I

Useful Applications of Earth-Oriented Satellites

SUMMER STUDY ON SPACE APPLICATIONS

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Useful Applications of Earth-Oriented Satellites

FORESTRY-AGRICULTURE-GEOGRAPHY

Prepared by Panel 1 of the
SUMMER STUDY ON SPACE APPLICATIONS
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PREFACE

In the fall of 1966, the National Aeronautics and Space Administration (NASA) asked the National Academy of Sciences to conduct a study on "the probable future usefulness of satellites in practical Earth-oriented applications." The study would obtain the recommendations of highly qualified scientists and engineers on the nature and scope of the research and development program needed to provide the technology required to exploit these applications. NASA subsequently asked that the study include an analysis of cost-benefit relationships.

Designated "The Summer Study on Space Applications," work began in January 1967, guided by a Central Review Committee (CRC) appointed by the Academy. The Study's Chairman was Dr. W. Deming Lewis, President of Lehigh University.

Technical panels were convened to study practical space applications and worked intensively for periods of two to three weeks during the summers of 1967 and 1968 at Little Harbor Farm in Woods Hole, Massachusetts. The work of each panel was then reported to the Central Review Committee, which produced an overall report. Panels were convened in the following fields:

Panel 1: Forestry-Agriculture-Geography
Panel 2: Geology
Panel 3: Hydrology
Panel 4: Meteorology
Panel 5: Oceanography
Panel 6: Sensors and Data Systems
Panel 7: Points-to-Point Communications
Panel 8: Systems for Remote-Sensing Information and Distribution
Panel 9: Point-to-Point Communications
Panel 10: Broadcasting
Panel 11: Navigation and Traffic Control
Panel 12: Economic Analysis
Panel 13: Geodesy and Cartography

The Panel on Forestry, Agriculture and Geography compiled an interim report during the summer of 1967. This final report was prepared during the summer of 1968 under the leadership of Dr. R. Keith Arnold, panel chairman.

The major part of the Study was accomplished by the panels; the function of CRC was to review their work, to evaluate their findings, and, in the context of the total national picture, to derive certain conclusions and recommendations. The Committee was impressed by the quality of the panels' work and has asked that the panel reports be made available to specialized audiences. While the Committee is in general accord with the final panel reports, it does not necessarily endorse them in every detail. It chose to emphasize the major recommendations in its overall conclusions and recommendations, which have been presented in Useful Applications of Earth-Oriented Satellites: Report of the Central Review Committee.

In concluding this preface, it is emphasized that the conclusions and recommendations of this panel report should be considered within the context of the overall report of the Central Review Committee.

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1.0 SUMMARY

1.1 Description of the Field

The United States has the most efficiently operated agricultural business in the world. One of the factors that has contributed to this success is an efficient crop-reporting and land-use system that has been developed by U.S. farmers and the Department of Agriculture. This information system has been of value to the government in establishing agricultural policy, and to individual farmers in the conduct of their daily business. As the world enters a period of increasing population and potential food shortages, the necessity of applying new technology for the improvement of such information systems, in the United States and world-wide, becomes apparent.

As the world's population continues to grow, there is an accelerating shift to dense urban megalopolises; men's urban, rural and wildland environments deteriorate; and critical questions arise about the world's capacity to provide and distribute food -- particularly to adjust to changing seasonal crop conditions. The earth is now recognized as one large spacecraft whose self-contained environment must be maintained indefinitely by wise management of its food, fiber, water, air and other natural-resource systems. To do so requires real-time knowledge of man's interaction with all these factors.

Urbanization as a process in the United States, as well as in developing countries, is little understood; and its spread is so rapid that information available to local, state and federal goverments is neither accurate nor timely enough for effective management and planning.

Maps and statistical summaries and analyses are published 2 to 10 years after data are collected. Small-scale maps are neither uniform nor current -- in fact, 70 percent of the world's present maps (at scale of 1:600,000 or smaller) are deemed inadequate, and the remaining 30 percent are obsolete.

Information that requires up-dating at frequent intervals (e.g., snowpack changes for predicting water yield, air- and water-pollution states, seasonal crop-condition reports for agribusiness, surveys of natural and man-made disasters, transportation studies, and urban-area changes) still, for the most part, has to be gathered by on-the-spot surveys by some combination of air photography and ground visits. These conventional methods are too costly for repeated coverage, and the information thus obtained cannot be analyzed in time for user applications.

1.2 State of the Art

Experiments conducted in recent years by NASA, the Department of Agriculture, and universities have demonstrated the power of multi-spectral sensing techniques and multi-spectral photography for applications in the agriculture-forestry-geography area. Various kinds of trees and crops reflect light in the bands of the visible and infrared spectral ranges, in differing degrees. Imagery made in this way and combined in a special manner can reveal, within limits, the identity of the types of vegetation observed. Heretofore, this work has been conducted mostly from aircraft, but there appears to be no fundamental reason why such techniques could not be used in space.

With the improvement of agricultural efficiency has come increased urbanization. The geographers of our Study have indicated that the new multispectral techniques can provide information useful for urban and suburban planning. For example, imagery taken at yearly intervals can make apparent the patterns of urban growth and changing land uses, on national and international scales. The new technology can be of great use in this area because of its scale economies in data collection.

1.3 Benefits

The Report of the Forestry-Agriculture-Geography Panel contains conservative estimates of the value satellite reporting systems might have to the agriculture and forestry industry, United States and world-wide. These add up to many tens of millions of dollars per year. A comparable analysis was not made for urban and regional planning, or for management and policy-decision systems; but it is likely that these benefits could equal or surpass those projected for agriculture and forestry.

No attempt was made to anticipate potential benefits that might stem from associated new technological or management systems. However, the more intangible effects on increasing the efficiency of farming and forestry through new satellite technology are potentially significant, particularly as population pressures will require that the earth be treated as one agricultural cooperative. Modest improvements in agricultural efficiencies in developing countries, for example, can often mean the difference between subsistence and starvation, between stable and unstable governments. Crop- and forestry-information systems in themselves will not solve world food problems. Nevertheless, efficient agriculture and forestry practices, in the modern sense cannot proceed without such information.

1.4 Goals

At the beginning of its study, the Forestry-Agriculture-Geography Panel verified three general assumptions:

> That increased knowledge of earth resources will benefit society and contribute significantly to the progress desired by both the developed and undeveloped segments of society
>
> That data obtained by remote sensing can contribute to earth-resources knowledge
>
> That space technology developed by NASA and others can be effectively applied to provide the space-borne platforms, sensors, and communication links required

In fact there is little doubt that there is immediate need for a program that utilizes space technology to collect earth-resources data in the following two areas where remote sensing is now technically feasible for:

Inventory and productivity evaluation of the world's food, fiber, and other natural resources

Assessment of environmental conditions and of man-environment interactions.

The focus of the Panel then shifted to the problem of how to establish and implement an earth-resources information program. Many technical and non-technical considerations are involved in this problem, including the criteria to be used in formulating a program and organization to:

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.

