Practical Applications of Space Systems

Supporting Paper 4

Agriculture, Forest, and Range

A Panel Report Prepared for the

Space Applications Board

Assembly of Engineering

National Research Council

PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might gui · the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to nvolve, and to attempt to understand the needs of, resource managers and o .er decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

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*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state, and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, to study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings, and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports, as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee.* National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems.* National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

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INTRODUCTION

SCOPE

The Panel on Agriculture, Forest, and Range has developed a conceptual plan for a satellite remote-sensing global information system which might be achieved within the 1985-90 period. It is envisioned that this system will have the capability to provide timely and pertinent data to any user, anywhere in the world, who has need of information about present and potential agricultural lands, cultivated crops, forests, and rangelands. Particular attention is given to the type of valuable information about vegetative, land, and water resources that can be derived from this system on a local to a global scale.

APPROACH

The first task of the Panel was to review the recommendations made by the Forestry-Agriculture-Geography Panel of the 1967-68 summer study on space applications.* The Panel then examined the progress which has been made since 1968 in the application of aerospace sensing to agriculture, forestry, and range management and research. Special attention was given to the accomplishments and deficiencies of the ERTS experiments. (ERTS has since been renamed LANDSAT.)

The Panel developed a basic (but not exhaustive) array of possible applications of remote-sensing systems to agriculture, forest, and range and defined potential benefits to be derived from the technology. The next step was the conceptualization of a remote-sensing global information system with the capability of servicing agriculture, forest, and range on a local to a global scale with timely, usable, and frequently updated information about vegetative, land, and water resources.

Finally, the Panel developed a logical sequence of events which must occur and/or requirements which must be fulfilled if the goal of a remote-sensing global information system is to be achieved. These events and requirements include: (1) a continuous flow of satellite data, (2) a continuing research and development

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*National Research Council. *Useful Applications of Earth-Oriented Satellites: Report on Forestry-Agriculture-Geography*, (Panel 1). National Academy of Sciences, Washington, D.C., 1969.

program for remote-sensing systems, (3) a quasi-operational pilot study on a global scale, (4) educational and training programs to assure effective technology transfer to the user community, (5) essential basic and applied research, (6) workable institutional arrangements, and (7) adequate funding.

PROGRESS SINCE THE 1967-68 STUDY

RECOMMENDATIONS OF THE 1967-68 STUDY PANEL

The Forestry-Agriculture-Geography Panel in 1967-68 recognized the feasibility and need for utilizing space technology to collect earth resources data by remote sensing for

> "Inventory and productivity evaluation of the world's food, fiber and other natural resources
>
> "Assessment of environmental conditions and of man-environment interactions."

It recommended a program that would

> "Provide the earliest possible benefits, by initiating operations in appropriate aircraft and spacecraft with state-of-the-art sensors, to deliver earth-resources data to skilled interpreters and analysts in existing organizations;
>
> "Provide optimum long-term benefits, by initiating appropriate R&D programs to improve the ability and capability to obtain and interpret greater quantities and better qualities of data;
>
> "Accomplish the steps above at an acceptable budgetary level and within a reasonable time-frame." *

It further recommended

> "...that planning, with appropriate check-points, be initiated for the evolution of that early [satellite-aircraft] system to a substantially broader system, using more sophisticated sensors, over a period of the next 10-12 years. Responsibility for the

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***Forestry-Agriculture-Geography Panel Report* (1969), p. 3.

planning and coordination is a critical element of this program; the responsibility should be assigned early and should be clearly defined."

The 1967-68 Panel recognized that

> "The broad field of earth resources offers a rich potential for new understanding through--and uses for--the application of remote-sensing and data-handling techniques. Research in these areas is essential to education and training, and to the development of future systems."

It recommended

> "...significant expansion of the present broad-scope research program." *

THE ERTS PROGRAM

The results of the federal research and development programs instituted and carried forward since 1968 have confirmed the soundness and farsightedness of the recommendations contained in the 1967-68 study report.

An Earth Resources Technology Satellite (ERTS-1) was designed and launched in July 1972. The sensor system was more advanced than that suggested by the 1967-68 study panel in that a multi-spectral scanner (MSS) and a data collection system (DCS) were provided in addition to the return beam vidicon sensor (RBV). The MSS and the DCS have operated successfully. Electrical power problems have plagued the RBV system; as a result, the main products of the observational systems have been the multi-spectral digital tapes and the reconstituted black and white and color images made from them. The RBV may be used if the MSS fails.

To evaluate these products, NASA and other agencies and institutions funded about 300 domestic and foreign research investigators. Computer-compatible tapes and images were made available to investigators and others through a NASA data center at Goddard Space Flight Center and through a USDI data center at Sioux Falls, South Dakota. Other distribution centers were recently established through the USDA at Salt Lake City, Utah, and through the Department of Commerce at Suitland, Maryland.

A review of the research reports of these investigators has led us to conclude that experiments to accomplish many tasks important to the management of agricultural, forest, and range resources have been unusually successful. Important experimental successes include

> Identification of crops and of broad types of forest and rangeland vegetation,

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**Forestry-Agriculture-Geography Panel Report* (1969), p. 4.

- Identification of broad soil and land-use patterns in agricultural areas,
- Experimental detection on a limited scale of severe crop and forest damage due to stress (insects, diseases, drought, flood, and fire),
- Estimation for small test plots of wheat acreage, yield, and production by use of satellite data and a yield model incorporating meteorological data,
- Monitoring progress of crop harvests in small trial areas,
- Identification of vegetative biomass in rangelands permitting evaluation of range conditions,
- Determination of irrigated acreages, and
- Monitoring irrigation reservoirs and live-stock water impoundments.

The great majority of the investigators were not equipped originally for computer analysis of the ERTS digital tapes. Many of the tasks were experimentally performed by manual interpretation of the reconstituted images. As experience was gained with data processing, computer-assisted statistical analysis of the digital tapes has emerged as the preferred method for extracting maximum quantitative information from the multi-spectral scanner tapes. Also, computer-assisted digital analysis has permitted the registration of ground-resolution units (4500 m^2) recorded in successive passes of the satellite so that temporal changes in the scene can be used to aid in the identification task.

In many of the ERTS research projects, supplemental data were collected by field work on the ground and by low-altitude or high-altitude aerial photography. Both large-scale and small-scale aerial photography have proven highly useful and are likely to continue. However, advances in data products from future satellites of the ERTS-type may be expected to diminish the need for use of high-altitude (20 km to 30 km) photography to supplement satellite data in the analyses of U.S. production areas. It appears that low-altitude aerial photography and observations will continue to be needed to aid in the interpretation of satellite data. Low-altitude aerial photography is usually available locally in the United States. The 1967-68 study suggested the need for a *federally* sponsored aircraft remote-sensing system to supplement satellite systems. Until satellite sensor resolution is improved, the need continues, especially in areas of the world where commercial aerial photography services are unavailable.

Viewed as a research and development effort the ERTS program has been eminently successful. The Congress, NASA, the Department of the Interior, the Department of Agriculture, and the Department of Commerce, and all other agencies, institutions, and private companies who have so diligently cooperated in this program deserve our appreciation.

The ERTS program rivals the Apollo program in its impact on society's view of the finiteness of the earth's resources and the fragility of its ecosystems. It also offers to society hope of a basis for gathering sufficient and continuous information, without political bias, on the status of food resources and environmental conditions and thus for permitting intelligent management of a constantly changing support base for mankind.

RESEARCH PROGRESS

The 1967-68 study panel pointed out the need for an expanded program of applied research in hardware engineering and in applications and systems development to assure a proposed System for Earth-Resources Information (SERI). It recommended expansion of basic research in what was termed the sensor-signature area defined as specifically needing "...reputable data for, and exploration of, variations in emission and reflectance properties of biological and physical materials." *

The development and successful performance of ERTS, the research funded by NASA to prove its capabilities, and the development of a research program to inventory crops on a global scale and thus to demonstrate a large-scale application, are excellent examples of commendable performances in carrying out the applications and hardware research recommended by the 1967-68 study panel.

