	Operational
Rep. of S. Africa, Johannesburg	1980	MSS	Operational, TM upgrade planned for 1989
Saudi Arabia, Riyadh	1987	MSS, TM	Operational
Thailand, Bangkok	1981	MSS	Operational, TM upgrade completed end of 1987
United States, Greenbelt	1972	MSS, TM	Operational

Source: EOSAT Corporation, December 1987.

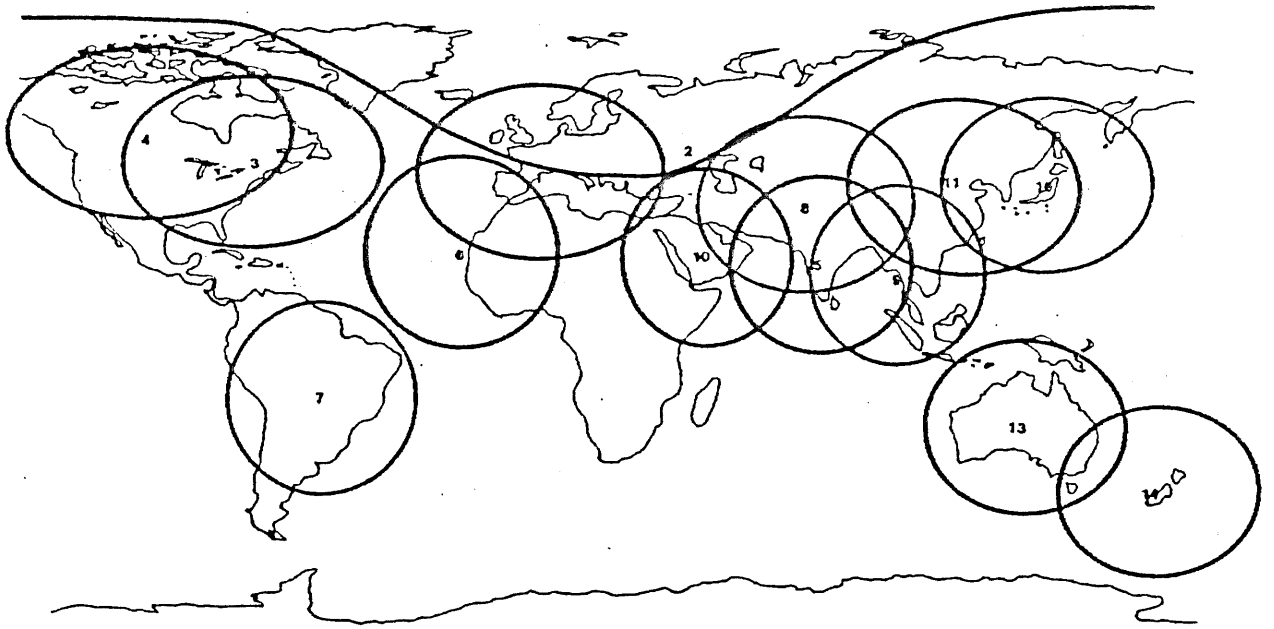

Figure 3: SPOT Receiving Station Coverage

	Station	Status
1.	France, Toulouse	Operating, February 1986
2.	Sweden, Kiruna	Operating, February 1986
3.	Canada, Gatineau	Operating, August 1986
4.	Prince Albert	Operating, August 1986
5.	India, Hyderabad	Operating, August 1986
6.	Spain, Maspalomas	Operating, October 1987
7.	Brazil, Cuiaba	Under Construction, est. early 1988
8.	Pakistan, Islamabad	Under Construction, est. early 1988
9.	Thailand, Bangkok	Under Construction, est. mid-1988
10.	Saudi Arabia, Riyadh	Under Negotiation, est. 1988
11.	China, Beijing	Under Negotiation, est. 1988
12.	Japan, Tokyo (Hatoyama)	Under Construction, est. end-1988
13.	Australia, Alice Springs	Under Negotiation, est. 1988
14.	New Zealand, Auckland	Under Negotiation, est. 1989

Note: SPOT's onboard tape recorders allow worldwide data acquisition. SPOT need not be within range of a receiving station in order to acquire data.

Source: SPOT Image Corporation, Reston, VA, December 1987.

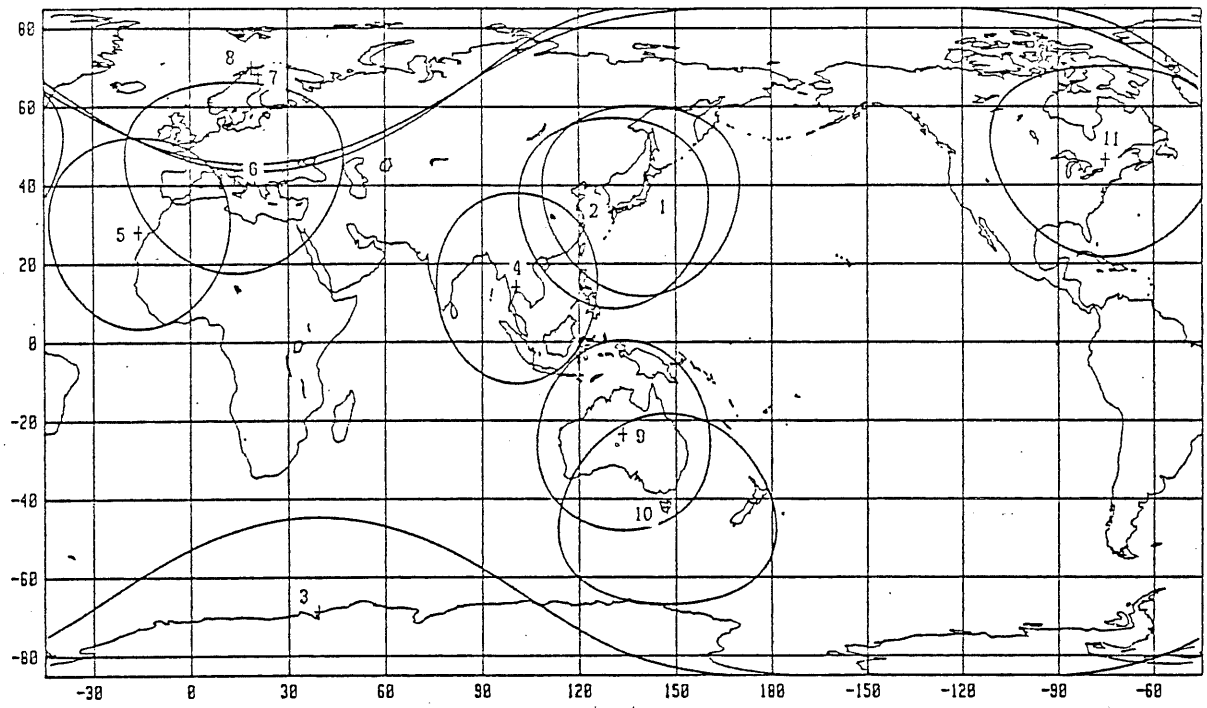

Figure 4: MOS-1 Receiving Station Coverage

Station	Status
1. Japan, Tokyo	Operating, February 1987
2. Japan, Kumamoto (private)	Operating, May 1987
3. Antarctica, Shouwa Station	Planned for 1989
4. Thailand, Bangkok	Planned for April 1988
5. ESA/Spain, Maspalomas	Test receiving started in
6. ESA/Italy, Fucino	September 1987; will be
7. ESA/Sweden, Kiruna	used for demonstration and
8. Norway, Tromso	verification purposes
9. Australia, Alice Springs	Planned for April 1988
10. Australia, Hobart	Planned for April 1988
11. Canada, Gatineau	Planned for July 1988

Source: RESTEC, Tokyo, Japan, October 1987.

4.2 Digital Image Processing Systems

The majority of users of satellite remote sensing data, especially in Third World countries, have traditionally been "picture-oriented." Landsat, and more recently SPOT, images have been interpreted in much the same manner as aerial photographs. Both black-and-white and color images, photographically printed at scales of 1:1,000,000 to 1:250,000 have provided a relatively inexpensive product for regional analysis and mapping. During the present decade, however, the most basic change in technique among remote sensing data users worldwide has been the increased use of computers for processing and analysis of satellite remote sensing images.

Computers, or hardware, together with analytical programs, or software, have evolved during the past two decades to provide advanced capabilities to store, retrieve, overlay, analyze, and interpret the vast quantitaties of data present in a satellite image. Today, digital processing of remote sensing data is a fundamental technique available to all levels of users. Three reasons applicable to any user, including new users, in a Third World environment are:

a. Digital image processing systems are now available at low cost, and require minimal facilities, maintenance, and training;

b. Users quickly realize that there is considerably more information available through a digitally processed image than from a photographic picture; and

c. Digital processing enables the users to focus their processing and analysis to a particular application or feature of interest.