1.5 Illustrative Programs

The systems visualized by the Panel are designed to collect appropriate synoptic data on a timely basis, and to interpret, analyze and present them in the form of useful information in four broad categories:

Synoptic information for management activities such as planning programs, predicting crop yields, manipulating snow packs and regulating water flows, and planning game harvests

Spot information required for on-the-ground management decisions such as planting plans and pest-control measures

Emergency information to determine the extent of disaster damages and to plan relief and rehabilitation measures

Scientific information for research and education

Within three years, a Global Land Use satellite system that provides imagery could be made operational. It would give synoptic coverage in 10,000-square mile thematic photographs leading to: land-use maps; indirect yield estimates for major food and forage crops; area measurements of water, snow, ice, vegetation types and conditions; surveys of urban areas and condition changes, cultural features, and transportation nets.

This first-generation system, though separately identified, is envisaged as part of a major R&D program aimed at developing a multi-channel, multi-sensor aerospace system linked to a national System for Earth Resources Information (SERI) which could be completely operational in 12 years. Such a system would produce synoptic, timely information in formats required for direct use by agribusiness and resource industries; by local, state, regional and federal agencies responsible for planning and action programs; and by other countries and international agencies.

The characteristics of that R&D program must include a selection of the most important problems and priorities, a dedicated effort to prove feasibility of solution by the combined talents of scientists and engineers who carry the solution to a test-operational phase, and the organization of these efforts around data-processing, ground-truth, and test-platform facilities. The R&D program must be evaluated in terms of its demonstrated and proven implementable programs. These programs will be a marriage of skills in earth-resources sciences for signature analysis (including temporal, spatial and spectral signatures), data-analysis and sensor skills, and experiment design.

A major recognition of this Panel is that basic sensor-signature research and development has the potential of yielding disproportionately great returns for a relatively modest investment. Such basic sensor-signature research is fundamental to the establishment of reliable ground truth for aerospace sensing, and is considered the likely pacing element in extending the earth-resources applications of space science, especially in the field of spectrometry.

1.6 Recommendations

We recommend that a satellite program to supply pictorial information be initiated immediately. This early implementation will afford a means to solve many of the future operational problems, and will provide much of the understanding required for future, more sophisticated systems.

We recommend that planning, with appropriate check-points, be initiated for the evolution of that early system to a substantially broader system, using more sophisticated sensors, over a period of the next 10-12 years. Responsibility for the planning and coordination is a critical element of this program; the responsibility should be assigned early and should be clearly defined.

We recommend that the R&D program for this evolution include substantial, focused efforts directed at carrying applications through to the test-operational phase. These efforts are required to prove-in new applications and techniques in a timely manner for incorporation into the evolving system. It is essential that these efforts be ranked according to priority and closely coordinated with the planning of that system.

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. We recommend significant expansion of the present broad-scope research program.

2.0 GENERAL STATEMENTS

2.1 Introduction

Technology developed for the nation's space program can, if properly adapted and applied, serve a major role in ameliorating many critical problems found by man in urban and rural areas. Such application and adaptation of space technology to problems of planet Earth should be actively pursued. As the world's population continues to grow, there is an inevitable shift to a more dense, urban environment, which is increasingly inadequate, and fails to meet even the basic needs of people. There is an ever-accelerating, often irreversible deleterious effect on our available resources, upon the quality of man's environment, and thus upon man himself. This global phenomenon, which threatens the future of mankind, must be and is being vigorously attacked by all levels of government and industry.

The dimensions of the overall environmental problem have been stated before by many concerned people. Vast and rapidly increasing populations are poorly fed and undernourished, live in crowded, dangerous ghettos and filthy, disease-breeding slums, drink polluted water and breathe polluted air, lack political, social, and economic security, are deprived of educational opportunities, and are entrapped in a chaos of disorder where planning and leadership are critically needed. Man has blindly abused and dissipated his natural resources, failed to bring to fruition the talents of many of his young, and left large segments of his fellows to face an empty future. The closed ecology of our one large spacecraft - the earth - is being spoiled, and man's greatest natural resource - man himself - is being wasted.

A central problem faced by decision makers, operation managers, and planners is the lack of timely and adequate data displayed in a usable form. Here remote sensing from space and aerial platforms can make a significant and perhaps critical contribution.*

Many examples come to mind. In the Great Lakes, Lake Erie is considered spoiled and Lake Michigan is now deteriorating, at what rate, in what direction, and in what ways remaining unanswered questions. Communities are dynamic, ever-changing, complex systems. What are today's boundaries of Detroit and Chicago? What are the rates of change in cities - the deterioration rates, the rehabilitation rates? What are the mobility patterns of people? What is the expected pattern of change on our Eastern Seaboard? What is the area of wheat planted? What is the corn-harvest requirement for boxcars? The questions go on and on. But the time grows shorter and shorter.

---

*Appendix A illustrates one of the classes of possible benefits from remote sensing in the agricultural field. Appendix B indicates possible importance of remote sensing in urban and regional planning.

Managers, planners and policy makers formerly could speak of a 30 year lead time for actions affecting the quality of man's environment. Now this is compressed, in some cases to 5 years, in others to still a shorter period, less than a year.

The tools available to planners are still under development. Conceptual models are being generated for specimen regions, in an attempt to obtain a predictive capability. There is a search for indicators of change. These include changes in distribution of flora, movement of population groups, creation and spread of pollution and pollution sources, as well as numerical census data such as levels of rent, ages of residents, ethnic patterns, growth of housing, presence and movement of cars, etc. Models are usually shaped by the data available, and these are most often dubious in quality, and too old. Attempts are made to use the models to predict the time-sequence of the spread of man through some region. If simulation of regional changes can be attained, alternative courses of management can then be examined in the fields of urban planning, metropolitan control, or urban-rural interactions, for example.

NASA should be complimented on its Earth Resource Survey Program, which started the development of scientific interest and technical capability with respect to earth resources applications of space technology. With the cooperation of NASA, the Departments of Agriculture and Interior have begun needed research efforts in-house, as well as at the Universities of Michigan, California, Stanford, Kansas, Purdue, and East Tennessee State, and with the Association of American Geographers. Results from the various study groups have consistently demonstrated the technical possibility and potential value of remote-sensing systems for agriculture, forestry, geography, and other related earth-resources activities.

In the 3-weeks available for the study, the panel members in agriculture, forestry, and geography undertook the broad task of outlining two informational systems. These are (1) the Global Land Use System (GLU); and (2) the System for Earth Resources Information (SERI), discussed in Section 3. 0. There was no attempt to make an engineering assessment of system alternatives, or to make an overall economic appraisal of their impact on the national or world economy. Answers to these problems can come only from major research efforts. Studies under way at present in NASA, USDI, and USDA should add much of the scientific and technical detail necessarily lacking in this report.

2. 2 Agriculture and Forestry

Agribusiness - the producing, processing, financing, supplying, and distributing of food and fiber-is a major component of our domestic economy. Worldwide shipment of U. S. food and other agricultural products contributes substantially to our trade balance, and is an important factor in foreign-policy decisions. The export of our agricultural technology comprises a significant aspect of our assistance programs for developing nations.

The need for increasing the world's agricultural capacity has been made amply clear in the recent report on "The World Food Problem" by the President's Science Advisory Committee. In the next 30 years world population is expected to double, to about 6 billion people. If world population continues to increase at 1965 rates, 52 percent more calories will be required in 1985.