We have not found satisfactory performance, however, in research advances in systems analysis and design of the proposed program nor in the area of basic research on spectral properties of natural materials. Subjects for research in the former area include work on crop and natural vegatation geography, and on design of the proposed System for Earth-Resources Information. Basic research is needed on spectral properties of major and minor economic crops, major types of natural vegetation, soils, rock types, water, and the variations of these encountered on the earth.

Here again, the shortfall in research products is probably due to the failure of federal agencies to invest sufficient funds in the earth resources program and their failure to assign responsibility for the development of an operational system.

FUNDING LEVEL OF EARTH OBSERVATION PROGRAMS

The successes of ERTS research programs have heightened interest in the use of this new satellite technology on the part of state and regional agencies and private industries with resource management responsibilities. However, as anticipated by the 1967-68 study panel, there is a severe scarcity of digital-data analysis facilities and trained personnel to help users explore applications of the full satellite technology. To relieve this and other constraints, the 1967-68 study panel recommended a higher level of funding than has yet been achieved in the federal program, the early institution of an operational system, and the formation or designation of an agency responsible for budgetary planning and execution.

The early success of the satellite meteorological program is due in large part to the development of an operational group (NOAA) within a single government

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***Forestry-Agriculture-Geography Panel Report* (1969), p. 33.

agency (the Department of Commerce) with responsibilities for budgetary planning and management. Organization of a comparable earth resources satellite program is much more complex in that many agencies of the federal government are already involved in managing and regulating the nation's natural and cultural resources.

We realize that it is only in the last 18 months that ERTS capabilities have been experimentally proven. However, we believe that the absence of budgetary and planning responsibilities for an operational satellite is already retarding progress in the evolution of the remote sensing information system envisioned by the 1967-68 study. For example, delays have been experienced in

> Development of digital-data analysis centers for ERTS compatible tapes in individual states and regions,
>
> Training of state, federal, and industry personnel at existing or developing digital-data analysis centers,
>
> Investment by state and federal regional agencies in processing and handling systems for ERTS
>
> The flow of information developed from ERTS data to farmers through government extension services and through private advisory groups.

State agencies, federal regional agencies, and private enterprises, all with land, food, and/or fiber missions, are not willing to invest in an experimental research system based on satellite data because there is no guarantee of continuity of data flow nor of format of data products. ERTS-1 has survived for a much longer period than its one-year design lifetime. Although ERTS-1 is still useful, its performance has degraded significantly in the several years since it was launched. ERTS-2 was launched in 1975 and is currently in experimental use. ERTS-C is planned for launch within the next several years. Beyond these important experimental satellites, there is as yet no plan for an operational system which should have back-up satellites either in orbit or in readiness for launch.

The present R&D earth resources satellite program does not provide federal funding for development of the digital-data analysis centers needed for training state, federal regional, and agricultural industry personnel, nor does it provide seed money for training. In an *operational* program the transfer of technology to potential users would be expected to receive very high priority in order to attract investments from state and industry sources and thus to hasten the evolution of a fully operational system.

ELABORATION OF APPLICATIONS AND BENEFITS

APPLICATIONS BASED ON USER NEEDS AND REQUIREMENTS

Needs for agricultural products and forest and range resources to satisfy a growing population generally have been met throughout history by development of new lands and technological advances. To keep up with world population growth and expanding demands, mankind will have to depend on continued technological progress and further development of land resources.

Earth-oriented satellites offer an opportunity to provide potential users with informative and useful data and facts concerning world agriculture, forest and range resources. To utilize this information appropriately, the user must have assurance of continuity and reliability of that data. Future research and systems development should provide capabilities for more frequent coverage, increased resolution, and better sensor signature identification to assure maximum user participation.

The user community may be divided into categories. Each, in some direct or indirect way, can benefit from satellite-based information. Broadly defined, the users are: (1) federal, state, and local government agencies in the United States, (2) foreign governments, (3) international organizations, (4) universities, and (5) the private sector (the industrial community, trade associations, and individuals). As applications of earth-oriented satellites develop, many additional users will emerge and further needs will certainly evolve.

User needs of the 1975-80 time period are studied for two reasons: (1) By the late 1970's ERTS operational satellite performance evaluation will be available and (2) there is great need for guiding research and development during this time period so that agriculture can achieve maximum operational benefits during the 1980's and beyond.

Applications of data derived from earth-oriented satellites are discussed in categories related to cultivated crops, to land and water resources, to forest and range resources, and to other agriculturally oriented areas.

Cultivated Crops

Satellite data on cultivated crops may provide information about

Crop identification and mensuration,

Yield prediction,

Crop stresses due to disease, insect infestation, moisture deficiency or surplus, nutrient deficiencies, and weeds,

Natural (flood, hail, frost, wind, and fire) and man-induced (herbicide, misuse, etc.) disasters,

Cropland history record (individual fields), and

Crop progress (planting to harvest).

The United States currently has information systems that provide timely agricultural facts. However, systems of this type have not been developed in much of the rest of the world. Today, countries have crop-data systems capabilities that range from sophisticated to none. Satellite observations provide a crop inventory on a uniform global basis. The data gathered by earth-oriented satellites can provide broader coverage and be available more quickly than data now obtained through other means.

A program of crop-yield prediction would combine many factors such as crop stresses, soil moisture, soil temperature, crop progress, and others. Crop stress observations will provide the world's users with frequent advance warnings of unfavorable conditions. Early assessment of crop disasters can offer an opportunity to take corrective action.

Today ground crop progress assessment normally takes weeks. Crop progress can be monitored by an earth-oriented satellite to provide to the world a report comparable to the United States weekly weather-crop report. This program will monitor land preparation, the speed at which the crops are planted, development during the season, and finally harvest progress.

Land Resources

Satellite data may be applied to land resources in

Inventory of agricultural land-use,

Surveys of land-use capability,

Soil productivity ratings (vegetative cover),

Soil mapping,

Identification of special soil problems (e.g., salinity),

Soil-erosion (wind and water) studies,

Soil-moisture measurements,

Identification and measurement of wetlands, and

Determination of landform characteristics.

With the increasing scarcity of new land available for agricultural purposes, the world must use the land resources that are available much more efficiently. An inventory of agricultural and wild land characteristics is needed to ascertain what land resources are currently available in the world. This would set the stage for land use capability surveys and productivity ratings. Many areas (in particular remote wild land regions) lack soil mapping and this can be done satisfactorily by satellite. Special soil problems resulting from irrigating or cultivating lands can be studied. Soil erosion has a major impact on agriculture as was experienced in the "Dustbowl" of the 1930's. Erosion also is experienced when heavy rains occur. Soil moisture and temperature can have major effects on crop yield. Inventory and characterization of agricultural wetlands will prove beneficial as available lands decrease. Knowledge of landform and soil characteristics will enable better management decisions to be made on wild lands and on cultivated lands by providing accurate information concerning site potential for production and use.

Water Resources

Satellite data may be applied to water resources in

Inventories of surface and ground water,

Predicting water available from snowpack and runoff,

Monitoring irrigation,

Identification of potential irrigable areas,

Identification of drainage patterns,

Evaluation of water-conservation practices, and

Monitoring water pollution.

These applications play a primary role in the management of areas that depend on irrigation or in climatic regions that receive heavy amounts of rainfall and have drainage problems. Water pollution as it relates to soil erosion and to agricultural operations requires monitoring. Prediction of water runoff from mountainous snowpack zones would generate significant benefits to both wild land managers and the ultimate water user.