Computer technology is essential for handling the masses of data acquired from Landsat or SPOT; each satellite has the capability of transmitting millions of quantitative reflectance measurements from the earth's surface each second. Because of satellite-derived data are transmitted to ground receiving stations in digital form, computer processing is essential for transforming the data into useful products or information. Computers are used in two different ways to accomplish this transformation. First, is to produce images as pictures, in black-and-white or color, at scales generally ranging from 1:1,000,000 to 1:250,000. Such functions are performed by the ground stations using large, expensive, image processing systems. Resultant photographic products are distributed to users worldwide. Similarly, ground stations distribute images in digital form, a product of increasing popularity to users with local computer processing capabilities.

At the user level, computer processing can produce higher quality images for visual analysis by human interpreters, images processed to enhance features of interest for their particular application.

The second use of the computer, at the user level, is to analyze digital data by pattern-recognition software, to produce an image and/or tabular data based on a classification of a specific area or features(s) of interest.

The following discussion and accompanying *Table 4*, reviews the evolution of digital image processing systems, an evolution that has followed advances in computer technologies of the past two decades. Presently available digital image processing systems vary considerably in hardware and available software programs as well as levels of sophistication, accuracy and cost. Today's digital image processing systems, and more recently GIS systems discussed in Section 4.3, are standard fixtures in national mapping and remote sensing agencies, and commercial remote sensing facilities, world-wide.

4.2.1 Hardware Systems

In the early 1970's, development of the current generation of digital image data collection systems began with the Landsat family of satellites. These new data systems required new techniques for the processing of digital image data. The first image processing systems were developed and provided by NASA and NASA's academic and commercial support organizations. Early systems typically ran under punched-card batch modes on IBM 360s, DEC-10s, and other big mainframe systems. JPL's VICAR/IBIS, Penn State's ORSER, Purdue's LARSYS, NASA ERL's ELAS, and the GE IMAGE 100 were among the most popular of the first digital image processing systems.

Soon thereafter, private companies like I^2S (International Imaging Systems), DeAnza, Comtal, DIPIX, Spectral Data, Spatial Data, and ISI (Interpretation Systems, Inc., now a subsidiary of LogEtronics) configured color display systems with early 8-bit, then 16-bit, and now 32-bit mini-computer systems, and programmed them with an expanding range of image processing algorithms in support of this industry. Initially, these systems were developed and installed in key U.S. remote sensing labs in support of the pioneering Landsat satellite imaging industry. Gradually, countries cooperating in these programs began setting up labs in which some of these major systems were installed. Some provided ideal locations for ground stations providing line-of-sight communication with the orbiting satellites (Argentina, Brazil, Canada, Iran, Italy, the Philippines, South Africa, Sweden, Thailand, etc.). The more advanced countries began developing their own image processing systems; the undeveloped countries relied heavily on U.S. companies (and more recently European and Japanese) and

TABLE 4: IMAGE PROCESSING SYSTEMS

COMPANY	SYSTEM/SOFTWARE	HOST COMPUTER(s)
ESL	IDIMS	VAX/SUN/PRIMES
MDA	Meridian	VAX

Comments: These are the big systems used by petroleum companies, well funded government labs, and satellite ground stations (production facilities). They frequently feature multiple display stations and multiple hosts in a central cluster, with division of functions to maximize efficiency. The MDA/Meridian system grew from ground station processors, and has strong geocoding and spatial operations.

NASA/GSFC	LAS	VAX
JPL	VICAR/IBIS	VAX/PRIME/IBM Mainframe/(PDP-11)
NASA/NSTL	ELAS	VAX/PRIME/VARIAN
USA CoE	GRASS	MassComp/SUN

Comments: These are government developed systems. They include most of the popular algorithms, but are typically not as user friendly or as well implemented as commercial systems. ELAS is popular because it is relatively inexpensive, but none of these are sufficiently efficient to be commercially attractive. Government packages also tend to be not as well documented or supported as the commercial systems, and have not had a planned organized development.

I^2S	Model 75, System 600, & IVAS	SUN/VAX/MassComp/ PRIME/(PDP-11)
(DIPIX)	(ARIES-I, -II, & -III)	VAX/(PDP-11)

Comments: These are the popular middle-of-the-line systems that are strong on general interactive processing and display but limited multi-spectral capabilities. DIPIX went into receivership in early November 1987; they had not diversified hosts allowing a wider selection to their customers, and lost out to I2S and to less expensive PC-based systems.

GOULD (DeAnza)	IP 8000 Series, LIPS	VAX/SUN/(PDP-11)
PIXAR		SUN/Silicon Graphics
COMTAL (3M)	Vision Lab	VAX

Comments: These are primarily interactive imaging displays with some hardware implemented special functions but generally have limited image manipulation or multispectral capability. They have not gained the integrated system popularity of I2S or DIPIX.

EarthSat	GEOPIC/GEOMAS	PRIME/VAX	
ERIM		VAX/PDP-11	
GEMS-Cambridge	GEMSTONE		M-68020
GeoScan	(Australian)		PC
VEXCEL Corp	VEXISS	VAX	

Comments: Several private companies have begun licensing their proprietary image processing software to other users. Efficiency of operation and functionality of application developed through internal use are their strong points when compared integrated hardware/software systems.

ERDAS		PC/SUN/VAX	
PCI (Canada)	EASI/PACE	PC/SUN	
Terra-Mar	MicroImage	PC/SUN	
Decision	Images	Decision-8, -32	PC
NUMELEC (France)	Pericolor	PC	
MicroBrian	(Australian)		PC
Digital Image Inc.	RIPS, VIP	PC	

Comments: These are among the more popular PC-based systems. All are oriented to small array processing and are strongly interactive. They are generally weak on hard copy orientation, and lack sophisticated multispectral programs, but are good general purpose, low cost systems. ERDAS is the most advanced and most popular, strong on GIS components, has an explicit topographic module, and exists in several hardware configurations.

PURDUE	LARSYS		IBM
PENN STATE	ORSER		IBM
IBM	HACIENDA		IBM
GE	Image 100	PDP-11	
BENDIX	M-DAS	PDP-11	

Comments: These are institutionally developed systems, which for all practical purposes have become extinct.

donor organizations for both financial and technological assistance. Industry specific conferences in the mid-1970's sponsored by Purdue, the Tullahoma Space Institute, ERIM, and and the Pecora Conferences at EROS Data Center provided effective forums for discussions, demonstrations, and early technology transfer.

The Digital Equipment Corporation (DEC) systems gradually became the dominant computers in the image processing community, and evolved from early PDP-8's to the extremely popular 16-bit PDP-11, and now the 32-bit VAX family of systems. The most powerful (and expensive) of the commercial systems is ESL's (TRW subsidiary) IDIMS... a VAX-cluster based multi-display typically configured with 2 VAXs, an array processor, and a small room packed full of disk drives. System prices ranged from $400,000 - $2 million. This system is strongly interactive and has good multispectral processing features. IDIMS was developed for the petroleum market and a number of USG labs. Overseas their systems appeared in Denmark, Taiwan, Bangladesh and Saudi Arabia. IDIMS users are technically sophisticated, highly competent, well funded, and are organizations with large image processing arrays/data base management jobs to do, in an industry where time is money and competition is rigorous. The IDIMS is not a beginner's system.

The next level down, in terms of price and complexity, in the early 1980s was dominated by I²S and DIPIX. Their systems were based on a single DEC host and a single display, and targeted the single-user workstation lab with a budget in the $120-400K range. The ISI EarthViews system was also in this range, but was not very successful in the market place, and did not make the jump necessary for survival from the 16-bit PDP-11 to the 32-bit VAX. The first DIPIX ARIES-1 system was installed at ONERN in Peru by CIDA, and has recently been upgraded to an ARIES-III. Other DIPIX installations followed in Holland, India, and Asia where the system became very popular. EarthViews system installations included Chile (SAF) and Ecuador (CLIRSEN) as well as China. Delta Data Systems, a NASA ERL spinoff, placed a system at AIT (Thailand).

I²S systems were popular throughout the US, Europe, and China. They evolved from a line of specialized processors and are strong on general interactive processing and display. The DIPIX systems are also strong on general interactive image processing and display, with emphasis on geometric registration, corrections, and transformations for interactive digital mosaic processing. Drawing an analogy, I2S and DIPIX produce the Cadillacs and Chryslers, while ESL's IDIMS is equivalent to the top of the line BMW or Mercedes. There was a definite distinction between these two levels of systems in terms of both price and capability.

Then the IBM-PC appeared on the scene. Dramatic increases in performance of the attractively priced personal computers over the past 3-4 years have expanded greatly their range of applications. Past tasks which were restricted for reasons of practicality to mainframe and mini-computers can now be executed by an off-the-shelf PC. Special purpose boards and peripheral devices

have further expanded the PC's capability to handle most image processing tasks. Processor speed, memory addressability, and on-line disk storage capacities of today's advanced Personal Computers rivals that of the mainframes of several years ago.