At the present time there is no worldwide shortage of food either in terms of quantity (calories)or quality (protein). The serious nutritional problems that exist throughout the globe, and particularly in developing countries, are due to uneven distribution of food supply among countries, and to the lack of sound economic incentives that encourage farmers to produce more food and fiber. Despite foreign aid and emergency food-distribution programs, peoples of these developing countries continue to exist on substandard diets. It is obvious that education, as well as other techniques, must be pursued and developed if the number of hungry is to be reduced and future populations are to be fed. It is generally agreed that in developing nations, native subsistence agriculture must be converted to a commercial system.

The cornerstone of economic progress in any nation is the development of its natural resources and people. However, internal development cannot progress without knowledge of events occurring elsewhere. These events may be competitive or complementary. Agriculture is an international business. Development of food and fiber production on a sound economic basis requires an accurate inventory and a timely, continuing assessment of food and fiber resources on a global basis. While this type of information is generally available for the United States, it is often not timely. In many developing countries, this information is nonexistent or inadequate. Yet our own domestic agriculture, its programs, policies, and business are directly influenced by events in these foreign countries. Effective management of our domestic food and fiber agribusinesses requires accurate, worldwide information available in near-real time to every governing body and to the private investment community.

Wood and wood products have been a mainstay in the economic development of our nation and of most other nations of the world. The traditional use-pattern of forest resources has been a progression from exploitation, through periods of more careful utilization, to systems of intensive management and sustained production. This pattern has often been accompanied by an evolution from export of the raw material to the processing of wood products.

At the present time we find nations of the world at various stages in this evolution toward the development of industries based on the fabrication of wood products for final consumers. The European countries are well developed in the intensive management and utilization of their forest lands. The United States is rapidly approaching this stage, followed closely by Canada. Many of the tropical countries are barely in the exploitation stage of forest-land use.

Forest lands are used for production of many goods and services in addition to wood. Recreational use is growing rapidly in the United States and in other nations. Wildlife, which provides food as well as recreation, depends to a great extent upon maintenance of suitable forest or other wild land habitat. Forest and related range lands provide food for domestic cattle, sheep, and horses, under commercial management of this land resource. Forest lands are also a major source of water for agriculture, industry, and municipalities.

The expanding population and economic growth of the United States and of the world require the continued development of the world's forest resources. Two principal ingredients are needed if we are to take advantage of these resources, which occupy one third of the land area of the world. The first is reliable information about this resource, not only in advance of its exploitation, but also as its protection and management are intensified. The second ingredient is the continued development and application of modern technology to reduce the costs of utilization, protection, and production of the varied goods and services from forests and related land areas. The program proposed by this Panel is designed to provide the first ingredient more effectively through a System for Earth Resources Information (SERI) which will serve the United States and other nations of the world.

Remote sensing by aircraft and satellites offers the possibility of obtaining global land-use surveys, timely crop reports, and current management and operational information never before available to agribusiness and related government agencies.

Crop reporting, comprising timely, accurate information on local, regional, and foreign agricultural conditions, for major crops, would assist government agencies concerned with planning and the agribusiness community as well.

Yield forecasts of major crops, on a global basis, are needed for program guidance, to add stability to national food and fiber programs, and to ensure adequate supplies of food and fiber for all.

In addition to crop reports, intensive management of agriculture and forest lands requires information and operational guides on a real-time basis. Adjustment of acreages, fertilization, pest control, flow of goods and services toward the farmer and toward the consumer must be improved if we are to clothe, feed, and house the world's population at a reasonable economic expenditure.

A global resource-information system to maintain a continuous condition survey of the world's food and fiber is not a panacea, and should not be construed as a "solution" to the world food problem. The proposed system simply will supply more accurate and timely information for the complex decision processes required by all those concerned with action programs of international agriculture. This information is crucial to the application of the other modern technology (irrigation, fertilization, and pest control, for example) needed to increase production and efficiency in developing nations.

The Global Land Use operational system and the 12-year R&D program that are proposed appear technically feasible. Total net dollar benefits have not been estimated in this Summer Study, but the estimated cost-value of the information to agriculture and forestry appears to justify the continuing program outlined. The new methods of gaining more information are expected to be needed as agricultural and forestry production processes are intensified to supply the increasing needs of the future. Furthermore, the sequence of program development from a simple, easily understood land-resource survey to a complex, highly instrumented, crop-reporting network with data-processing and information centers should be politically acceptable to reasonable governments.

A specific example of remote sensing as an accomplished operational tool is the infrared mapping of large forest fires from aircraft; a successful technique which is the product of research and development of the USDA, Forest Service.

The Coyote fire which burned in the hills above Santa Barbara, California from September 22 to October 1, 1964 devastated 67,000 acres of valuable residential property and watershed lands. This fire cost $2.5 million to suppress and did $20 million damage, including $4.5 million in insured structural loss. However, the costs and damage would have been far greater had it not been for the newly developed airborne infrared mapping system which located and followed the spread of the critical northeast sector of the fire at a time when smoke made visual observations impossible. Given exact knowledge of the fire's location and progress, it was possible to construct control lines in time to prevent the fire from crossing into two unburned watersheds. Experienced personnel estimated that the fire would have burned at least half again as much acreage had the infrared system not been available. This would have resulted in an additional $9 million in fire-fighting costs and resource damage.

2.3 Geography

A great deal of evidence indicates that as world population increases, the strategies employed by man to organize his activities on the surface of the earth become increasingly critical. Systematic studies of the patterns of cultural and natural phenomena, and of changes in these patterns, require constant monitoring of the state of the environment. The special interest of geographers in the technology under review is to obtain more up-to-date information for such studies of man-environment interactions. There is a critical need for uniform data collected over short periods of time on a world-wide basis. Information presently available varies greatly in quantity and quality, is obsolete for many areas, and is completely lacking in others. Aerial photography has been an invaluable tool for 40 years in a variety of applications. Multisensor imagery from space offers orders of magnitude improvements in capability, will fill large gaps in knowledge, and will provide timely, broadscale observations never before available.

Synoptic coverage of the type envisaged, combined with data collected by other means, into an articulated information system, will provide more accurate and more efficient delineation of the cultural and physical patterns on the earth's surface. These patterns include major cultural complexes such as transport nets, cities, and agricultural areas, as well as vegetational and physiographic associations. Single worldwide coverage will constitute a unique calibration of man's home. Repetitive coverage will yield information from which to calibrate the magnitudes and directions of change, the crucial dynamics of the man-environment system: expansion of cities, of transportation facilities, and of pollution; conversion of agricultural land to other uses; changes in snow or botanical cover; and the complex of interactions between all of these elements.

The information collected in this manner will be of major practical and scientific value. A few examples will suggest their range. Urbanization of the United States is proceeding at such a rate that nearly 80 percent of the population is expected to be agglomerated into vast megalopolises containing 265,000,000 people and 23 urbanized regions by 2000 AD. Estimates of the expenditures required to remedy current malfunctions (blight, congestion, and so on) of the urban strategy for environmental organization range up to $100,000,000,000. Up-to-date synoptic information on the state of the environment is clearly a prime requisite for urban and regional planners in defining areas of problems and of opportunities, and in designing functional solutions. Orbital sensors can contribute information toward these ends. At present the rate, direction, and nature of areal expansion for each urban community in the United States are not known. Census figures provide gross estimates every decade in this country; but the problem exists all over the world, and in many underdeveloped nations census data are inadequate or lacking. Synoptic coverage coupled with ground samples will permit highly improved census estimates over large areas of the earth, and thus simplify calibration and verification of analytical models of geographical growth and diffusion.