Forest Management

Potential applications of satellite data in forest management include

Inventories of forest types,

Inventories of timber volumes by species and by size, Monitoring harvest activities,

Monitoring responses to silvicultural practices,

Inventories of logging residues,

Identification and monitoring of clear-cut areas,

Evaluation of forest stresses from insects, diseases, air pollution, and wind throw, and

Prediction and detection of forest-fire damage.

The forest information system currently operational within the United States provides, from a number of sources, basic data pertinent to timber inventories and forest site characteristics. These data are expensive to collect and, in some cases, exhibit major deficiencies in accuracy. On a global basis these data problems expand since many nations have few, if any, forest-related data banks. The developing nations of Latin America, Africa, and Asia need this information to begin efficient management of their forest resources to meet growing world demands.

There are widespread opportunities for the application of satellite data concerning forests in supplementing current information in the United States and in initiating fundamental inventory programs in developing countries. The capability to use particular data is now the only major difference between forest users in the United States and in other countries of the world.

In classifying wild lands, user needs begin with data requirements for major type classifications such as forests, grasslands, marshlands, rocky barrens, etc. These delineations are of major value currently in charting remote regions of the United States and unmapped areas of foreign countries. Expanding these categories gives the next subdivision involving detailed categorizations based on soil, landform, and species. This subclassification is of major importance to forest-management planning. Accurate satellite data concerning these classification attributes will provide criteria for the selection of forest resource management units. These units furnish the basis for multi-resource management including forest recreation and wild life habitat as well as timber production.

Although some of the data collected for wild land classification are useful in *timber inventory*, further satellite information will be required on a continuing basis to fulfill this forest-user need. Inventories by species and by size will require annual to triennial data to determine timber volumes, growth, removals, and mortality. These data are necessary for forecasting timber trends and for developing sustained-yield long-range programs on a national, regional, or local basis.

Applications other than basic inventory and classification may require more frequent satellite observation and data acquisition. For example, detection of stresses on forest vegetation prior to the epidemic stage will be extremely valuable in permitting remedial action to be initiated before major damage can occur. Satellite identification of the extent of stress and damage will aid in expediting appropriate ground operations.

Forecasting of weather conducive to fires and detection of fires offer a significant application of satellite information in a real-time mode.

This includes prediction and detection of cloud-to-ground lightning contacts and the recording of meteorological and surface data necessary to fire forecasting and planning for fire suppression. When fires occur, the extent of damage can also be evaluated quickly.

Monitoring of activities such as harvesting progress (area logged and road construction), responses to silvicultural practices (thinning and fertilization), and reforestation success (numbers and vigor) can all be done through timely satellite data on timber volumes, areas, and quality. This information is most valuable for remote and relatively inaccessible forest areas so often found in the western United States and in developing countries.

Inventories of locally available logging residues are becoming increasingly important to the timber industry. Little information is available concerning the amount, size, and quality of these residues now in the field. Satellite data concerning this source of wood raw material will supplement other information for increased utilization of the timber product.

Range Management

Potential applications of satellite data in range managment include

Vegetative mapping,

Identification of rangeland uses,

Estimation of forage production (carrying capacity),

Monitoring the effects of range fires,

Monitoring encroachment of undesirable vegetation, and

Monitoring livestock-water development.

Proper management of rangelands is needed to supply maximum forage production for livestock and wildlife. Management planning is complicated, however, because the users of the lands are varied and because much of the rangelands of the world is extremely inaccessible. Ranges in some localities serve as recreational areas. Still others are located in regions which are rich in minerals and energy resources such as coal, oil shale, oil and gas deposits, and geothermal resources.

Earth-oriented satellites can be utilized to monitor ranges and to study conditions and vegetation characteristics. Using data from satellites, the impact of disease and insect damage can be assessed and proper action taken. The energy demands of the world must be weighed against other activities for which rangelands can be used. The response to warnings of fire conditions can be observed and burnt areas studied for management decisions. Fire-danger rating is currently obtained daily throughout the growing season using ground-based observation methods. In the future this information may be obtainable from a satellite system but the procedure will become operational only if justified by cost and efficiency.

Other Agriculturally Oriented Applications

Satellite data may be used in such other agriculturally oriented applications as

General vegetative surveys,

Identification of locations for roads, railroads, navigable streams, villages, etc., in developing nations, and

Surveys of population density in developing nations.

General vegetative surveys on a global basis will increase in importance with the passage of time. Areas of the world which are developing but to which access is still limited need to be surveyed and characterized.

Summary of Anticipated Applications

Table I (page 16) summarizes anticipated applications of satellite data to agriculture, forestry, and range management in the two time frames of 1975-80 and from 1981 to the future. The resolution required to give the accuracy needed and the required frequency of observation are shown in the table.

The information derived from satellite observations will be utilized on an ascending scale from local (individual farm for cropland history or small area for inventory of forest-livestock-water developments) to national and global (vegetative inventory, crop stress, etc.). The need for global coverage can be foreseen for all these potential applications. While a sophisticated ground-based information collection system exists in the United States, ground-based data collection systems are much less effective or even non-existent in other countries. The urgent need, then, is for a *global* inventory system.

Information systems in the United States for forest and range resources are not as complete as for cultivated crops and, therefore, preliminary efforts need to be concentrated on surveys of the United States.

The required frequency of observation ranges from daily (fire-danger rating) to weekly (soil erosion and crop stress) to once every five years (broad inventory of forest types).

Most cultivated crops develop from planting to harvest within a period of four months. During that four month period, weekly observations for stress are needed. These observations must be made on a global scale. If we take corn as a specific example, the development period in the United States is about from May 15 to September 15. In Argentina the period is about from November 15 to March 15. To determine when and where the satellite should observe crop stress, an independent study for each crop is required. With global information on crop stress, it would become possible to better assure a stable world food supply by taking into consideration, in planting, the quantity and condition of crops in regions where they develop during different parts of the year.

For all applications which require frequent updating (1 to 3 weeks), delivery of data to the user is desirable within 72 hours and mandatory within 5 days after acquisition. Applications that require comparisons of data from different satellite passes over the same area also require radiometric and geometric correction so that a mporal overlay can be made, matching pixels* exactly, for change detection.

*A pixel (picture element) is the smallest discernible element of information in a satellite-derived image of the surface of the earth.

Time Frame / Status		Type of Application	Resolution Required (in meters)	Frequency of Observation Required
		CULTIVATED CROPS		
1975-80	Operational	Cropland inventory (large scale)	80	Monthly
		Crop stress (now identifiable)	80	Weekly
		Crop disaster (now identifiable)	80	Weekly
		Crop progress (planting to harvest)	80	Weekly
1975-80	R&D	Crop stress (not now identifiable)		
		Crop disaster (not now identifiable)		
		Crop-yield forecast		
		Cropland history record (small scale)		
1981 on	Operational	Cropland inventory (large scale)	30	Monthly
		Crop stress	30 (10 m desirable)	Weekly
		Crop disaster	30 (10 m desirable)	Weekly
		Crop progress (planting to harvest)	30	Weekly
		Crop-yield forecast	30	Weekly
		Cropland history record (small scale)	10	Annually
1981 on	R&D	Continued increase in accuracy of crop-yield forecasts and crop-stress factors		

LAND RESOURCES

1975-80	Operational	Agricultural land use inventory	80	Annually
		Soil mapping	80	Every 5 years
		Soil erosion studies	80	Weekly
		Wetlands inventory	80	Annually
1975-80	R&D	Land use capability survey		
		Soil productivity rating		
		Soil moisture measurement		
		Soil temperature measurement		
		Identification of special soil problems		
		Determination of landform characteristics		
1981 on	Operational	Agricultural land use inventory	30	Annually
		Soil mapping	30	Every 5 years
		Soil erosion studies	30	Weekly
		Wetlands inventory	30	Annually
		Land use capability survey	30	Annually
		Soil productivity rating	30	Annually