A number of companies (ERDAS, Terra-Mar, PCI, etc.) appeared with PC based image processing systems and began to slowly but surely build a broad user base and to eventually penetrate the business of the big system vendors. Because of their price/performance popularity, good image processing software development for PC-based systems has proliferate at a respectable pace. DIPIX failed to diversify with competitive configurations and to provide consistent or timely quality service and software upgrades; sales dropped below the critical level and they have recently gone into receivership. I^2S has expanded capabilities on lower cost new technology hardware to remain adequately competitive; they, and ESL, have adopted the 32-bit SUN MicroSystems processors. SUN MicroSystem mini-computer configurations, with a cost range of $25-100K currently have the popularity previously occupied by DEC.

At the PC micro-computer level, ERDAS and Terra-Mar have taken the development lead, expanding their image processing software capabilities simultaneous with the development of new PC technologies, such as the IBM PC/XT, followed by the PC/AT and compatibles. These systems provide small array processing and are strongly interactive. ERDAS, for example, has installed over 500 systems throughout the U.S. as well as 38 countries, including such developing countries as Morocco, Zimbabwe, Kenya, Thailand, Indonesia, Nepal, China (PRC), El Salvador, Costa Rica, Panama, and Portugal. Similarly, Terra-Mar systems have been installed in Sudan and Kenya, both funded by USAID, as well as in Thailand; several additional installations are planned in the near-term in South America and southeast Asia.

Perhaps most significant for PC-based image processing systems was the introduction of personal computers built around the INTEL 80386 microprocessor chip, which appears to have quickly and dramatically altered the 32-bit workstation market. Compaq introduced the DESKPRO 386 in the fall of 1986. Zenith and IBM followed with their versions in 1987. Hardware benchmarks of the 80386 chip running at 16 MHz have demonstrated 3-4 MIPS (Million Instructions per Second) performance, comparable to many of today's super-mini computers. The 640 KBy memory/disk addressability limitations of PCs operating under MS-DOS and limitations on true multi-tasking provide the major remaining division between the mid-sized image processing systems and the PC based systems. Processing/throughput time for complex operations still takes a while on the PCs, but respectable PC-based systems for image data processing have come of age. Their enhancement continues, driven by a healthy demand. Clearly, as the availability of systems, components, and market performance worldwide have shown, it is now practicable to base a combined image processing and GIS system, as discussed in Section 4.3, around personal computer technology.

People now entering the image processing industry frequently do so via the PC route. Those who have serious (volume) image processing work to do and who continue to be sufficiently successful to afford growth, however, usually make the transition to a larger system out of computing frustration and/or competitive need. ERDAS, Terra-Mar, and PCI are developing UNIX versions of their code for the SUN Systems to address this midrange portion of the market as well.

4.2.2 Software Implications

Regardless of a digital image processing system's hardware configuration, software, including the types of algorithms and processing functions is fundamental. While the image processing algorithms are often similar, their implementation differs, typically by hardware considerations. Basic capabilities of most digital image processing software include:

- Ability to handle Landsat MSS-TM, SPOT MS & Pan, MOS, AVHRR, and similar remotely sensed imagery available in digital format.

- Ability to perform image classification using multispectral data.

- The application of statistical spectral pattern-recognition techniques to multispectral remotely sensed data for the purpose of land-cover classification is the most common use of digital image processing systems. Both supervised and unsupervised techniques have been employed to achieve fairly accurate classifications of land cover features such as urban, agriculture, rangeland, forest, water, wetlands, barren land, snow/ice, etc.

- Ability to perform image enhancements, including contrast adjustments, spectral band combinations, ratioing and principal components, image magnification/minification, annotations, and various arithmetic operations. Image enhancement capabilities generally consist of contrast enhancement, filtering, and multi-band combinations, the later including band-ratioing, linear band combinations and principal components analysis. Each technique is intended to improve the quality of the resultant image and to increase its interpretability for either general or specific applications analyses.

Not basic to most available digital image processing systems are an extensive list of requirements for geometric and radiometric calibration corrections. Such corrections are performed by the ground station processing systems on data prior to distribution and are available as system corrected products.

Some digital image processing systems provide algorithms for correcting image geometry to a user defined map projection. This may include use of established and available ground control points (GCPs), enabling the resultant image product to serve as a map. Such accuracy is critical when images are digitally merged for large area mosaics, when digital images are integrated into a GIS, and when other data are georeferenced, either manually or digitally (GIS), to overlay topography or other resource/environmental data.

Unfortunately, for interested users, few digital image processing systems have been subjected to rigorous benchmark comparisons. The market place for commercial systems is highly competitive, leading the principal contenders to maintain active and ongoing software development programs and software modifications to meet new hardware configurations. Particularly among the rapidly expanding PC-based image processing systems, such as ERDAS, Terra-Mar and PCI as well as others, software improvements, changes and new functions are being continuously released.

4.2.3 Facility Implications

In order to sustain management's interest, an investment in anything has to produce positive results. Regardless of the computer configuration chosen for an image processing facility, careful attention should be paid to three areas of importance to successful system use and to management's appreciation (and continued support) of this technology.

a. The facility must be appropriately set up and maintained,

b. A continual budget for maintenance and for hardware and software upgrades must be planned for, and

c. System users must be skilled and adequately trained, in both system operations and specific applications, to get the desired results from their system.

This last item includes establishment of a continuing dialog with the system vendor and with users of similar systems and applications interests in order to maintain an awareness of new approaches to pertinent problems and advances in technology. Budgets for post-warranty hardware maintenance (service contracts and maintenance calls), software maintenance (upgrades), and operator maintenance (technical subscriptions, refresher courses, workshops, and associated travel funds) are equally as important as the initial system acquisition budget.

A facility's environment must be prepared properly and maintained. This includes sufficient clean and stable electric power important to sensitive electronics and memory, a sufficiently clean (reasonably dust free) environment - important to disk and tape

drives and cooling fans, and sufficiently clean or purified water if the facility includes a photographic hard copy lab. Site preparation and post-installation maintenance is a cost to be considered.

In light of the last few preceding paragraphs, an interesting possible disadvantage to the generic PC-based image processing systems for developing countries is their relatively low, consequently attractive price. In the case of the "big-computer" image processing installations, site-preparation and maintenance costs are proportionately small and "reasonable" expenditures. These were sometimes included in the "package" price of the larger systems, and price margins were sufficient to absorb some "free support" provided by some vendors. In the case of the PC systems, however, these costs may equal or exceed the price of the total system. Provisions for stable power and other environmental preparations for installations in developing countries must be properly prioritized, and planned for financially. The possibility of insufficient budgetary planning, and planning for support over several years, increases the risk of a user's failure to produce the "positive results" desired.

As these facility preparation and "system" (hardware/-software/operator) maintenance costs for a developing country are added to the total price of image processing capability, the cost differences between PC and larger host based systems may become less of an issue. Additional line items in the budget should be planned for these preparations. System and support-vendor(s) selection for developing country prospects should be made, not to minimize Image Processing System price, but to maximize the probability that the users will succeed in achieving their intended goals.

4.3 Geographic Information Systems

Geographic Information Systems (GIS) is a relatively recent technological development for merging various independent spatial data (maps) into a form representing information (presented as custom maps and tables for specific applications). GIS include four main elements, a processing unit, an input device, software and an output device. These systems all designed to store, process, and analyze spatial data sets. GIS's represent a rapidly developing technology bringing together many disciplines-among them cartography, computing, geography, photogrammetry, remote sensing, statistics, surveying and other disciplines concerned with handling and analyzing spatially referenced data. GIS is of interest to a wide and increasing range of users, including land and resource managers, market researchers, planners, property assessors and those responsible for utilities planning and development. At a more general level, policy makers and administators in government departments are utilizing GIS technology for their decision making. Systems have been/are being developed or considered at scales from the cadastral to the global for a wide variety of purposes, yet they have many features in common and face similar problems.

4.3.1 Characteristics of GIS

In many respects geographic information systems are similar to automated information systems. This commonality is based on the following:

- Data collection;
- Transformation of the data into machine readable form;
- Editing and updating of the data files;
- Storage of the data;
- Computer analysis and manipulation of the data;
- Retrieval of entire files or selected portions of one or more files; and
- Generation of a variety of outputs, including maps, charts, and statistics.

Many, in particular those in the computer sciences, view GIS as a subsystem in an information management system. The most significant difference between a GIS and other information systems is in the spatial or geographic nature of the data handled by a GIS. The data must be georeferenced, that is, it is tied to locations on the surface of the earth, to create information with which managers, planners and scientists can interact.