Global land-use patterns are one of the most significant indicators of man's strategy for coping with his environment. They are the result of an entire complex of decisions and interactions. It would be pretentious to claim that this system of decisions is well understood. Generally speaking, information passes between urban centers, along the hierarchy from world centers to the agricultural village; human decisions interact with each other; influence and are influenced by the biotic and physical surroundings; and the global land-use pattern is one result. In its static form it presents an inventory of our planet. Dynamically, it reverberates to natural or man-made catastrophes, often in most unexpected ways—sometimes quickly, sometimes slowly. Synoptic global delineation of the land-use pattern permits inferences regarding some of the most subtle and complex of these interactions at regional, national, and international levels. Specific consequences of floods, earthquakes, fires, riots, etc. could be determined, as well as longer-range impacts of droughts or fluctuations in the earth's energy budget. Early detection of unexpected deviations in land-use patterns might be indicative of serious disequilibria. A large educational impact can be expected from global imagery as it reveals the effects of management policies on land use, and the ecological consequences.

As our technological capabilities have improved, geographically larger projects (with geographically larger consequences) have been contemplated. There does not appear to be any reason for this trend to cease. Synoptic imagery of large areas will facilitate preliminary engineering for new transport and pipeline routes, ports, and river-control projects, in remote and little-known areas such as the Amazon Basin, and would be useful in the United States in the early phases of engineering investigations of large-scale reclamation or interregional water-transfer projects.

As a special example of space applications of remote sensing, the following problem areas in archeology offer opportunities for new and improved exploration:

Determine population fluctuations from archeological sites (Saudi Arabia - 10th century BC era)

Establish water supply and table, dams and reservoirs, underground dams, wells

Locate canal patterns

Locate past trails, roads, caravan stops

Determine past land-use boundaries, farms

Establish past forest/tree patterns, orchards

Locate past mining-operations sites

Map ancient stream beds

Locate past population centers and dwellings

3.0 SYSTEMS OF SPACE APPLICATIONS

Agriculture, forestry, and geography have projected a two-pronged attack toward practical application of space technology: (1) a Global Land-Use Satellite System for early operational capability (GLU) and (2) a 12-year research and development program to produce a complete Earth-Resources Information System (SERI).

Both systems aim at world requirements. The two systems are phased so that each complements and adds to the other; but each can be justified on its own merits.

3.1 Global Land-Use System (GLU)

3.1.1 Mission Objectives

1. To provide for global collection and dissemination of land-use information as described in Table 1.3.1, including indirect yield estimates of major food and forage crops
2. To provide capability to discriminate water, the presence of water-borne constituents, snow, ice, soil, vegetation, and certain vegetation types and conditions, urban areas, cultural features, and major transport nets
3. To provide synoptic coverage in units of approximately 10,000 sq mi (100 x 100 mi) with linear distortion no greater than 1 percent in an output format of thematic photographs and land-use maps
4. To provide continuous command performance to observe seasonal changes in agriculture, natural vegetation and snow cover, and allow flexibility in meeting limitations imposed by cloud cover
5. To utilize existing photo interpretation capabilities and thus assure maximum early utilization of information
6. To be operable also as a conservative cost program, so as to establish application systems and international political acceptance for more sophisticated, costly, and powerful systems to follow
7. To be operating in 3 years and continue in operation for at least 4 years.

3.1.2 System Requirements

1. The system must provide hard-copy imagery.
2. Each processed photograph should cover an area approximately 100 mi on a side, to meet the synoptic coverage requirements. (Negatives, 9 in x 9 in, provide an adequate scale for contact prints ((approximately 1:700,000)) and enlargements.

TABLE 1. 3. 1

APPLICATIONS OF THE GLOBAL LAND-USE (GLU) SYSTEM

Use and Phenomena	Information Frequency			
	10 year	5 year	Annual	Seasonal (one to three times a year as required)
Macro land classification				
Urban, suburban, and open land			1	
Agricultural, forest, and range lands			1	
Desert and mountain areas	1			
Snow, ice, and permafrost areas				1
Major transportation units			1	
Gross swamp, and water patterns				1
Gross land patterns			1	
Agriculture				
Land-use patterns (fields, roads, canals, etc.)				1
Acreages of major crops				1
Failure and damage assessment (drought, hail)				1
New land potential		1		
Pest detection				1
Forestry				
Commercial hardwood/conifer inventory		1		
Insect and disease detection				1
Timber potential	1			
Range condition and potential				1
Wildlife habitat			1	
Recreation areas			1	
Damage assessment (fire, insects, disease, wind)				1
Settlement				
Urban delimitation and area			1	
Gross internal urban features (large industrial sites, shopping centers, suburbia, major roads, etc.)			1	
General town and rural patterns		1		
Slash and burn agriculture			1	
Transportation				
Major highway and railway units		1		
Railroad yards		1		
Airports			1	
Canals		1		
Port facilities		1		
Vessels				1

TABLE 1.3.1 (continued)

Use and Phenomena	Information Frequency			
	10 year	5 year	Annual	Seasonal (one to three times a year as required)
Special				
Flood assessment				1
Pollution assessment				1
Erosion, siltation			1	

3. Each month some parts of the world need to be covered to record agricultural data, interpret snow cover, detect seasonal changes in natural vegetation, or avoid cloud-cover limitations. A small satellite should have an operational life of 1 year or longer. The orbit should be sun-synchronous, circular, at 300-500 mi altitude, with sun angle 30° at 50° N latitude at the vernal equinox.

4. Sensed data should provide the opportunity to distinguish water, soil and vegetation, and to recognize major condition changes or states in these earth resources. Three spectral bands appear appropriate for general user requirements. One band in the blue-green part of the spectrum is needed to accomplish (a) acceptable haze penetration and produce good penetration of ocean, bog and lake water for mapping of shallow underwater features, (b) representation of land form, and (c) distribution of cultural features. A second band is required in the red and near-infrared parts of the spectrum, which provides maximum observation of water for shoreline mapping, plus some estimation of moisture distribution and vegetation vigor. The third band lies between the first two, with no overlap. It is selected to improve the recognition potential of agricultural crops, and to provide for 3-band reconstitution of infrared color.

5. Spatial resolution should provide for discernment of objects (within the range of normal contrast) which are no larger than 100 ft in lineal dimensions.

6. The photohandling and data-processing unit should be designed for 50,000 processed original photos per year. It would index, copy, store, sort, and distribute. It would have enlarging capabilities to produce photos at 1:250,000 and provide directly up to 100 prints and master copies of each photo. Large-scale reproduction could be done commercially or by other government agencies. It is necessary to reconstitute color and infrared color.

3.1.3 System Load

On the assumption of imagery which covers an area 100 mi on a side, the following system load is projected. With an allowance of 60 percent for overlap and other duplication, 42,000 images (14,000 triads) will cover the earth's land area of 56 million sq mi. Actually, about one third of this area is in desert or Arctic regions and needs to be covered only once except at the borders. Intensively used areas (agriculture and urban) and shorelines need annual or more frequent reconnaissance-type coverage provided by GLU. A total of 33,000 images (11,000 triads) will provide 3-band coverage for 44,000,000 sq mi per year. This annual coverage could be used as follows:

Square Miles	
18,000,000	for the 6,000,000 sq mi of intensively used land areas which need to be imaged at least three times each year
10,000,000	for shorelines, continental shelf, estuaries and other areas of concern to oceanography
14,000,000	toward single coverage of the non-intensively used areas
2,000,000	for special problems and studies
44,000,000	TOTAL

The synoptic requirements of GLU pose some problems in the acquisition of imagery for the land surface of the earth, because of cloud cover. Preliminary estimates show that though some parts of the world are cloud-covered most or part of the year, 20 to 30 overflights over the course of a year should produce 90 percent or better coverage.