(continued)

TABLE I APPLICATION OF SATELLITE DATA TO AGRICULTURE, FOREST, AND RANGE MANAGEMENT

Time Frame / Status		Type of Application	Resolution Required (in meters)	Frequency of Observation Required
		LAND RESOURCES (continued)		
1981 on	Operational	Soil moisture measurement	30	Weekly
		Soil temperature measurement	30	Weekly
		Identification of special soil problems	10	Annually
		Determination of landform characteristics	30	Every 5 years
1981 on	R&D	Continued increase in accuracy of operational applications		
		WATER RESOURCES		
1975-80	Operational	Inventories of surface and ground water (over 2 acres)	80	Monthly
		Availability of water (snowpack and runoff)	80	Weekly
		Monitoring of irrigation	80	Weekly
		Identification of drainage patterns	80	Annually
		Monitoring of water pollution (reservoirs of over 10 acres)	80	Monthly
1975-80	R&D	Identification of potential irrigable acres		
		Evaluation of water conservation practices		

1981 on	Operational	Inventories of surface and ground water (over 2 acres)	30	Monthly
		Availability of water (snowpack and runoff)	30	Weekly
		Monitoring of irrigation	30	Weekly
		Identification of drainage patterns	30	Annually
		Monitoring of water pollution	30	Monthly
		Identification of potential irrigable acres	30 (10 m desirable)	Annually
		Evaluation of water conservation practices	10	Annually
1981 on	R&D	Continued increase in accuracy of operational applications		
		FOREST MANAGEMENT		
1975-80	Operational	Broad inventories of forest types (over 40 acres)	80	Every 5 years
		Evaluation of forest stress and damage (over 40 acres)	80	Weekly
		Inventory of forest-fire damage (over 40 acres)	80	Monthly
		Identification and monitoring of clear-cut acres	80	Annually

(continued)

TABLE I APPLICATION OF SATELLITE DATA TO AGRICULTURE, FOREST AND RANGE MANAGEMENT

Time Frame / Status		Type of Application	Resolution Required (in meters)	Frequency of Observation Required
		FOREST MANAGEMENT (continued)		
1975-80	R&D	Evaluation and verification of spectral signatures of various timber species throughout the world, to permit future qualitative and quantitative estimation of timber volumes and growth		
		Study of site characterization to determine site potential for all wild-land products		
		Identification and monitoring of energy-related and recreational activities		
1981-on	Operational	Identification and monitoring of energy-related and recreational activities	30	Annually
		Identification of species	10 or less	Every 5 years
		Inventory and classification to include timber volumes by species and by size	10 to 20	Every 5 years
		Early detection and quantitative estimation of losses due to damage and disease	10	Annually
		Monitoring of various timber-harvesting practices, including selection of logging sites	10 to 20	Annually
		Predictions of fire danger rating	30	Daily

1981 on	Operational	Monitoring of various silvicultural practices	30	Every 5 years
		Inventory of logging residues	30	Annually
		Estimation of site potential for various wild land outputs	30	Every 10 years
1981 on	R&D	Development of interpretation techniques and equipment to attain 95% accuracy in operational applications		
		RANGE MANAGEMENT		
1975-80	Operational	Vegetative mapping (over 40 acres)	80	Every 5 years
		Monitoring changes in uses of rangelands	80	Annually
		Mapping extent of range fires	80	Monthly
		Identification and monitoring of range-improvement practices (point facility or area over 2 acres)	80	Annually
1975-80	R&D	Extensive evaluation of spectral signatures associated with phenologic progression of range vegetation to permit future qualitative estimation of forage production, range condition, range readiness, and fire danger		
		Identification and monitoring of energy-related and recreational activities		

(continued)

TABLE I APPLICATION OF SATELLITE DATA TO AGRICULTURE, FOREST AND RANGE MANAGEMENT

Time / Status		Type of Application	Resolution Required (in meters)	Frequency of Observation Required
		RANGE MANAGEMENT (continued)		
1975-80	R&D	Identification and monitoring of range-improvement practices		
1981 on	Operational	Estimation of forage production	20 to 30	Monthly
		Evaluation of range conditions and state of range readiness	20 to 30	Weekly
		Prediction of fire-danger rating	To be determined	Daily
		Inventory of livestock water developments	10	Quarterly
		Identification and monitoring of major encroachments of undesirable vegetative species	10	Monthly
		Identification and monitoring of energy-related and recreational activities	30	Weekly
1981 on	R&D	Improvement in analysis techniques and equipment to attain 95% accuracy in operational applications		

TABLE I APPLICATION OF SATELLITE DATA TO AGRICULTURE, FOREST AND RANGE MANAGEMENT

BENEFITS

Multipurpose Nature of Space Systems

Space systems are usually multipurpose in character. A single system has the capacity to provide information which will be of value to a wide spectrum of users. This is particularly true of earth-oriented satellites. The system capabilities of ERTS, for example, have specific values in agriculture, forest and range management and research as well as in other sectors concerned with earth resources and problems related to their production, processing, and marketing.

This multi-user benefit aspect of the employment of space systems makes the estimation of "aggregate benefits" very difficult. In most cases, however, major and primary benefits can be identified and measured for most of the uses. If the total value of these identified major benefits leads to a favorable cost-benefit ratio for the space system being analyzed, then the system can be justified on the basis of these benefits alone. The knowledge that other beneficial uses have been identified but not quantified provides additional support for the justification of system operation.

As an alternative to justifying the use of space systems by aggregating benefits, efforts can be made to allocate total program costs among potential users. However, such efforts are almost prohibitively complex, especially since most of the programs involved are still primarily in a research and development stage. Under these circumstances, neither the total user population nor the relative employment of space systems by specific users can be determined at this time.

General Benefits

In general, acquiring and using data from space systems can benefit users in three ways

> Improvements in reliability, detail, and frequency of the information required by specified users,
>
> Reduction in costs associated with providing information currently available from other sources, and
>
> Increased capabilities to provide information which is needed but currently unavailable from existing sources.

The measurement of these benefits poses many complex and abstract problems. Information is not a "hard" product and its value is often dependent on the user's ability to interpret and use the data available to him. It becomes a decision tool which, if rightly interpreted, can produce a return but, if misused, can result in a loss. However, it generally can be assumed that better decisions can be made with more complete information.

General benefits, furthermore, may be either economic or social. If a monetary value can be assigned to a social benefit, it becomes, in effect, an economic benefit. Even where a monetary value cannot be assigned, it is possible to identify social benefits, to rank them in relation to their social importance, and to develop subjective rating schedules from which they can be assigned quantitative "rank-order" scores. Combinations of social benefits can then be scored and used as supplements to quantitative estimates in order to determine economic-social priorities as inputs to decision making.

Users and Specific Benefits

Benefits derived from the application of space systems to the problems of agriculture, forest, and range management are specifically related in the present study to information derived from satellite data. Such benefits are based on the capability of the satellite system to serve the needs of specific segments of the user communities. The benefit stream extends all the way from the basic source of the raw material to the ultimate consumer. Benefits may accrue in supply, marketing, storage, transportation, service, and processing operations, all vitally affected by changes in production and distribution. Because of the competitive nature of the industries involved, however, the major ultimate beneficiary will be the consumer.

There is a growing complex of local, state, regional, national, and international governmental and quasi-governmental organizations involved in servicing, regulating, financing, and monitoring agricultural, forest and range resources. Satellite data can be of major value to agricultural research and extension services throughout the world. Renewed and increasing concerns relative to global food and fiber needs bring in other national and international interests who can use the data to identify and predict emerging famine or shortage situations and thus design and operate relief programs.