GIS software can be distinguished by the types of data it is most efficient in processing. The more common systems use map based data in what is called vector format. Applications of the vector format are more cartographically oriented; examples can be found in engineering, boundary analysis, and contour/isohyet generation. A second system type uses image-based data, in what is called a raster format. Applications of the raster format are

image and remote sensing oriented. Most of the applications development in this format have been in the natural resource planning and management field because of the strong dependence on remote sensing for data base development. Interestingly, a review of GIS literature indicates that most research and development has involved the vector format, while raster format R&D has primarily been spinoffs from the image processing field. In addition, research underway at the Jet Propulsion Labs and several university centers are focused on developing new raster/vector interfaces to a standard interchange format as well as to specific existing software systems (for example, JPL's VICAR/IBIS raster-based GIS and Intergraph Corp's CAD/CAM/Mapping vector-based system). Such interfaces presently exist within several commercial GIS's (for example, ESRI's ARC/INFO and GRID systems).

o Vector Format

The basic unit of the vector format is the line, used to encode the locational description of an object. A line is represented as a string of coordinate points. Closed areas are defined as polygons, and represented by a set of lines that constitute their boundaries. The polygons define associated properties and provide the delineations for the spatial relationships. As an example, a polygon file may represent an area where a particular soil series or land use is located. Drainage features, power utilities, and transportation networks largely deal with streams and rivers, wires, and right-of-ways which are linear features best represented by points and lines. For these applications, vector format GIS's are most useful. Examples of vector format Geographic Information System's data structures include ESRI's ARC/INFO system, the Harvard Laboratory for Computer Graphics and Spatial Analysis ODYSSEY system, Terra-Mar's Terra-Pak system, and KorkSystem's KGIS.

o Raster Format

The basic unit of the raster format is the rectangular cell or pixel which represents a unit of space. The cell/pixel partitions the data plane into these units of space in a uniform manner. Each unit of space can have a given set of associated properties. Aggregating the cells/pixels representing the specific associated properties of interest provides the spatial relationships. As a pixel format example, all pasture land use may be represented by a certain cell value or color.

The grid cell approach to Geographic Information Systems was largely driven by simplicity in programming, and the raster/pixel was determined by hardware designs used in digital image processing systems. Natural resources managers and remote sensing scientists typically deal with areal data which may be provided by satellites or air photos. Where imagery is involved,

raster GISs are usually preferred. Examples of raster format GIS data structures include JPL's Image Based Information System (IBIS), ESL's Interactive Digital Image Manipulation System (IDIMS), and ERDAS's GIS.

4.3.2 Commercial and Institutional Development

Technological advances in computer hardware and software coupled with rising data demands for improved decision making have been the motivating forces in GIS technology development. Both advances and demands have occurred simultaneously, often in a synergistic manner: development of a new algorithm allows further data manipulation which in turn stimulates a new application. However, in general, technological advances have progressed at a much faster pace than applications. This trend should change as the technology becomes less expensive, the data demands for decision-making become more critical, and the technology's applications broaden in scope. The availability of accurate data bases and sources is now being recognized as a limiting factor in the adoption and expansion of GIS applications. Often suitable data do not exist and need to be generated, adding to the cost of a system's implementation. The advent the less expensive PC-based systems frequently places the cost of data base development at more than that of the system's hardware, software, and training.

Advances stimulated by the commercial sector have been primarily in hardware and software configurations. As computing technology has improved in speed, size, and user friendliness, commercial system vendors have been quick to integrate and adapt because of the increasingly competitive market.

A major trend in commercial GIS development has been in PC-based systems. The major GIS commercial vendors, Environmental Systems Research Institute (ESRI), Earth Resources Data Analysis Systems (ERDAS), Terra-Mar Resource Information Systems, Inc., and PCI (Canada) all offer GIS software for a PC-based configuration. These PC-based systems represent a significant cost reduction from the larger minicomputer based systems. Introduction of the less expensive systems has had a major role in allowing the expansion of GIS technology to problem solving, information management, and data development, in numerous fields and disciplines. Currently available commercial systems offer a range of capabilities to the user that have yet to be exploited fully.

While commercial systems development has instigated improvements in data manipulation and machine speed, system application and integration has been spurred by government departments and large institutional adaptations. These users frequently have large data base needs and system accessability demands from several different locations. While commercial turn-key systems may meet some of the departmental or institutional requirements, they can not

fulfill all of the design objectives. A custom system of some type is needed. Several of the commercial vendors also provide this type of system integration or development service.

Institutional considerations, based on interview comments, have been systems objectives oriented. Hardware and software considerations are secondary to system objectives, such as: multiple user capability; data base availability; hard copy output; data transportability; and remote sensing integration needs. Application objectives also are important considerations in GIS system design. These applications have an extremely wide range that appears virturally to be growing daily. Some illustrative examples are: wildlife habitat identification; natural resource exploration; site selection analysis; temporal change detection; land suitability analysis; agricultural crop monitoring; water quality monitoring; visual impact evaluation; cadastral simulation and recording; and traditional mapping functions. Often there are multiple application objectives. These systems invariably need some type of special design or installation, owing to the multiple user needs and demands.

In addition, numerous research and development efforts continue in both public and private research programs. Recent advances in automated scanning technology have reportedly made it possible for linework (maps) to be scanned on relatively inexpensive systems and to be output as raster images. Implementation of spatial data models, accommodating large quantities of data from a wide variety of sources (both raster images and vector maps), will be more flexible and efficient using expert systems. The major areas where expert system technology is being developed for GISs include map design, terrain/feature extraction, geographic database management, and geographic decision support systems.

4.3.3 Case Studies

Two government organizations in the U.S. Department of Interior that have implemented GIS technology for large scale applications are the Fish and Wildlife Service and the National Park Service. Both systems were developed with a particular application in mind and involve the collection and manipulation of large data bases. The specific application is to preserve biological diversity within their areas of authority through habitat identification and monitoring.

A GIS was developed initially for the Fish and Wildlife Service's (FWS) National Wetlands Inventory project. The system, the Analytical Mapping System (AMS) centers on mapping from aerial photography. The system was reprogrammed to run on a different hardware configuration by the Western Energy and Land Use Team (WELUT). WELUT has become the systems operator for the FWS, centralizing the functions of data entry, conversion and product generation at Fort Collins, Colorado. The system has three soft-

ware components: the Analytical Mapping System for digital data entry; the Map Overlay and Statistical System (MOSS) for data processing, analysis, and display; and the Cartographic Output System (COS) for enhanced cartographic products. MOSS is the analytical package of the system and has both raster and vector capabilities. The primary product of the AMS is high quality map products.

Applications of the GIS technology developed at WELUT focus on natural resource management and planning efforts. Computer assisted resource management applications supported by the AMS include:

- Fish and Wildlife Species Analysis and Modeling
- Fish and Wildlife Habitat Suitability Determinations
- Regional Resource Planning
- National Wetlands Inventory
- National Wildlife Refuge Master Planning
- National Wildlife Refuge Management
- Wetland Change Analysis
- Coastal Zone Planning
- Coastal Wetland Changes
- Riparian Habitat Assessment
- Land Use Planning
- Energy Development Assessment
- Resource Management Plan Development
- Coal Management Program
- Oil Shale Management Program
- Tarsands Development Planning
- Forest Management Planning
- Forest Pest Management and Impact Assessment
- Soils/Land Use Assessment
- Soils Primary Sample Unit Selection and Analysis
- Land Records Information Management

The National Park Service (NPS) has built a GIS that has as a basic requirement the integration of remote sensing and spatial data. This requirement was dictated by the NPS's mandate to preserve the park system's natural and cultural resources, yet provide for recreational and other nonconsumptive uses of the resources. This requires a great deal of data about the occurrence and spatial distribution of the various resources, which the NPS does not have. These data needs are frequently filled through the analysis of satellite imagery.

The GIS at the NPS's Geographic Information System Division (GISD) consists of three complimentary, public domain software packages: ELAS, a raster based image processing/GIS; GRASS, a raster based image processing/GIS with some vector capabilities; and SAGIS, a vector based GIS with some raster capabilities. These three packages were selected to provide flexibility and functional power for data base construction, analysis, and the transferability of data between users. The GISD provides both data base development and analytical support for the individual national

parks throughout the U.S. The GISD also provides system integration services as well as training for those individual parks that want systems capabilities at their locales. Thus GISD serves as a technology transfer agent within the NPS promoting data transportability, software transportability, and hardware independence.

4.3.4 Recommendations

Both case studies provide examples of the initial centralization of GIS technology that considered the following operational concepts; design and development based on identification of system objectives, the adoption of software packages that allow flexibility and variety of application, some degree of hardware independence, and the operational integration of the technology within the organization. The above design considerations can serve as an effective template for AID's future integration of GIS technology in its development projects.

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APPENDIX A

SELECTED SOURCES OF IMAGE PROCESSING AND GEOGRAPHICAL INFORMATION SYSTEMS

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Autometric Inc., 2629 Redwing Road, Fort Collins, Colorado, USA.

Suppliers of integrated software (DELTAMAP) for vector and raster thematic mapping, digital terrain models, etc., designed to run on DEC PDP-11, VAX-11, and DATA GENERAL MV-Service machines.

COMARK Services, 150 Executive Park Blvd, San Francisco, California, USA.

GIS package for thematic mapping incorporating a relational DBMS. Supported on Data General, DEC, IBM, and microcomputers under UNIX.

Construction Engineering Research Laboratory (CERL) of the U.S. Army Corps of Engineers, P.O. Box 4005, Champaign, IL 61820-1305.

The Geographic Resources Analysis Support System (GRASS) GIS and Image Processing system developed by U.S. Army environmental managers and planners, is a low cost public domain system running under the UNIX operating system.