Cloud cover becomes a serious problem in obtaining imagery for disaster information, crop reporting, and other uses requiring data at a specific time. For example, a flooded area may be cloud-covered. Likewise, crop reporting in India during the monsoon season is a difficult assignment because of the high percentage of cloud cover during the early growing season. However, it is anticipated that real-time cloud-cover data over specific areas will be available from weather satellites. This will permit specific programming of sensors to concentrate image gathering when cloud cover is absent or scattered.

In addition to the processing center, the only centralized function planned for the GLU system is the preparation of global land-use maps.* The U.S. Geological Survey, with its authority and capability, may be the appropriate agency for this "pilot" project, leading to the development of a global land-use map. Several international scientific groups and international organizations could contribute significantly in the work of a global land-use survey. For example, the International Geographic Union has an established Commission on Land Use which has demonstrated an interest in remote-sensing application to land-use studies. Likewise, the Pan American Institute of Geography and History, associated with the Organization of American States, has encouraged land-use studies for economic-development purposes. It would appear that cooperation from the OAS and the UN and its affiliated agencies such as FAO, and UNESCO is essential for the successful completion of a world land-use map using multisensors from spacecraft with an adequate system of ground-truth checks.

3.1.4 System Possibilities

Requirements for GLU have been determined on the basic assumption that a satellite specifically designed for earth-resources survey is

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*It is not planned for the GLU processing center to have map-making capability. This work will be done by contract or by other cooperative arrangements.

technically feasible and can be in orbit in less than 3 years. This time limit is vital because of the wide array of possible applications by a large number of government and private users, and the need to get global applications and interpretations underway. Available imagery should stimulate and feed existing university and government research in application potentials, as well as provide existing users with better information. Time then dictates a minimum of R&D, and some relaxation of operational requirements, if necessary, to assure early availability of earth-resources imagery from space.

A TIROS-M-type satellite with the 3-channel TV camera system suggested for EROS should meet the requirements for GLU. But some question remains about the capability of the TV system to meet GLU requirements in 3 years. Satellite photography using color and infrared color in two cameras, with film capsule return, could also do the job. Further engineering study is required to determine the best available GLU system for activation in 3 years.

The Global Land-Use system is one which can be operated cooperatively by the U.S. Department of Interior, the U.S. Department of Agriculture, and the National Aeronautics and Space Administration as principal participants, with varying contributions and participation by the Departments of Health, Education and Welfare, Housing and Urban Development, Defense, Commerce, and others. The mission may be assigned to one Department or operated via an interdepartmental mechanism. (Early decision is critical.) Katz* compares aircraft and satellite systems and suggests that GLU requirements can be met by aircraft. Ultimate tradeoffs between aircraft and satellites hinge not so much on cost differences as on the ultimate potential for real-time repeated coverage of the entire earth on a synoptic basis in units of at least 10,000 sq mi. The answer probably is not going to be "either satellites or aircraft," but an optimum combination which will be determined by the projected R&D program.

3.1.5 System Costs

3.1.5.1 General Considerations

Cost estimates were based on the following considerations:

1. Primary objectives of the cost-benefits methodology were to identify the major cost components of the system hypothesized by each technical panel and to maintain consistent coverage and treatment of these cost components among the several technical panels. Hopefully the pursuit of this objective served to make more comparable the system costs presented for each panel.
2. Costs were estimated only to the detail deemed necessary to permit program comparisons and evaluations on a consistent basis.
3. This costing process reflects neither the extensive nor intensive tradeoff analyses that might be considered for each system. Furthermore, costs (and quantifiable benefits) were not discounted, nor was the impact of the inflation question specifically addressed in view of the approximate

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*Katz, Amrom H., "Comments on Aircraft and Space Survey Systems." This appears as Appendix E, Report on Sensors and Data Systems (Panel 6 of this Study) - Ed.

nature of the estimates. In short, although costing was performed within a relatively consistent framework, the dollar quantities (like the system configured) must be viewed as approximate.

4. Generally, the elements included in the costing procedure were incremental costs only, i. e., those costs that would be incurred by implementing the hypothetical satellite system. It is important to note, however, that the estimates presented do not include the following major cost items that undoubtedly would be incurred because of implementation of a particular system:

   a. Costs incurred by user agencies for education or extensive training and upgrading of personnel and procedures
   b. Costs of analysis and interpretation (e.g., photographic interpretation) of the data received by user agencies
   c. Any costs incurred by individuals or organizations "downstream" from the user agencies, e.g., costs to a farmer to revise his farming methods or to replace machinery due to new information provided by the satellite system

5. The primary functional categories were divided into collecting data from space, and processing and distributing these data to user agencies:

   a. Space-segment costs
      (1) Spacecraft (satellite) and sensors
      (2) Launch (launch vehicle, launching-pad costs)
      (3) Ground system (in general, ground stations, communication links, and tracking used to monitor, track and control the satellite)
      (4) System management and administration of the space system
   b. Processing- and distribution-segment costs
      (1) Spectral-signature analysis and ground truth
      (2) Ground system (in general, ground stations, communication links, and tracking needed to read out imagery and other information collected)
      (3) Processing (equipment for processing, organizing collected data into a form suitable to the user agencies, and distributing the data)
      (4) System management and administration of the processing and distribution
      (5) Platform equipment, such as buoys, balloons, and various types of ground collection transmitter stations

3.1.5.2 Specific Considerations

Cost estimates are made under the following assumptions:

1. Time frame: Three-year R&D followed by 4 years proto-operational.*

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*Global land-use maps will be completed within the 4 years. Seasonal and spot information will continue to be provided as part of the aircraft R&D of SERI.

2. Spacecraft (satellite)
    a. Polar orbiter, TIROS-M type, with 1 year life costing $1 million each. Provides photographic imagery with a 3-channel vidicon system and peripheral equipment. One in orbit at all times.
3. Launch vehicles
    a. Thor-Delta type vehicle, priced at $3 million. Launching-pad operations costs are $2 million.
4. Contingencies
    a. One spare satellite and launch vehicle are provided for the the system, and launching costs for spare are assumed in the total.
5. Other
    a. Processing of photo-imagery into approximately 11,000 triads per year at $1000 per triad, including 110 copies of each triad furnished to various user agencies ($11 million per year.)

TABLE 1.3.2

GLOBAL LAND UNIT SATELLITE SYSTEM—SEPARATE DISCIPLINES

COSTING ESTIMATES
(millions of dollars)

	Research and Development	Initial Investment in Capital-like Equipment	Operations and Maintenance	Total
SPACE SEGMENT				
Spacecraft (satellite and sensors) - near-polar orbit	14	5		19
Launch (vehicles, pad costs)- near-polar orbit		15	10	25
Ground system (station, network, tracking)	2	4	6	12
Systems management			2	2
TOTAL - SPACE SEGMENT	16	24	18	58
PROCESSING AND DISTRIBUTION SEGMENT				
Signature analysis and ground truth	4			4
Ground system (station, network)	2	3	4	9
Processing (equipment, data handling, film, distribution)	1	3	44	48
Systems management			8	8
TOTAL - P&D SEGMENT	7	6	56	69
GRAND TOTAL	23	30	74	127

3.1.6 General Comments

The total estimated cost of developing GLU and operating it for 4 years--on the assumption that its operation form will be a satellite-borne vidicon system--is $127 million. An estimated $39 million is required to make the system operable in 3 years. Annual operating costs are $22 million, and if cost-benefit studies indicate GLU should be continued for a longer time, during the R&D phase of SERI, it would cost $22 million for each additional year.