The United States has a relatively sophisticated system for collecting, analyzing, and disseminating agricultural, forest and range management information. These activities fall within the responsibilities of a variety of federal and state agencies which would be major potential users of information derived from satellite data. At the federal level the principal user agencies will include the USDA, the USDI, and the Army Corps of Engineers. In addition, information derived from the satellite data may be expected to be of benefit to other agencies such as the Environmental Protection Agency, the National Commission on Water Quality, the Tennessee Valley Authority, the Federal Energy Administration, the Agency for International Development, the Bureau of the Census, and others. At the state level, primary users will include departments of agriculture and natural resources, federal and state crop and livestock reporting services, land-use planning agencies, universities, and agricultural experiment stations and extension services.

These federal and state agencies have an interest in the various types of information on agricultural, forest, and range resources which can be obtained from satellite data. However, use of such information will depend on their acceptance of the ability of the satellites to provide required data at a lower cost, in a shorter time, and with a higher degree of accuracy than is possible through data-collecting methods now in use. Initially, the agencies will become involved on an experimental basis. It is important to recognize that they will be reluctant to abandon current data-collection systems until they can be assured that the satellites are established on an operational basis and can supply data with guaranteed continuity at acceptable levels of resolution, accuracy, and frequency. However, major benefits can result from use of the satellites on an experimental basis and, where applicable, as a means of providing objective checks on data developed by other means.

One of the major improvements to be expected from use of ERTS data by federal and state agencies is the "common data base" characteristic it provides. Currently the factual data exchanged between agencies frequently requires many man-days -- or even man-weeks -- to extract the information needed because of the diversity among agencies in how they classify and measure similar or identical land resources. The saving in man-hours to be gained from this common use of classified ERTS picture elements by all agencies will likely be sufficient to assure cost effectiveness of the ERTS system at the state level.

Economic benefits from the applications of satellite data can be either direct or indirect. *Direct benefits* result where documented reductions in costs can be shown for satellite information equal in quality to similar information obtained from ground observations or from conventional aircraft. A potential saving in the survey of range resources by satellite rather than by conventional methods represents a good example. In some situations, more timely or more complete information regarding production and harvesting of grains will permit more effective planning of merchandising, storage, and transportation and should lead to an attendant reduction in the cost of performing these functions. Timely information on projected weather conditions, soil moisture, or the spread of plant diseases and insect infestations can enable producers to take corrective actions to increase yields of affected crops. These yield increases can be translated into increased earnings, provided that simplifying assumptions are made about the proportion of all producers who receive and act on the information. *Indirect benefits* pose more complex measurement problems. Examples of indirect benefits which may be real but difficult to measure are

Effects on consumer prices of applications that reduce production and/or marketing costs,

Secondary multiplier effects resulting from increased agricultural incomes,

Savings to user agencies which could result from the adoption of a common data base, and

Reduction of marketing and processing margins as a result of reductions in risk and uncertainty, made possible through better or more timely information.

Although quantification of indirect benefits is difficult, examples of success do exist in agriculture as the results of studies made on price elasticity, income multiplier effects, and the costs of risk and uncertainty in production and marketing.

A few examples of social benefits that may result from applications of satellite data to agriculturally related problems include

> Opportunities for increasing general and technical educational levels in rural areas; this social benefit could be quantified by cost comparisons with requirements of providing such services through conventional systems,
>
> Increasing consumer awareness of emerging agriculture developments that affect potential supplies and prices of foods throughout the world,
>
> Monitoring actual and potential development of agricultural areas as related to population distribution or rural-urban migration patterns,
>
> Determining impacts of agricultural developments, particularly in developing nations, as they may relate to political-military situations in these nations, and
>
> Relating agricultural developments to nutritional and health status of population.

Existing and potential benefits of applying satellite data to agriculture, forest, and range management are shown in Table II (page 28). Principal benefits are classified in terms of the type of technical benefit (increased geographic coverage, detail, reliability, or frequency) and in terms of the type of economic benefit (cost-reduction or income-increasing opportunity) which each application permits. A rough estimate is made of the potential relative dollar value benefits which may result. The dollar values shown are relative only and are intended to place the potential benefits in perspective according to how widespread their applicability, that is, in terms of local, regional, and national or international scope of application. As may be noted in Table II, most of the economic benefits are related to cost reductions. These reductions would result from the use of satellite data to develop information that would otherwise be obtained from ground observations or from conventional aircraft. Ultimate benefits from more effective or efficient production, marketing, distribution, etc., that may have resulted from use of satellite data have not been quantified. A logical claim for additional benefits can be made in instances where satellites represent the only available means of acquiring information which will permit better management or production.

Specific benefits that are particularly significant may be summarized as

> Increased reliability of acreage and yield estimates of major crops (e.g., wheat); increased detail on extent of soil erosion in specified areas; and increased frequency of monitoring rangeland conditions (e.g., forage production),
>
> Reductions in costs associated with obtaining information on planted acreage of crops throughout the world, in performing

inventories of agricultural land use, and in monitoring progress of crop diseases (e.g., corn-blight watch) and of insect infestations (e.g., grasshoppers), and

Increased capabilities to provide information, currently unavailable from existing sources, that makes possible, for example, acreage and yield estimates of wheat in the U.S.S.R. or China and identification of areas subject to cultivation in western Sudan.

Application	Technical Benefit	Economic Benefit	Potential Relative Dollar-Value Benefit by Area of Application*		
			Local	Regional	National or International
CULTIVATED CROPS					
Crop identification and mensuration	Increased frequency, reliability, and geographic coverage	Reduced cost; increased return	1**	2	2,3
Yield prediction	Increased reliability and geographic coverage	Increased return	2	2	3
Crop stress identification	Increased geographic coverage	Reduced cost; increased return	2	2	3
Disaster (flood, hail, wind, fire, etc.) determination	Increased geographic coverage	Reduced cost		2	3
Cropland history record (individual fields)	Increased reliability and detail	Increased return	1		
Crop progress	Increased reliability and detail	Increased return	1	2	2
LAND RESOURCES					
Agriculture land use inventory	Increased geographic coverage	Reduced cost		2	2,3
Land use capability survey	Increased geographic coverage	Reduced cost		2	2,3

Soil productivity ratings (vegetative cover)	Increased geographic coverage and reliability	Reduced cost	1	2	2,3
Soil mapping	Increased geographic coverage	Reduced cost	1	2	3
Soil erosion studies	Increased detail and reliability	Reduced cost	2	2	3
Identification of special soil problems (e.g., salinity)	Increased reliability, geographic coverage and detail	Reduced cost	1		
Soil moisture measurement	Increased detail and geographic coverage	Reduced cost	1	2	
Soil temperature measurement	Increased geographic coverage	Reduced cost	1	2	
Identification and measurement of wetlands	Increased reliability	Reduced cost	1	1	
Determination of landform characteristics	Increased geographic coverage	Reduced cost	1	1	2

(continued)

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* *Local* designates up to one county in area; *Regional*, multi-county or multi-state; *National or International*, nation, multi-nation or world.