Dames & Moore, 445 South Figueroa Street, Suite 3500, Los Angeles, CA 90071.

Geographic Information Management System (GIMS) is a raster-based GIS focusing on environmental applications. The system is compatible with VAX, PRIME, CDC Cyber, and TBM, includes engineering applications such as volumetric and cross-section analysis.

DIPIX Systems Limited, 120 Colonnade Road, Ottawa, Ontario, Canada K23 7J5.

Turn-key systems for image analysis and remote sensing based on DEC PDP-11 and VAX-11 hardware.

ERDAS, Earth Resources Data Analysis Systems, Inc., Advanced Technology Development Center, 430 Tenth Street, N.W., Suite N206, Atlanta, Georgia, USA.

Suppliers of software packages and turn-key systems for integrated GIS and satellite image analysis with relational database and topographic modeling capabilities running on IBM PC's and compatibles, SUN, DEC, Data General and other machines.

ESL, Inc., 495 Java Drive - MI, Sunnyvale, CA 94086

IDIMS (Interactive Digital Image Manipulation System), a highly sophisticated and very powerful turn-key image processing system with some GIS capabilities, supported on PRIME, VAX, SUN, IBM-PC and other machines.

ESRI, Environmental Systems Research Institute, 380 New York Street, Redlands, California, USA.

Suppliers of very sophisticated software (ARC-INFO) for mainly vector-based overlay geographical information systems including DBMS capabilities.

GIMMS Limited, 30 Keir Street, Edinburgh, Scotland.

GIMMS is a low-priced, general purpose integrated geographical processing system for producing medium to high quality thematic maps on pen plotters.

Harvard Laboratory for Computer Graphics and Spatial Analysis Gund Hall, 48 Quincy Street, Cambridge, Massachusetts.

The developer and supplier of GIS programs such as SYMAP, GRID, IMGRID, DOT-MAP, ODYSSEY.

Hunter GIS (successor company to Aeronca Electronics, Inc.), 1121 Wood Ridge Center Drive, Charlotte, North Cardina 28217.

Microbased GIS and Image Processing Systems built around the 286 and 386 line of PC's. Strong support of video image analysis, and concentration on data format conversion program modules.

I²S, International Imaging Systems, 1500 Buckeye Drive, Milpitas, CA 95035.

Turn-key systems for image analysis and remote sensing. Image analysis system includes own hardware linked to DEC PDP-11 and VAX-11 and other machines. Sophisticated and powerful hardware/-software for many image processing and GIS applications.

Intergraph, One Madison Industrial Park, Huntsville, AL 35807-4201.

Worldwide producer of highly sophisticated turn-key interactive graphics systems with specialist applications in mapping.

ITC International Institute for Aerial Survey and Earth Sciences, P.O. Box 6, 7500 AA Enschede, The Netherlands.

A range of systems for geodata processing including PC-based.

Jet Propulsion Laboratories, 4800 Oak Road, Pasadena, CA 91103.
VICAR/IBIS, raster-based image processing and GIS systems developed for resources, military and space sciences applications.

Kork Systems, Inc., 6 State Street, Bangor, Maine 04401.

Kork Geographic Information System (KGIS), a turn-key digital mapping and GIS on Micro VAX machines.

MapInfo, Hendrick Hudson Building, 200 Broadway, Troy, New York, 12180.

The Map Information Display and Analysis System (MIDAS) is a PC-based street address - specific computer mapping GIS system with relational DBMS capabilities.

Terra-Mar Resource Information Services, Inc., 2113 Landings Drive, Mountain View, CA 94943.

A PC-based image processing (MicroImage) and vector-based GIS (Terra-pak) system with relational database capabilities.

TYDAC Technologies, Suite 320, 1655 North Fort Myer Drive, Arlington, VA 22209.

TYDAC Spatial Analysis System (SPANS) is a microcomputer raster based GIS system using a guadtree data structure.

APPENDIX B

REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS NEWSLETTERS

APPENDIX B

REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS NEWSLETTERS*

A. *REMOTE SENSING NEWSLETTERS*

1. COMMERCIAL

EOSAT Landsat Data Users Notes
Earth Observation Satellite Company (EOSAT)
4300 Forbes Boulevard
Lanham, MD 20706

GEOSAT News
The Geosat Committee, Inc.
University of Oklahoma
Physical Sciences Building
Room 438-C
Norman, OK 73019

Aplications
Decision Images, Inc.
1000 Herrontown Road
Princeton, NJ 08540

ERDAS Monitor
ERDAS, Inc.
Advanced Technology Development Center
430 Tenth Street, NW
Suite N206
Atlanta, GA 30318

IEEE Geoscience and Remote Sensing Society Newsletter
Geoscience and Remote Sensing Society of the Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street
New York, NY 10017

Polar Orbiter Newsletter
P.O. Box 8313
Temple Hills, MD 20748
Subscription: $90/yr - U.S. & Canada
$100/yr - all others

SPOTLIGHT
SPOT Image Corporation
1897 Preston White Drive
Reston, VA 22091-4326

Washington Remote Sensing Letter
P.O. Box 2075
Washington, DC 20013
Individual Subscription: $210/yr

Aerial Advantage
Kodak Aerial Systems
1099 Jay Street
Rochester, NY 14650

DAEDALUS Newsletter
Daedalus Enterprises
P.O. Box 1869
Ann Arbor, MI 48106

GRASSCLIPPINGS
Institute for Technology Development
Space Remote Sensing Center
Bldg. 1100, Suite 308
NSTL, MS 39529

The Photogrammetric Coyote
E. Coyote Enterprises, Inc.
Mineral Wells Industrial Complex
Route 3, Bldg. #228
P.O. Box 1119
Mineral Wells, TX 76067

* Based on material prepared by Dr. James W. Merchard and Loyola M. Caron, University of Kansas, Lawrence, KS 66045-2069.

2. U.S. - NATIONAL AND STATE/REGIONAL

CIMSS View
Coopertive Institute for
Meteorological Satellite Studies
Space Science and Engineering
Center
1225 West Dayton Street
University of Wisconsin - Madison
Madison, WI 53706

ELAS User Group Newsletter
Florida Department of Natural
Resources
100 8th Avenue SE
St. Petersburg, FL 33701

Institute for Technology Development/ Space Remote Sensing Center (SRSC) Newsletter
Institute for Technology Development
Space Remote Sensing Center
Suite 308, Building 1100
National Space Technology
Laboratories
NSTL, MS 39529

National Space Science Data Center (NSSDC) News
National Space Science Data Center
NASA/Goddard Space Flight Center
Code 633
Greenbelt, MD 20771

Remote Sensing Status Report
U.S. Department of Agriculture
Soil Conservation Service
P.O. Box 6567
Fort Worth, TX 76115

Tech-Tran
U.S. Army Corps of Engineers
Engineers Topographic Laboratories
Fort Belvoir, VA 22060-5546

Video Technology Newsletter
USDA/Agricultural Research Service
P.O. Box 267
Weslaco, TX 78596

EARTHQUEST
Office for Interdisciplinary
Earth Studies
University Corporation for
Atmospheric Research
P.O. Box 3000
Boulder, CO 80307

Forest Pest Management Methods Application Group Newsletter
U.S. Forest Service
3825 East Mulberry
Fort Collins, CO 80524

NASA Report to Educators
National Aeronautics and Space
Administration
Education Services Branch
Public Affairs Division (LFC-9)
Washington, DC 20546

National Cartographic Information Center (NCIC) Newsletter
U.S. Geological Survey
NCIC, 507 National Center
Reston, VA 22092

Remote Sensing in Archaeology Newsletter
Space Remote Sensing Center
Building 1100, Suite 308
NSTL, MS 39529

Remote Sensing in the Corps of Engineers
U.S. Army Corps of Engineers
Cold Regions Research and
Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

Satellite Data Users Bulletin
National Oceanic and Atmospheric
Administration (NOAA)
National Environmental Satellite
Data and Information Service
(NESDIS)
Office of External Relations,
Information and Communications
Room 3308, FB-4
Washington, DC 20233

U.S. - STATE/REGIONAL COVERAGE

Center for Remote Sensing and Energy Research Newsletter
Center for Remote Sensing and Energy Research
Texas Christian University
Department of Geology
Fort Worth, TX 76129

Illinois Map Notes
Illinois State Geological Survey
Natural Resources Building
615 East Peabody Drive
Champaign, IL 61820

Mid-South Newsletter and Technical Notes
ASPRS Mid-South Region
c/o TVA Mapping Services Branch
200 Haney Building
Chattanooga, TN 37401

Nebraska Calmit Newsletter
University of Nebraska
Center for Advanced Land Management Information Technologies (CALMIT)
Conservation and Survey Division
113 Nebraska Hall
Lincoln, NE 68588-0517

Technology Applications Center (TAC) News
Technology Application Center
University of New Mexico
Albuquerque, NM 87131

University of Arizona Remote Sensing Newsletter
Arizona Remote Sensing Center
University of Arizona
Office of Arid Lands Studies
845 North Park Avenue
Tucson, AZ 85719