Costs of an aircraft system to meet the requirements of GLU and provide additional information via radar and infrared imagery have been estimated by Katz[1] to be $0.31 per square mile. Today's commercial experience and military-data-project costs of $10 to $12 per square mile. It is probable that aircraft costs would be in the order of $4 to $6 per square mile and thus be slightly higher than satellite costs but could provide more varied data at an early date. Costs of handling imagery and constructing land-use maps would be considerably higher.

Global Land Use is a separate and distinct entity within the Earth-Resources Information system. It may be authorized and funded without reference to the SERI system as a whole. However, it should be noted that GLU serves a threefold mission in SERI over and beyond the direct benefits it provides to earth resources:

1. GLU is a backup satellite system capable of improvement, step by step, if there is undue delay in development, testing, and operation of a multisensor system.
2. GLU provides the information necessary for the design and programming of the SERI application technology.
3 GLU provides the unusual opportunity for developing, country by country, the pilot cases of international cooperation, leading to agreements for SERI to provide a worldwide information service and appropriate communications with earth-resources information centers in other countries.

If SERI is an active program, GLU central processing and program management become part of the SERI research program in application technology, as shown in Table 1.3.4.

Figure 1.3.1 presents a system diagram of the Global Land-Use system if TV cameras are used. Any change in satellite-sensor systems would change the portion of the chart shown above the Central Photo Office.

3.2 System for Earth-Resources Information (SERI)

The system for Earth-Resources Information (SERI) is a complete informational program for:

Inventory and productivity evaluation of the world's food, fiber and other natural resources;

Assessment of environmental conditions and of man-environment interaction.

3.2.1 Objectives

The system is designed to collect appropriate synoptic data on a timely basis; and to interpret, analyze and present them in the form of useful and needed information in four broad categories:

1. Synoptic information for management activities such as planning and predicting crop yields, measuring snow packs and water flows, planning game harvest
2. Spot information required for on-the-ground management decisions for plans, pest-control measures, and traffic control
3. Emergency information to determine extent of disaster damage and to plan relief and rehabilitation measures
4. Scientific information for research and education

Table 1.3.3 presents a description of the kinds of uses and potential users for information which might ultimately be generated within SERI. The sensor systems projected for SERI will provide data in quantities and varieties which will dwarf anything heretofore envisioned in earth-resources information. Data control, cataloging, programming, and use will have to be controlled primarily by computers. Though it is not planned that SERI will be an analytical center, SERI will have to process the data far enough to make it directly usable by those who do predict crop yields and develop management and control information, and so SERI will require some R&D capability. SERI thus will be one of the larger computer facilities in the world. In some cases, existing agencies may wish to contract for a complete analysis program. In others cases, new, better, or more information will be fed from SERI to existing information analyzing and dissemination offices.

SERI is planned to be operational in 12 years, at the expiration of the time required for its R&D program. As an information system, its data input will flow from any one or some combination of the subsystems shown in Figure 1.3.2. Actually, the R&D program is designed to provide an operational satellite with a multichannel-multisensor system covering the entire electromagnetic spectrum, as needed. The aircraft system and GLU system inputs are available as backup should the R&D effort fail to provide a completely operable satellite, and in any event to serve as needed supplements, as required. A schematic diagram of the projected system is shown in Figure 1.3.3. As with GLU, an interdepartmental organization, or the assignment of SERI to one Department should be decided at an early date.

3.2.2 Research and Development

SERI is projected as a 12-year R&D program in three areas: hardware engineering, applications research, and systems development, as shown in Figure 1.3.4. It plans 2 years of experimental operations, with full operational capability in 12 years. Time during the 1967 Summer Study did not permit the detailed analysis of the full R&D program. However, it did permit the development of the broad outline, with the critical timing of the phases of the three areas. Unless the research in hardware engineering, applications research and systems development go on concurrently, and unless the phases follow the coordinating scheme shown in Figure 1.3.4, SERI goals will be difficult to achieve in 12 years.