** *1* designates less than $1 million; *2*, $1 million to $10 million; *3*, more than $10 million

TABLE II SPECIFIC BENEFITS FROM APPLICATION OF SATELLITE DATA TO AGRICULTURE, FOREST AND RANGE MANAGEMENT

Application	Technical Benefit	Economic Benefit	Potential Relative Dollar-Value Benefit by Area of Application		
			Local	Regional	National or International
WATER RESOURCES					
Surface and ground water inventories	Increased geographic coverage and detail	Reduced cost		2	2,3
Water availability prediction	Increased reliability, detail, and geographic coverage	Reduced cost	1	2	
Monitoring of irrigation	Increased detail	Reduced cost	1	2	
Identification of potentially irrigable areas	Increased geographic coverage	Reduced cost	1	2	
Evaluation of drainage patterns	Increased detail and geographic coverage	Reduced cost	1	2	
Evaluation of water conservation practices	Increased detail and geographic coverage	Reduced cost	1	2	
Monitoring of water pollution	Increased detail and reliability	Reduced cost	1,2	2	
FOREST MANAGEMENT					
Forest type inventory	Increased geographic coverage, detail and reliability	Reduced cost	1	2	2

Monitoring of harvests	Increased geographic coverage, detail and frequency	Reduced cost	1		
Evaluation of stress and damage	Increased frequency, detail and geographic coverage	Reduced cost; increased return	1	2	
Timber inventory by volume	Increased geographic coverage, detail and frequency	Reduced cost	1	2	2
Estimation of site potential	Increased detail and geographic coverage	Reduced cost; increased return	1	2	
Monitoring of silvicultural practices	Increased geographic coverage and detail	Reduced cost; increased return	1		
		RANGE MANAGEMENT			
Vegetative mapping	Increased reliability and geographic coverage	Reduced cost	1	2	
Estimation of forage production	Increased frequency and geographic coverage	Reduced cost	1	2	
Evaluation of range readiness	Increased reliability	Reduced cost; increased return	1		
Encroachment by undesirable plants	Increased frequency, detail and geographic coverage	Reduced cost	1,2	2	
Estimation of range fire damage	Increased geographic coverage and detail	Reduced cost	1		

(continued)

TABLE II SPECIFIC BENEFITS FROM APPLICATION OF SATELLITE DATA TO AGRICULTURE, FOREST AND RANGE MANAGEMENT

Application	Technical Benefit	Economic Benefit	Potential Relative Dollar-Value Benefit by Area of Application		
			Local	Regional	National or International
RANGE MANAGEMENT (continued)					
Monitoring of range improvement practices	Increased geographic coverage and reliability	Reduced cost	1	1	
Monitoring of small-scale water development	Increased geographic coverage, detail, and reliability	Reduced cost	1	1	
Prediction of fire danger rating	Increased reliability, frequency and coverage	Reduced cost	1	2	3
Identification of energy-related activities	Increased detail and geographic coverage	Reduced cost	1	1	
Identification of recreational activities	Increased geographic coverage	Reduced cost	1		

TABLE II SPECIFIC BENEFITS FROM APPLICATION OF SATELLITE DATA TO AGRICULTURE, FOREST AND RANGE MANAGEMENT

ACTIONS RECOMMENDED FOR APPLICATIONS DEVELOPMENT

GOALS OF GLOBAL-SYSTEM CONCEPT

The massive demands which will be placed on the world's agricultural, forest, and range resources during the closing decades of the twentieth century require a system that can provide essential, timely information to make possible rational exploitation and management of these resources. Without the needed information man will be hard pressed to meet, on a global basis, his food, clothing, and housing needs in the years ahead. Users of information related to these resources will derive untold benefits from a system which can provide current data about vegetative, land, and water resources on local, regional, national, and global scales. It is important that the system provide the capability to relate, overlay, and/or combine information on these three resources. All information should flow freely without military considerations and should be accessible in usable form to any user anywhere in the world.

Data from the system will be of such value on a global scale that there should be a world center, secure against any possible loss or deterioration, for processing and storing earth resources data. Storage of all data from a global information system is impracticable. Careful attention must be given to the development of techniques for rational selection of data to be stored and data to be discarded. A select committee should be established to consider this problem.

Goals of this global-system concept, which ought to be achieved in the 1985-90 period, are presented separately for the three resources.

Vegetative Resources

A system is required which can provide current (updated weekly) inventories and predicted yields for all major crops in the world. Information on the location, areal extent, and severity of vegetative stress caused by drought, disease, insects, weeds, excess moisture, mechanical damage, and fire should be available for crop, forest, and range resources. The condition and progress of seeding, crop developments, and harvesting also should be reported.

Land Resources

A system is required which can provide a current inventory of land use, including location and areal extent of cultivated lands, forested areas, and rangelands. Current information (updated semiannually) on changes in use is required for rational management of these lands. The system must be able to survey, map, and monitor conditions that cause deterioration of land use capability and soil productivity. These conditions include wind and water erosion, inadequate drainage, mechanical damage, and salt accumulations.

Water Resources

The user community requires a system which can provide current information (updated weekly) on available or potentially available moisture. This should include available soil moisture; amount and distribution of recent precipitation; deviation from normal percipitation; amount and location of stored surface water; location, amount, and accessibility of ground water; and transpiration losses. It is also important to have information on the areal extent of inundated lands and on the rate of subsidence of flood waters.

HOW DO WE GET THERE?

If an effective global system to provide information on agricultural, forest, and range resources is to be achieved within the next 15 years, a logical and rational research and development program must be continued without interruption. There must be continued planning for and implementation of a continuous flow of satellite data on these earth resources. Strong emphasis and support must be given to research which will provide a more complete understanding of (1) the reflective and emissive properties of biologic materials and earth resources, (2) the effects of external factors on the reflectance and emittance from earth surface features, (3) the use of temporal data to identify and characterize features of interest, and (4) data gathering, processing, analysis, and dissemination. Increased communication and interaction must occur between the community engaged in remote-sensing research and the user community. Appropriate educational programs must be set in motion to implement the transfer of technology to the user. These should begin in the early grades of primary school. Workable institutional arrangements which provide timely acquisition, processing, analysis, and interpretation of usable data to all potential users anywhere in the world must be established. Adequate funding must be provided for all segments that are essential to the development of the complete global information system. At the earliest possible time, operational use of this system should be demonstrated and implemented. Only then can credible and quantifiable benefits be determined.

Global Wheat Inventory

A growing body of evidence from the results of the ERTS experiments suggests that data from these satellites can be used, together with supplemental ground-observation data, to prepare a global wheat inventory. To this end, an experiment is being planned to evaluate the feasibility of using computer-assisted analysis of data from ERTS to identify, survey, and measure the areal extent of wheat in eight major production areas of the world. Participants in this experiment include federal agencies (USDA, NASA, NOAA) and state and private research institutions.

Results of this quasi-operational experiment should provide valuable experience and clues for the planning, design, and implementation of future operational remote sensing systems. This experiment should also be useful in evolving workable and effective institutional arrangements for carrying to completion a global task that involves close interagency and inter-institutional cooperation across a broad array of disciplines. Invaluable data will be generated for conducting cost and benefit studies. Successful demonstration that a global wheat inventory can be made with present technology will be an important advance toward the recommended complete and operational global information system.

Technology Transfer

Although the ERTS experiments have provided great impetus to techniques using digital-data and computer-assisted analysis, at present only a small proportion of the potential-user community has ready access to computer hardware and software and the technical background to make effective use of this new technology. The volume of earth-resources data to be generated by future information systems will require the use of computer-assisted analysis. If maximum benefit is to be obtained from these systems, an effective educational program at the national level, and/or other appropriate levels, must be implemented to produce an adequate number of trained technicians to service the needs of agriculture, forestry, and range management. A broad array of training is needed. Some users will require very little training for interpreting imagery or tabular data from small areas. At the opposite extreme will be the users of data from large geographical or global areas for whom the most sophisticated hardware and software are required in the analysis, interpretation, and utilization of data. Provision must be made for the transfer of needed technology to users at all levels.

During the next few years potential user agencies and institutions will be well advised to use present training programs and the satellite earth-resources data now available to prepare technical personnel for the effective use of future satellite information systems.

Research

The electromagnetic spectrum can be as useful for managers of agricultural, forest, and range resources as historically it has been for the analytical chemist and the astronomer. The ERTS system has proven that it can be usable from space for differentiating earth surface features. The chemist and the astronomer have found new important information as they have improved the resolution of their spectrometers and explored new bands of the spectrum. Similarly we can expect new information on terrestrial materials and ecosystems to be forthcoming as we explore additional spectral bands.