The Cornell Laboratory for Environmental Applications of Remote Sensing (CLEARS) Review
CLEARS
Cornell University
464 Hollister Hall
Ithaca, NY 14853

Kansas Applied Remote Sensing (KARS) Program Newsletter
Kansas Applied Remote Sensing Program
University of Kansas
Space Technology Center
2291 Irving Hill Drive - Campos West
Lawrence, KS 66045-2969

Minnesota Land Management Information Center (LMIC) System Notes
Minnesota Land Management Information Center
Minnesota State Planning Agency
65 Metro Square Building
7th and Robert Streets
St. Paul, MN 55101

SPECTRUM
Center for Remote Sensing
Michigan State University
302 Berkey Hall
East Lansing, MI 48824-1111

Texas Natural Resources Information
Texas Natural Resources
P.O. Box 13231
Austin, TX 78711-3231

Wisconsin Mapping Bulletin
State Cartographer's Office
144 Science Hall
University of Wisconsin-Madison
Madison, WI 53706

3. CANADA - NATIONAL AND PROVINCIAL COVERAGE

Alberta Remote Sensing Newsletter
Alberta Remote Sensing Center
Oxbridge Place
9820 106th Street
Edmonton, Alberta T5K 2J6
Canada

Remote Sensing in Canada
Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario K1A 0Y7
Canada

SRC News
Saskatchewan Remote Sensing Program
Saskatchewan Research Council
15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
Canada

Maritime Remote Sensing Newsletter
Maritime Remote Sensing Committee
P.O. Box 2254
1660 Hollis Street
Halifax, Nova Scotia B3J 3C8
Canada

Remote Sensing in Manitoba
Manitoba Remote Sensing Centre
Department of Natural Resources
Surveys and Mapping Branch
1007 Century Street
Winnipeg, Manitoba R3H 0W4
Canada

4. AUSTRALIA

ACRES News
Australian Centre for Remote Sensing
Division of National Mapping
Department of Resources and Energy
P.O. Box 28
Belconnen, A.C.T. 2616
Australia

Remote Sensing Newsletter
Remote Sensing Section
Division of Plant Industries
NWS Department of Agriculture
P.O. Box K220
Haymarket, New South Wales 2000
Australia

Australian Landsat Station Newsletter
Australian Landsat Station
22-36 Oatley Court
P.O. Box 28
Belconnen ACT 2616
Australia

5. EUROPE

EARTHNET Review (European Space Agency)
Earthnet User Services
ESRIN
Via Galileo Galilei, CP64
00044 Frascati (Rome)
Italy

National Remote Sensing Centre (NRSC) Newsletter
National Remote Sensing Centre
Space Department
Royal Aircraft Establishment
Farnborough, Hants GU14 6TD
United Kingdom

Earth Observation Quarterly
European Space Agency
Publications Division
ESTEC-Keplerlaan 1
2200 AG Noordwijk
The Netherlands

6. AFRICA

Earth Resources Mapping in Africa
Regional Centre for Services in Surveying, Mapping and Remote Sensing
P.O. Box 18118
Nairobi, Kenya

Remote Sensing for Southern Africa
Remote Sensing for Southern Africa
CSIR Foundation for Research Development
P.O. Box 395
Pretoria, 0001
Republic of South Africa

7. ASIA

Asian Regional Remote Sensing Training Center (ARRSTC) NEWS
Asian Regional Remote Sensing Training Center
Asian Institute of Technology
G.P.O. Box 2754
Bangkok 10501
Thailand

Remote Sensing Newsletter
ESCAP/UNDP Regional Remote Sensing Programme
Economic and Social Commission for Asia and the Pacific
United Nations Building
Rajademnern Avenue
Bangkok 10200
Thailand

Thailand Remote Sensing Centre (TRSC) Newsletter
Thailand Remote Sensing Center
National Research Council
196 Phahonyothin Road
Bangkok 10900
Thailand

8. LATIN AMERICA

BOLETIM DE SENSORIAMENTO REMOTO
Instituto de Pesquisas Espaciais (INPE)
C.P. 515 - 12201
Sao Jose dos Campos, SP
Brazil

SELPER NEWSLETTER
SELPER
Av. dos Astronautas, 1758
C.P. 515 - 12201
Sao Jose dos Campos, SP
Brazil

B. GEOGRAPHIC INFORMATION SYSTEM NEWSLETTERS

B-1 UNITED STATES

AM/FM SCRIBE
AM/FM International
Administrative Office
c/o Barbara Emery
8775 East Orchard Road
Suite 820
Englewood, CO 80111

FDC Newsletter
Federal Interagency Coordinating Committee on Digital Cartography
Department of the Interior
U.S. Geological Survey
516 National Center
Reston, VA 22092

GIS News Layers
Geographic Information Systems Unit
Valuation Services Bureau
Division of Equalization and Assessment
Agency Building #4
Empire State Plaza
Albany, NY 12223

GIS Review
Land Systems Corporation
73 Daniel Street
Portsmouth, NH 03801
$4.00/year

L.M.I.C. News
Land Management Information Center (LMIC)
Minnesota State Planning Agency
65 Metro Square Building
7th and Robert Streets
St. Paul, MN 55101

NCIC Newsletter
National Cartographic Information Center
Department of the Interior
U.S. Geological Survey
507 National Center
Reston, VA 22092

Cartographic Information
North American Cartographic Information Society
6010 Executive Boulevard
Suite 100
Rockville, MD 20852

GIMS (Geographic Information Management Systems) News
GIMS Committee
American Society for Photogrammetry and Remote Sensing/American Congress on Surveying and Mapping
210 Little Falls Street
Falls Church, VA 22046

GIS Report
NYS Office of Parks, Recreation, Historic Preservation
Empire State Plaza
Agency Building #1
Albany, NY 12238

Illinois Map Notes
Illinois State Geological Survey
Natural resources Building
615 East Peabody Drive
Champaign, IL 61820

MASS-GIS Newsletter
MASS-GIS Project
80 Boylston Street, Suite 955
Boston, MA 02116

MSFWIS Newsletter
Multi-State Fish and Wildlife Information Systems
Dept. of Fisheries and Wildlife Sciences
School of Forestry & Wildlife Resources
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

New Jersey GIS Update
Geographic and Statistical Analysis Unit
Office of Science and Research
Department of Environmental Protection
401 East State Street, 6th Floor
Trenton, NJ 08625

Texas Natural Resources Information System Newsletter
Texas Natural Resources Information System
P.O. Box 13231
Austin, TX 78711-3231

Wisconsin Land Information Newsletter
Center for Land Information Studies
1040 WARF Building
610 Walnut Street
Institute for Environmental Studies
University of Wisconsin-Madison
Madison, WI 53705

Oregon Cursor
Oregon Water Resources Department
3850 Portland Road, NE
Salem, OR 97310

Rhode Island GIS Newsletter
Department of Natural Resources Sciences
210 B Woodward Hall
University of Rhode Island
Kingston, RI 02881

URISA News
Urban and Regional Information Survey and Human Settlement
319 C Street, S.E.
Washington, DC 20003

Wisconsin Mapping Bulletin
State Cartographer's Office
155 Science Hall
Madison, WI 53706-1404

2. CANADA

Canadian Cartographic Association Newsletter
Department of Geography
University of Calgary
Calgary, Alberta T2N 1N4
Canada

SORSA News
Spatially-Oriented Referencing Systems Association
P.O. Box 3825, Station "C"
Ottawa, Ontario K1Y 4M5
Canada

LRIS (Land-Related Information Services) Newsletter
Land-Related Information Services) Newsletter
Bureau of Surveying and Mapping
Alberta Forestry, Lands and Wildlife
3rd Floor, Victoria Place
10009-108 Street
Edmonton, Alberta T5J 3C5
Canada

3. AUSTRALIA

AURISA News
Australian Urban and Regional Information Systems Association
GPO Box 4743
Sydney, N.S.W. 2001
Australia

LANDFORM
Land Information Unit
Department of Lands
GPO Box 1047
Adelaide, South Australia 5001
Australia

SLIC Newsletter
State Land Information Council Directorate
Room 110, 1st Floor
Department of Lands Building
GPO Box 39
23-33 Bridge Street
Sydney, N.S.W. 2001
Australia

4. EUROPE

Mapping Awareness
Miles Arnold
High Winds
Cassington
Oxford 0X8 1DL
England

USEMAP Newsletter
Department of Urban Survey and Human Settlement Analysis
International Institute for Aerial Survey and Earth Sciences (ITC)
P.O. Box 6, 7500 AA
Enschede, The Netherlands

5. AFRICA

6. ASIA

C. NEWSLETTERS FOCUSED ON SPECIFIC GIS SOFTWARE

ARC News
Environmental Systems Research Institute
380 New York Street
Redlands, CA 92373

AUTOGIS Newsletter
Autometric Inc.
5205 Leesburg Pike
Suite 1308/Skyline One
Falls Church, VA 22041

GEOMAP Newsletter
PAMAP Graphics Ltd.
Suite 301-3440 Douglas Street
Victoria, British Columbia V8Z 3L5
Canada

GIMMS Newsletter
GIMMS Ltd.
30 Keir Street
Edinburgh EH3 9EU
Scotland, U.K.