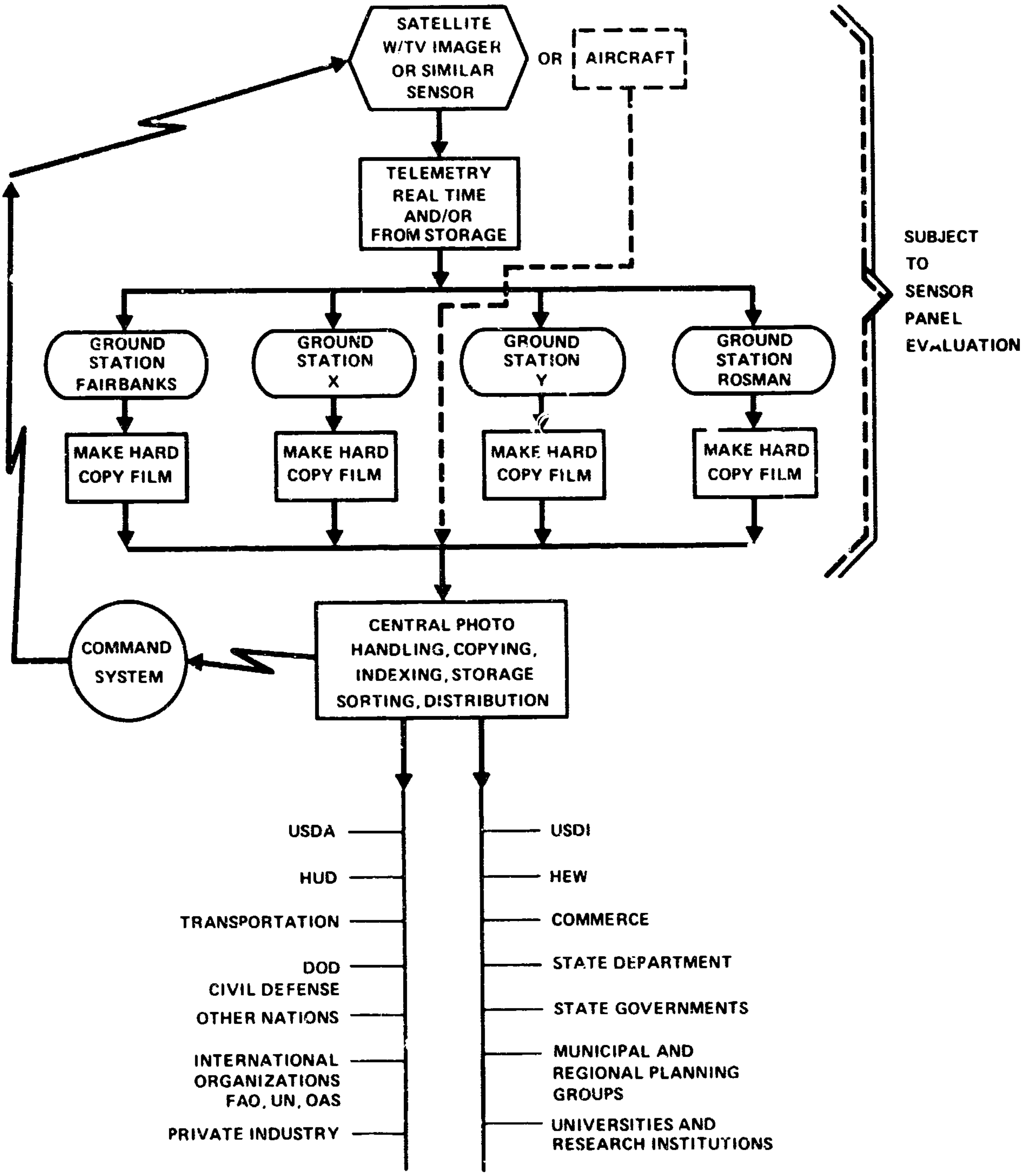

FIGURE 1.3.1. Global land-use system (GLU)

TABLE 1. 3. 3

SUMMARY OF PHENOMENA AND POTENTIAL USES OF REMOTE-SENSING SYSTEM INFORMATION

Agriculture, Forestry, and Geography

Basic assumptions underlying this table: Availability of synoptic global land-use information from GLU including monthly coverage at about 100 ft resolution, sampling spot coverage capability down to 5 ft resolution and ground-truth samples in accessible areas. Also assumes worldwide, or near worldwide, operation.

Use Category and Phenomena	Illustrative Applications	Potential Users
Agriculture		International organizations Government Producers Commodity groups Agribusiness (suppliers, processors, transport agencies, credit and insurance firms, etc.) Irrigation managers Commodity markets Range managers
Acreage and condition of major crops failure Insect and disease infestation	Crop reporting and yield forecasting Information for commodity markets Study of farm response to long-range weather forecasts, etc. Compliance with government regulations and allotments Allocation of transport equipment prior to harvest Programming of insurance, relief, and famine operations Early warning and control of insects and diseases	
Soil moisture and water supply	Timing of cultivation and planting operations Planning of crop mix Dust-control operations Water-table and waterlogging monitoring to guide drainage and irrigation operations	
Soil conditions and nutrient deficiencies	Assessing fertilizer needs Salinization monitoring and countermeasures	
General agricultural land use	Monitoring changes and trends in production potential, new irrigation, land fractionation and abandonment Prediction of changes in markets for equipment and supplies	
General rangeland condition and extent Special rangeland conditions: snowcover, floods, fires	Livestock estimates Adjustment of grazing permits and schedules to range conditions Planning of countermeasures for special conditions	
Forestry		International organizations Governments Producers and processors Trade organizations Insurance and finance institutions
Forest areas and composition	Inventory of stands; yields estimation Planning and location of logging engineering and transport facilities Assessment and adjustment of cutting rates	
Insect and disease infestation	Planning countermeasures and assessing losses	
Fires	Planning countermeasures and assessing losses	

TABLE 1. 3. 3 (continued)

Use Category and Phenomena	Illustrative Applications	Potential Users
Other Resource-Oriented Activities		
Wildlife census	Wildlife inventory and management operations	Governments
Habitat, rookery, and flyway conditions	Habitat management	Wildlife and recreation organization
Surveillance of preserves (parks, reserves, closed waters, etc.)	Control and regulation	Tourist bureaus Regional park and recreation planners
Wildlands-marshes, islands, etc.	Assessment and planning of new recreation areas	International organizations
Recreational vehicles	Census of recreational use and pressures	
Fishing vessels and traps	Assessment and regulation of fishing effort	Industry groups
Erosion, siltation, and pollution indications	Assessment and inhibition of destructive activities	
Cities		
Location and gross morphology	Land classification and inventory	Governments
Industrial, commercial, and residential areas	Updating housing and population censuses Updating traffic generation and routing studies	Planners Urban consulting firms
Highways and streets	Locating cordon stations for traffic counts Updating road and street inventories and condition reports	Real estate developers
Density and congestion	Delimitation and prediction of blight	
Open space and recreational areas	Monitoring change for planning, zoning, and land development	
Transportation facilities	Comparative study of cities Monitoring floods and urban floodplain use Updating tax records Assessing annexation potentials Assessing park and recreation needs and potentials	
Other Settlement		
Location and distribution of of settlements and rural dwellings	Census estimating	Governments International organzations
Transportation connections	Assessing transportation needs for rural development	Resource managers and planners
Enroachment on forest and agricultural land	Assessing changes in production potentials	
Land abandonment	Assessing changes in production potentials and/or population	
Scale and nature of agricultural and forest operations	Assessing levels of institutional and technical development	
Transportation		
Transportation nets, facilities, and equipment	Inventory of transport stocks Assessment of needs Location of new and abandoned facilities Preliminary planning and engineering of facilities	Governments Industry: owners, shippers, etc. Regional and city planners Transportation consultants

TABLE 1. 3. 3 (continued)

Use Category and Phenomena	Illustrative Applications	Potential Users
Transportation (Cont'd)		
Movement of transportation equipment (cars, trucks, etc.)	Measurement of flows and capacity Assessing impact of new facilities on related activities	Transportation engineers
Physiography and Other Terrain Features		
Terrain configuration Lakes, swamps Snowline and snowcover Permafrost areas Glaciers and permanent snowfields Sea and freshwater ice Vegetation patterns Deserts Landslides Flooded areas	Hydrologic studies Reconnaissance engineering of transport routes and other facilities Prediction of fishery production sensitive to lake ice and permafrost Observing long-term weather changes related to snow and ice bodies, forest-grassland interface, etc.	Mapmakers Engineers Hydrologists Regional planners Recreation planners Fish and game managers Transport route maintenance crews
Science and Education		
Biogeographical phenomena Contemporary cultural features and patterns Archeological and historical evidence	Study of ecological relationshops Discovery of ecological trends Measurement of environmental change Location of unutilized resources for agriculture, forestry, etc. Hydrologic studies Heat-budget studies Study of cultural systems and changes Archeological investigation Calibration and validation of spatial dynamic models and predictions	University scientists Educators Government laboratories Industrial laboratories
Disaster Relief and Rehabilitation		
Evidence of disasters: floods, earthquakes, major fires, hurricanes, etc. Damage to cultural and natural features	Determining location and extent of damaged area Estimating type and amount of damage to structures, transport facilities, etc. Locating available transportation and structures for emergency use Determing open transportation routes for shipping relief materials Rehabilitation planning and allocation of resources	Civil Defense Agencies Red Cross and other disease-relief agencies Government resource and planning agencies Industries concerned with rehabilitation Utility and transportation agencies Public Health Service Insurance organizations