Research is needed on spectral properties of fields of crops and plant communities in different stages of development, of plants undergoing stress, of different soils, of soils in varying moisture modes, and of the diverse natural and cultural scenes encountered in agricultural areas. Further, atmospheric effects on incoming and outgoing radiation from agricultural scenes are not fully understood.

A greatly expanded research support base is essential to improve techniques in data processing and analysis and in pattern recognition. We must increase our knowledge of current global crop geography. We must develop a flow of information on changes in the production areas of major crops, if we are to be effective and efficient in conducting a global crop inventory. Finally, we must expand our knowledge of yield prediction models of major crops for this same purpose.

In all the areas mentioned, expanded research support will contribute to our supply of trained personnel. However, we believe a federal program in graduate traineeships should be established. Emphasis here might be placed on training young people who could enter data-processing and information-management positions in industry and in state and federal agencies as well as in educational institutions. An annual support level of $20 million for research and training is recommended.

Management System

Effective management of the total system will be essential if the proposed global information system is to meet the operational goals outlined earlier in this report. While the Panel's attention was focused on applying satellite-derived information to the problems of agriculture, forest, and rangelands, the proposed system will provide information related to other earth resources. Accordingly, the Panel considered in some detail a system management concept under which operational goals for a global earth resources information system can be met and technology can be infused into a multilevel user structure.

The system management concept developed by the Panel is a generalized model. One essential feature of this concept is a management element which might take the form of a quasi-public corporation, somewhat along the lines of the approach adopted by the United States to the operational use of satellites for international communications. Another important feature is the provision for strong interaction with users and suppliers, which will permit developing the support which is necessary if resources adequate to meet priority requirements are to be allocated.

The concept is discussed in general terms and described in detail in the Appendix. The Panel proposes this management concept as one option for an approach to implementation of a global earth resources information system in the hope that its merits and its shortcomings will be debated.

Funding

Although it is difficult with present data to document a favorable cost-benefit ratio for ERTS or for a future operational satellite remote-sensing system, evidence for a cost-effective system continues to evolve from the ERTS experiments. The Panel on Agriculture, Forest, and Range believes that effective monitoring and managing of world food and fiber supplies with present inadequate information systems will be extremely difficult in the years ahead. The Panel therefore strongly recommends that sufficient funds be appropriated on a continuing basis to guarantee the development and implementation of an operational satellite global information system dedicated to earth resources. If this goal is to be accomplished, funds must be made available to provide (1) continuity of data from satellites, (2) improved remote-sensing systems, (3) a more complete understanding of remote-sensor measurements and the properties of the earth's features being measured, (4) an effective program of technology transfer (technology infusion), and (5) the establishment of an institutional entity, one option for which has been suggested in this report, to implement and manage an operational satellite global information system.

SUMMARY

Demands for the world's agricultural, forest, and range resources in the closing decades of the twentieth century *absolutely* require that accurate and timely information be available to make possible the rational use of these resources. Without such information, mankind will be hard-pressed to meet even basic needs. The Panel proposes, therefore, that immediate efforts be made to work toward the development, within the next decade, of a global system that can provide the needed information. This global system should gather information from all sources, such as earth-observation satellites, weather satellites, ground observations, and aircraft flights. Information should flow freely, be accessible to any user anywhere in the world, and be available on a selected (regional) or a total (global) basis. There should be a world storage center and it should be secure against possible loss and deterioration of data.

An Earth Resources Technology Satellite (ERTS-1) has been in orbit for two years. Analyses in the last 18 months by more than 300 investigators have indicated many possible applications of satellite data in the fields of agriculture, forest and range management. Some of these applications have been verified; others need reconfirmation or replication under alternative circumstances. Data from ERTS-1--which is an experimental satellite--are now available to the public from the Department of the Interior (USDI) at Sioux Falls, South Dakota, the Department of Agriculture (USDA) at Salt Lake City, Utah, and the Department of Commerce at Suitland, Maryland. A review of the experiments points to attractive uses in inventorying and monitoring major crops, forests, and rangelands, both locally and on a worldwide scale.

The Panel on Agriculture, Forest, and Range feels that it is *now* time to implement a satellite remote-sensing global information system to provide earth-resources data on an *operational* basis. The overall system is viewed as including the acquisition of satellite data on a continuing basis; coordination with weather and climate data from the National Oceanic and Atmospheric Administration (NOAA); processing and verifying conversion of the data to useful information; distribution of the data and/or information to users, whoever they may be; education or training of current and potential users in further processing and in interpretation of the data; and planning and conducting necessary research and development programs to meet present and future technological needs of the users.

User needs or requirements have been identified and/or defined in five categories for both short-term (1975-80) and long-term (from 1981 on) operational modes. Not only are research and development (R&D) gaps identified to meet the long-term operations, but also continuing R&D requirements are described.

These five categories include application to: (1) cultivated crops, as in crop inventories and yield prediction, (2) land resources, as in land-use and erosion monitoring, (3) water resources, as in inventories of surface and ground water and identification of drainage patterns, (4) forest management, as in detailed forest inventories and evaluation of forest stress, and (5) range management, as in vegetative mapping and estimation of forage production.

Potential benefits from the applications of satellite data to more than 40 identified user requirements in these five areas are discussed in considerable detail. Dollar values of these direct and indirect benefits are difficult, if not impossible, to estimate. Nevertheless, it is obvious that significant dollar benefits could be attained. Certain benefits apply to all five areas. These include: (1) reduced cost of information gathering, (2) improved reliability of information, (3) more frequent information, and (4) acquisition of information otherwise unobtainable.

Such benefits of a satellite-based information system will allow mankind to make better use of environment and natural resources for survival and for improved quality of life. There will be direct benefits to intermediate users all along the flow of food and fiber from production to consumption, through harvesting, processing, and transporting to market. The *real* beneficiary is the ultimate consumer. It is a basic premise of the free enterprise system that all advantages to intermediate users eventually are passed along through the competitive system to the consumer.

Goals of the proposed global-system concept, which should be achieved in the 1985-90 period, are set forth in three areas: (1) vegetative resources, (2) land resources, and (3) water resources. It is important that the system be capable of coordinating information in these three areas.

Suggestions are made for a possible course of action to achieve the required global information system within the next 15 years. The global wheat inventory planned by USDA, NOAA and NASA can serve as a pilot project. Planning and implementation of this quasi-operational project should proceed to a fully operational system. Coordination within and management of the total global system should be initiated at an early date. The institutional arrangements for this system need further careful study. A procedure for educating and training users should be implemented. Coordinated research and development is vital to the program. Adequate funding is essential and needs further study.

SUMMARY OF RECOMMENDATIONS

The Panel on Agriculture, Forest, and Range recommends the initiation now of steps to establish, within the next two decades, a satellite remote-sensing information system that can serve local to global needs. Specific recommendations are to

Implement steps to make the second ERTS satellite (ERTS-2) serve operational functions, e.g., ground-data handling,

Expedite planned global wheat inventory as a pilot project,

Accelerate basic and applied research to develop technology for meeting needs of identified users,

Implement a third ERTS (ERTS-C) with thermal band to assure continuity of data,

Develop an Earth Observatory Satellite following ERTS-C to satisfy both operation and R&D requirements,

Establish institutional arrangements to implement and manage the satellite global information system,

Implement education and training of users, and

Initiate plans for cataloging and storing selected earth-resources data.

APPENDIX

MANAGEMENT SYSTEM

Effective management of the total system will be essential if the global information system proposed by the Panel on Agriculture, Forest, and Range is to meet its operational goals. One concept for a management system, which the Panel believes would be effective, is discussed herein.

Management of the proposed system will involve three distinct elements: (1) a user element, which may be a federal, state, or local government agency, a private institution, or an individual corporation, and (2) a technical-support element which may be a government agency (NASA, NOAA, etc.), a consortium of states and/or state institutions, a university research center, or a private institution. These two elements cannot function effectively in isolation so their activities must be integrated by (3) the management element. The management element, supervised by a board of directors including representatives from technological and user communities, would be responsible for the efficient and economical development of diverse applications, coordination of efforts to develop the technology required, and assurance that all activities have sufficient financial support.