GRASSCLIPPINGS
Institute for Technology Development
ATTN: Carol Moore
Space Remote Sensing Center
Bldg. 1100, Suite 308
NSTL, MS 39529

Hunter GIS Forum
Hunter GIS, Inc.
Suite 170
1121 Wood Ridge Center Drive
Charlotte, NC 28217

Interactions
Synercom
P.O. Box 27
10405 Corporate Drive
Sugar Land, TX 77478

InterVue
Intergraph Corporation
One Madison Industrial Park
Huntsville, AL 35807-4201

MAP-NEWS
[The Newsletter of Map Analysis Package (MAP) Users]
Yale University
School of Forestry and Environmental Studies
205 Prospect Street
New Haven, CT 06511

MONITOR
ERDAS, Inc.
Advanced Technology Development Center
430 Tenth Street, N.W.
Suite N206
Atlanta, GA 30318

APPENDIX C

INDIVIDUALS WITH WHOM THE INVESTIGATORS MET

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INDIVIDUALS WITH WHOM THE INVESTIGATORS MET

BOGOTA, COLOMBIA

1. Instituto Geografico "Augustin Cadazzi"/Centro InterAmericano de Fotointerpretacion (IGAC/CIAF)

Dr. Carlos Molina	Sub-director of CIAF
Profa. Myriam Ardila	Remote Sensing/GIS
Prof. Rafael Galeano	Remote Sensing
Prof. Antonio Montoya	Remote Sensing
Prof. Eduardo Vargas	Civil Engineering
Prof. Gonzalo Ricardo	Forestry
Prof. Jaime Lopez	Soils
Prof. Alberto Cristancho	Geology
Ing. Elder Gutierrez	Orthofoto/IGAC
Mr. Leonard R. Leos	IAGS Project Chief

2. U.S. Embassy

Mr. James Smith	AID Representative

QUITO, ECUADOR

1. DESFIL Workshop (Informal Discussions Ref. IQC Task Order)

Dr. David Hess	AID/Bolivia
Dr. Howard Clark	AID/REA (Lima)
Mr. Juan Carlos Quiroga	CUMAT/Bolivia
Mr. Bruce Kiernan	AID/Ecuador

2. Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos (CLIRSEN)

Mayor Ing. Mario Costales	Gerente Operacions
Ing. Patricio Toledo R.	Subgenerente Inv. RN
Ing. Guillermo Bixby	Dpto. Estudios Integrados
Ing. Edgar Penaherrena	Dpto. R. Norenov.
Ing. Fernan Sandoval	Dpto. Banco de Datos

3. Ministry of Agriculture

Dr. Loyd Brown	AID/Sigma One Corp
Mr. Jack Rosholt	AID/TR&D - Cadastral project

LIMA, PERU

1. AID Mission

Mr. Ray Waldron	Agric & Rural Development
Mr. Robert Sparks	Agric & Rural Development/PADI
Mr. Steve Rosholt	Consultant/Special Projects Office

2. APODESA

Dr. Arnold Kriesman	AID/RONCO Corp.

3. Oficina Nacional de Evaluacion de Recursos Naturales (ONERN)

Dr. Luis Masson	Acting Director
Ing. Mauro Mendoza	Dpto Informatica (GIS)
Ing. Carlos Vargas	Dpto Informatica (GIS)
Ing. Walter Danjoy	Dpto Remote Sensing

SAO PAULO, BRAZIL

1. Instituto de Pesquisas Espacias (INPE)
(Sao Jose dos Campos and Cachoiera Paulista)

Dr. Marcio Nogueira Barbosa	Director of Remote Sensing
Dr. Roberto Pereira da Cunha	Technology Transfer
Ing. Sergio de Paul Pereira	Image Generation
Ing. Jose Luiz de Barros Aguirre	System and Instermentation Development
Ing. Roberto Martini	Geology

FRASCATI, ITALY

1. European Space Agency (ESA), Earthnet Program Office

Mr. Livio Marelli	Manager, Earthnet Program
Dr. Gianna Calabresi	Head, User Services

ROME, ITALY

1. United Nations Food and Agriculture Organization (FAO), Research and Technology Division, Remote Sensing Center (AGRT)

Mr. Z.D. Kalensky	Acting Director, AGRT Senior Officer (Technology Transfer Group)
Dr. John A. Howard	Chief, Remote Sensing Center
Mr. Jelle U. Hielkema	Remote Sensing Officer (Monitoring)
Mr. Carlo Travaglia	Remote Sensing Officer (Education and Training)

ABIDJAN, IVORY COAST

1. USAID, Regional Economic Development Services Office, West and Central Africa (REDSO/WCA)

Mr. Arthur M. Fell	Director, REDSO/WCA
Mr. Jeff W. Goodson	Science & Technology Officer REDSO/WCA

2. Ivory Coast Federal Government

Dr. Mamadori Fofana	Chief, Autonomous Teledection Unit, Direction and Control of Public Works (Supra-Agency)

NIAMEY, NIGER

1. AGRHYMET Program, AGRHYMET Center

Mr. D. Larbergeon	Director of Operations
Mr. Delorme Pascal	Crop Yields Specialist (GIS)

2. USAID

Mr. Dennis E. Panther	Project Director
Mr. Marc P. Manland	Project Officer (Livestock Project)
Dr. Steve Daus	Project Officer (Forestry-Land Use Planning (FLUP))
Mr. John Gregg	Technical Consultant, FLUP
Mr. John Hermans	Technical Consultant, FLUP
Mr. Gregg Minnick	Technical Consultant, FLUP
Mr. Jim Rapant	Peace Corps Volunteer
Mr. Brad Phelps	Peace Crops Volunteer

NAIROBI, KENYA

1. Regional Center for Services in Surveying, Mapping and Remote Sensing

Dr. Hassan M. Hassan	Director, Remote Sensing Department
Dr. Allan Falconer	Remote Sensing Advisor

2. Kenya Range Ecological Monitoring Unit (KREMU)

Dr. Andere	Director
Mr. Wilber K. Ottichilo	Systems Ecologist
Mr. John-Pierre Delsol	Remote Sensing Expert

Mr. Jess Grunblatt	Technical Consultant, GIS

3. United Nations Environmental Program, Global Environmental Monitoring System (UNEP/GEMS)

Dr. Harvey Croze	Project Scientist

DHAKA, BANGLADESH

1. Bangladesh Space Research and Remote Sensing Organization (SPARRSO)

Dr. Farouk A. Khan	Chairman
Dr. A.M. Choudhury	Director of Research
Dr. A.A.H. Pramanik	Director of Technology
Mr. Thomas W. Wagner	ERIM Advisor to SPARRSO

2. Bangladesh Bureau of Statistics (BBS)

Mr. ___ Salam	Director General
Mr. Hamidul Hoque Bhunan	Project Director, Statistical Cartography
Mr. Robert Torene	Economic Statistics Advisor to BBS (USAID)

3. Bangladesh Agricultural Research Center (BARC)

Dr. Bruce Currey	Winrock International, Institute for Agriculture Development, Human Resources Development Division

4. USAID Mission

Mr. Alan R. Hurdus	Deputy Director, Office of Food and Agriculture

BANGKOK, THAILAND

1. National Research Council, Remote Sensing Division

Mr. Suvit Vibulsresth	Director
Mr. Chancai Peanvijarpong	Asst. Ground Station Manager
Mr. Art Collins	Canadian Centre for Remote Sensing (assigned to NRC)

2. Asia Institute of Technology (AIT)

Dr. John Lukens	Remote Sensing Program Coordinator
Dr. Bertrand Fleutiaux	Remote Sensing Lab Manager
Mr. John Castiglia	Managing Director, Thai Cascolor Co., Ltd.

3. Thailand Development Resources Institute (TDRI)

Dr. Dhira Phantumvanit	Exec. Director, Natural Resources and Environment Program
Dr. Buddy Atwell	Advisor

4. United Nations Development Program (UNDP/ESCAP)

Dr. Heng L. Thung	Project Manager/Coordinator, Regional Remote Sensing Program

5. USAID

Mr. Willy D. Baum	Proj. Officer, Project Development and Support
Mr. Will Knowland	Advisor, Natural Resources & Environment
Mr. Mintara (Min) Silawatshananai	Chief Engineer

TOKYO, JAPAN

1. Tokai University, Research and Information Center

Prof. Dr. T. Sakata	Director

2. Earth Resources Data Analysis Center (ERSDAC)

Dr. Yasufumi Ishiwada	Special Advisor
Mr. Atsushi Iwashita	Manager, Research Division, Technical Department
Mr. Jiro Komai	General Manager, Tech. Dept.
Mr. Shoichi Masuda	Research Assoc., Tech. Dept.
Dr. Masaharu Sano	Manager, Research Div. Tech. Department
Dr. Osamu Takano	Sr. Scientist

3. Remote Sensing Technology Center of Japan (RESTEC)

Mr. Hiroshi Ishigami	General Manager, Data Service Department
Dr. Keiji Mauro	Managing Director
Mr. Tadafumi Sakai	Senior Managing Director

4. Ministry of Foreign Affairs, Japan International Cooperation Agency (JICA)

Mr. Y. Motomura	Director, Development Cooperation Division, Economic Cooperation Bureau, Min. of Foreign Affairs

5. Engineering Consulting Firms Association, Japan

Dr. Shoichi Kobayashi	Chief Economist

6. The Overseas Economic Cooperation Fund (Japan)

Mr. Seizaburo Komine	Director, Tech. Appraisal Coord. Coord. and Planning Division, Economic Research and Technical Appraisal Department
Mr. Takao Ozaki	Deputy Director, Tech. Appraisal Coord. and Planning Div., Economic Research and Tech. Appraisal Department

7. JAPEX Geoscience Institute, Inc.

Dr. Hiroshi Watanabe	Sr. Geophysicist, Manager Remote Sensing Section, Department of Geology
Mr. Koya Tsukada	Sr. Geophysicist, Manager Graphics (Image Processing and Mapping)

8. PASCO (value-added company)

Mr. Hideaki Sakai	Asst. Manager, International Operations
Mr. Toru Kawasaki	Director, Interntional Operations
Mr. Kiyoto Hayakawa	Manager, International Operations
Mr. Noboru Ikenish	General Manager, International Sales
Mr. Shinsuke Hirai	Director, Planning Department JICA

9. National Coordination Agency for Surveys and Mapping (BAKOSURTANAL) (Met in Tokyo)

Mr. Riadika Mastra

NEW YORK, N.Y. USA

1. United Nations, Department of Technical Cooperation for Development (UN/DTCD)

Mr. Nicky Beredjick	Deputy to the Under-Secretary General, Director Natural Resources and Energy Div.
Dr. Karl-Heinz Szekielda	Chief, Remote Sensing Unit

DENVER, CO USA

1. National Park Service, Geographic Information Systems Division

Mr. Maurice O. Nyquist	Chief, Remote Sensing Branch

2. Fish and Wildlife Service, (Ft. Collilns, CO)

Ms. Barbara White	Support Branch, National Ecology Center
Mr. Robert G. Waltermire	Data Base Management Specialist (TGS Technology Inc.)

3. Bureau of Land Management

Mr. Carl A. Zulick	Planning and Environmental Analysis Specialist, GIS Implementation
Mr. James A. Turner	Remote Sensing Geologist

ATLANTA, GA USA

1. Earth Resources Data Analysis Systems Inc. (ERDAS)

Mr. Bruce Rado	Vice President
Mr. David Sawyer	Director of Research

2. Terra-Mar Resource Information

Mr. Donald Walklet	President

WASHINGTON, DC USA

1. World Bank

   Mr. Wayne Luscomb Environment Department

2. InterAmerican Development Bank

   Mr. Luis Ferrate

3. Imaging Specialists, Inc.

   Mr. James Deigan

GLOSSARY OF ACRONYMS

GLOSSARY OF ACRONYMS

AC/EMP	Agro-climatic/Environmental Project (SPARRSO, Dhaka, Bangladesh)
AGRHYMET	Agriculture, Hydrology, Meteorology Regional Center in Niger
AgRISTARS	Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing
AID	Agency for International Development
AIT	Asian Institute of Technology (Bangkok, Thailand)
AMS	Analytical Mapping System (FWS)
APS	Automatic Picture Transmission Station
ARRSTC	Asian Regional Remote Sensing Training Center (Bangkok, Thailand)
ARTEMIS	Africa Real-Time Environment Monitoring Using Imagery Satellites
AVHRR	Advanced Very High Resolution Radiometer
BSS	Bangladesh Bureau of Statistics
BARC	Bangladesh Agricultural Research Center
CIAF	Centro InterAmericano de Fotointerpretacion (IGAC, Bogota, Colombia)
CIDA	Canadian International Development Agency
CILSS	Inter-State Committee to Combat Drought in the Sahel
CLIRSEN	Centro a Levantamientos Integrados de Recursos Naturales por Sensores Remotos (Quito, Ecuador)
CNIE	Comision Nacional de Investigaciones Espaciales
CNPQ	National Research Council (Brazil)
COPUS	Committee on the Peaceful Uses of Outer Space
COS	Cartographic Output System
CRTO	Regional Remote Sensing Center (Ouagadougou, Burkina Faso)
CUMAT	Centro de Investigacion del Estudio de la Capacidad de Uso Mayor de la Tierra (La Paz, Bolivia)
CZCS	Coastal Zone Color Scanner
DEC	Digital Equipment Corporation
DESFIL	Development Strategies for Fragile Lands Project (AID/LAC)
DTCD	Department of Technical Cooperation for Development (United Nations)
DTM	Digital Terrain Models
ECLA	Economic Commission for Latin America (United Nations)
ECWA	Economic Commission for Western Asia (United Nations)
EOSAT	Earth Observation Satellite Company
EPA	Environmental Protection Agency
ERDAS	Earth Resources Data Analysis Systems, Inc.
ERIM	Environmental Research Institute of Michigan
ERL	Earth Resources Laboratory (NASA)
ERSDAC	Earth Resources Data Analysis Center (Japan)
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESCAP	Economic and Social Commission for Asia and the Pacific (United Nations)

ESMR	Electric Scanning Microwave Radiometer
ESRI	Environmental Systems Research Institute
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization (United Nations)
FEMA	Federal Emergency Management Agency
FEWS	Famine Early Warning System
FLUP	Forestry Land Use Planning (Niamey, Niger)
FNOC	Fleet Numerical Oceanography Center
FWS	Fish and Wildlife Service
GEMS	Global Environmental Monitoring Systems (UNEP)
GCP	Ground Control Points
GIS	Geographic Information System
GISD	Geographic Information Systems Division (National Park Services)
GMS	Japanese Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite (NOAA)
GRASS	
GRID	Global Resource Data Base (UNEP/GEMS)
HRPT	High Resolution Picture Transmission
HRV	High Resolution Visible
IBIS	Image Based Information System
IDB	InterAmerican Development Bank
IDIMS	Interactive Digital Image Manipulation System
IFG	Institute for Applied Geosciences (???)
IFOV	Instantaneous Field of View
IGAC	Instituto Geografico "Augustin Cadazzi" (Bogota, Colombia)
INPE	Instituto de Pesquisas Espaciais (Brazil)
IR	Infrared
IRS	Indian Remote Sensing Satellite System
ITC	International Training Center (Enschede, The Netherlands)
J-ERS-1	Japanese Earth Resources Satellite-1
JICA	Japanese International Cooperation Agency
JMA	Japanese Meteorological Agency
JOBRESA	Joint Board for Remote Sensing Activities
JPL	Jet Propulsion Laboratory
KREMU	Kenya Range Ecology Monitoring Unit
LISS	Linear Imaging Self Scanning Cameras
MAG	Ministry of Agriculture
MECB	Missao Especial Completa Brasileriva (INPE, Brazil)
MESSR	MOS-1's Multispectral Electronic Self-Scanning Radiometer
METEOSAT	Europe Meteorological Satellite
MOPS	Meteosat Operational Program
MOS-1	Japan's Marine Observation Satellite
MOSS	Map Overlay and Statistical System
MSR	MOS-1's Microwave Scanning Radiometer
MSS	Multispectral Scanner (Landsat)
MT	Metric Tons

NASA	National Aeronautic and Space Administration
NASDA	National Space Development Agency of Japan
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
OFDA	Office of Foreign Disaster Assistance
ONERN	Oficina Nacional de Evaluacion de Recursos Naturales (Peru)
RBV	Return Beam Vidicon
RCSSMRS	Regional Centre for Services in Surveying, Mapping, and Remote Sensing (Kenya)
RESTEC	Remote Sensing Technology Center of Japan
RRSP	Regional Remote Sensing Programme (UNDP)
SAR	Synthetic Aperature Radar
SeaWifs	Sea-Viewing Wide Field of View Sensor (EOSAT)
SELPER	Society of Latin American Remote Sensing Specialists
SLAR	Side-Looking Airborne Radar
SPARRSO	Bangladesh Space Research and Remote Sensing Organization
SPOT	System Probatoire d'Observation de la Terre
SWIR	Short-Wave Infrared Radiometer (JERS)
TDRI	Thailand Development Resources Institute
TDRSS	Tracking and Data Relay Satellite System
Terra-Mar	Resource Information Systems, Inc.
TM	Thematic Mapper (Landsat)
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
USAID	United States Agency for International Development
VAS	Visible Spin Scan Radiometer and Atmospheric Sounder
VNR	Visible and Near-Infrared Radiometer (J-ERS)
VTIR	MOS-1's Visible and Thermal Infrared Radiometer
WAPI	World Aerial Photographic Index (FAO)
WELUT	Western Energy and Land Use Team (FWS)