Early in the development of the system the management element should encourage and participate in the design of an overall information system for states and/or regions of the U.S. whereby the data from ERTS is effectively collated at some future early date with related demographic, census and economic data for timely delivery to users.

The key to success in the management of a total system is the relative and definable role each management element performs in pre-operational and operational activities, which include:

Requirement definition,

Design specification,

Technology application,

Implementation planning,

Technology transfer and user training,

Definition of R&D needs, and

Basic research to optimize system utilization.

Within the context of these activities, the Panel on Agriculture, Forest, and Range suggests that both operational activities and management functions be taken into consideration in defining responsibilities for management, user, and technical-support elements within the overall system.

Management Element

User requirements dictate system development and therefore directly affect management. However, multi-users applying multidisciplinary approaches to derive solutions to problems require consistent direction in order to pursue efficient and economical system development. The role of the U.S. federal management element in the development of applications to agriculture, forest, and range should include the following responsibilities:

Overall coordination of technology applicable to the entire spectrum of user requirements,

Establishment of a clearing house for available technology related to data gathering and processing,

Coordination and distribution of available supporting resources according to the requirements of competing users,

Integration of implementation plans with state and/or regional, U.S. plan and needs, and international information needs,

Identification and resolution of redundant development and research efforts,

Preparation and maintenance of a master plan for application of space technology to current needs and formulation of budget requirements to support that plan, and

Maintenance of cost factors associated with acquisition, pre-processing, and initial distribution of remotely sensed data.

These responsibilities should in no way obstruct nor otherwise impair application of remotely sensed data to a user's unique problem nor should they restrict information products prepared and disseminated as a result of subsequent data processing.

User Element

As defined here the user may be a governmental agency, local, state or federal; an institution; a business; or individual. Such users perform a critical function in the economical management of the proposed total-system concept. The user must assume responsibility for the articulation of data and system requirements to meet his needs. At the same time, the user must assist the management element in maintaining an overall applications master plan, in developing cost factors, and in defining research requirements. Additionally, the role of the user in applications development must include the following responsibilities:

Translation of the initial statement of requirements into a format suitable for use by a technical-support element,

Implementation planning and product definitions,

Participation with technical-support element in definition and planning of user training required to effect technology transfer,

Coordination with other interested agencies,

Identification of R&D required to supplement development,

Preparation of strong budgetary justifications, based on user requirements, in R&D and in operational status, and

Development of cost-budget approach to support cyclical funding requirements.

In summary, the user element must function as the management catalyst in that its aggregate requirements define the responsibilities of the management and technical-support elements.

Technical-Support Element

The technical-support element functions as the "resource arm" of the management element and may be brought to bear upon unique user problems or upon overall system development. The ultimate success of system-management techniques depends heavily upon the effective utilization of technical resources. These resources currently and in the foreseeable future consist of government agencies, such as NASA, NOAA, USDA etc.; university research centers; and private institutions.

The needed technical resources must be recognized, planned for, and funded in the initial stages of determining and coordinating user requirements. The planning must extend through the development process, implementation phases, and transfer of technology. Specific functions performed by the technical-support element in applications development are:

Development of data-acquisition systems to meet user requirements,

Performance of R&D efforts in support of applications, e.g., automatic data-processing techniques, hardware and software components, and communications, Performance of basic research to optimize system utilization, e.g., spectral resolution, spectral properties of materials, and microwave techniques,

Preparation of funding estimates necessary to support requirements defined by the management element, and

Provision for training and technology transfer.

In the opinion of the Panel, the management concept described herein draws its strength from its provision for interaction between the users of information, the suppliers of the technology being applied, and the system management element. Figure I presents a model of the management concept which has been discussed herein.

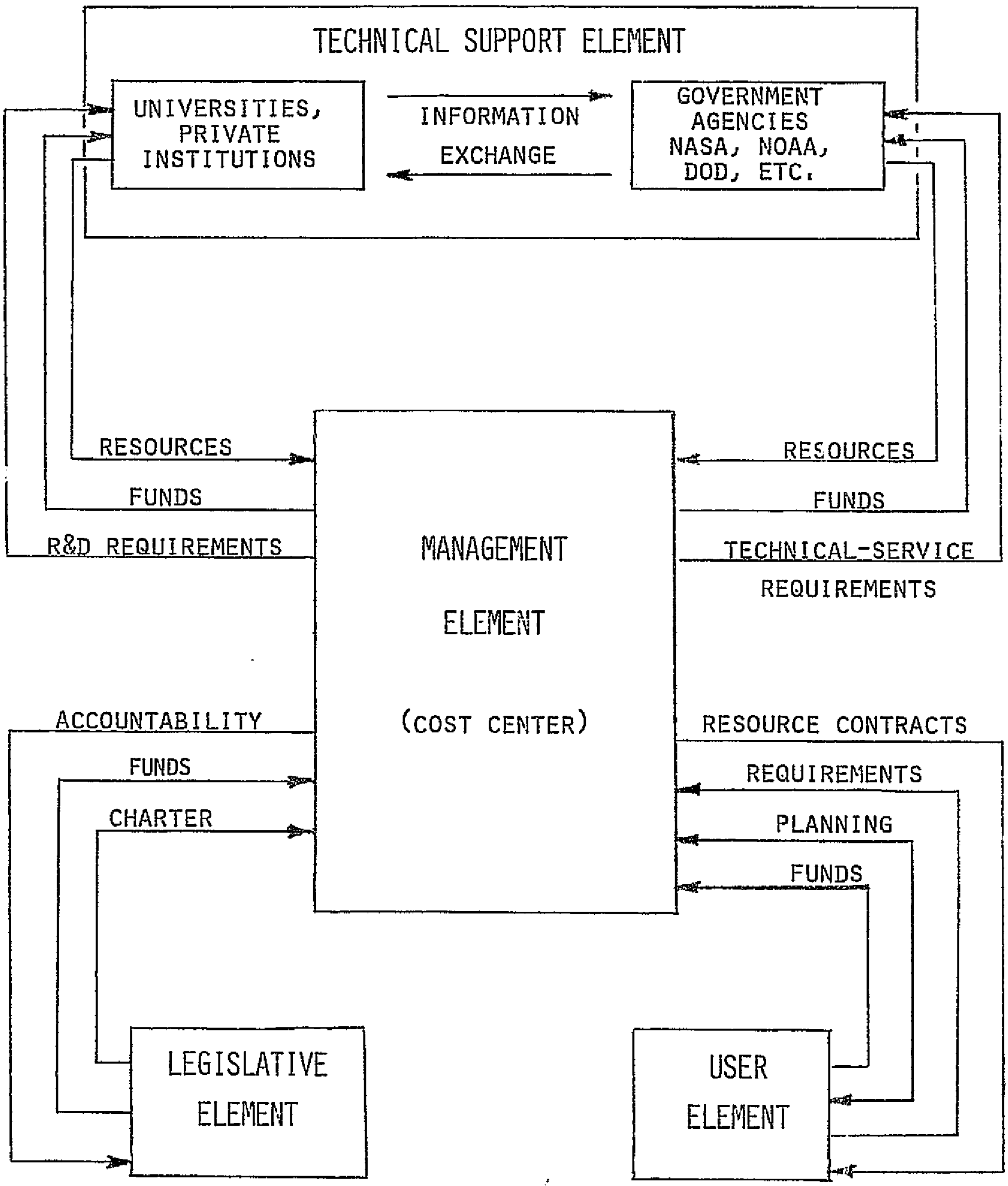

FIGURE I SYSTEM MANAGEMENT CONCEPT