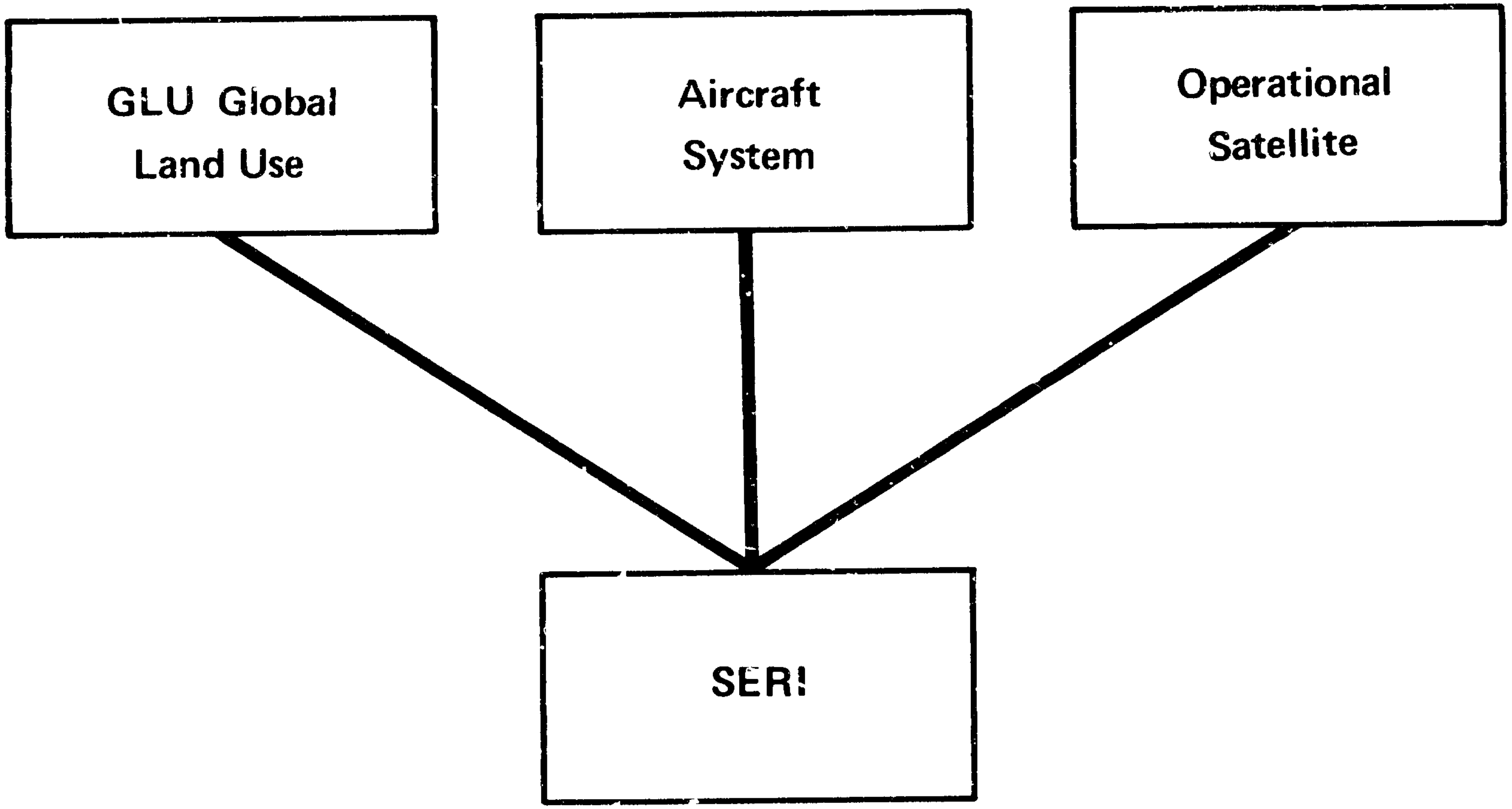

FIGURE 1.3.2 SERI Data-Input System

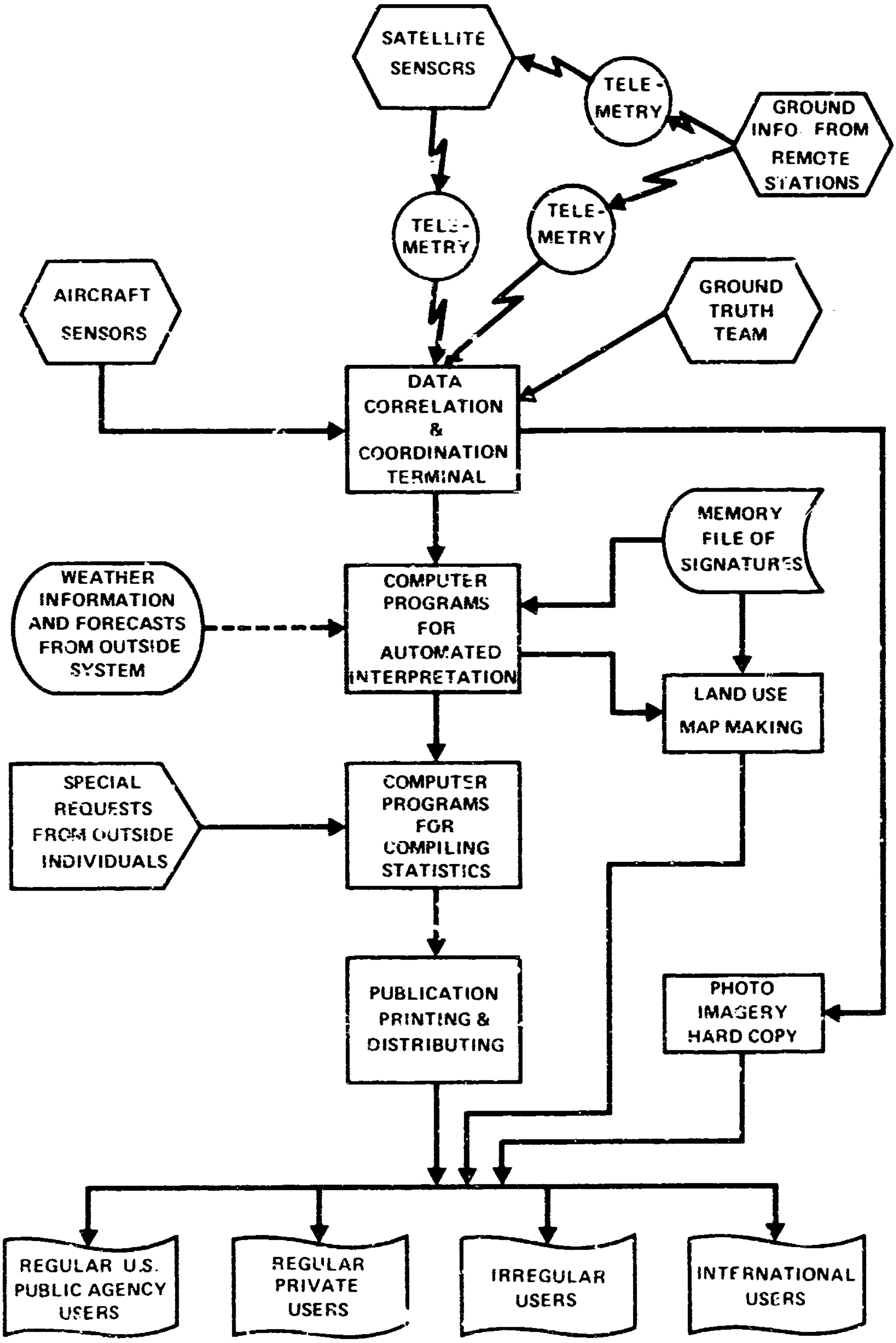

FIGURE 1.3.3 SERI system

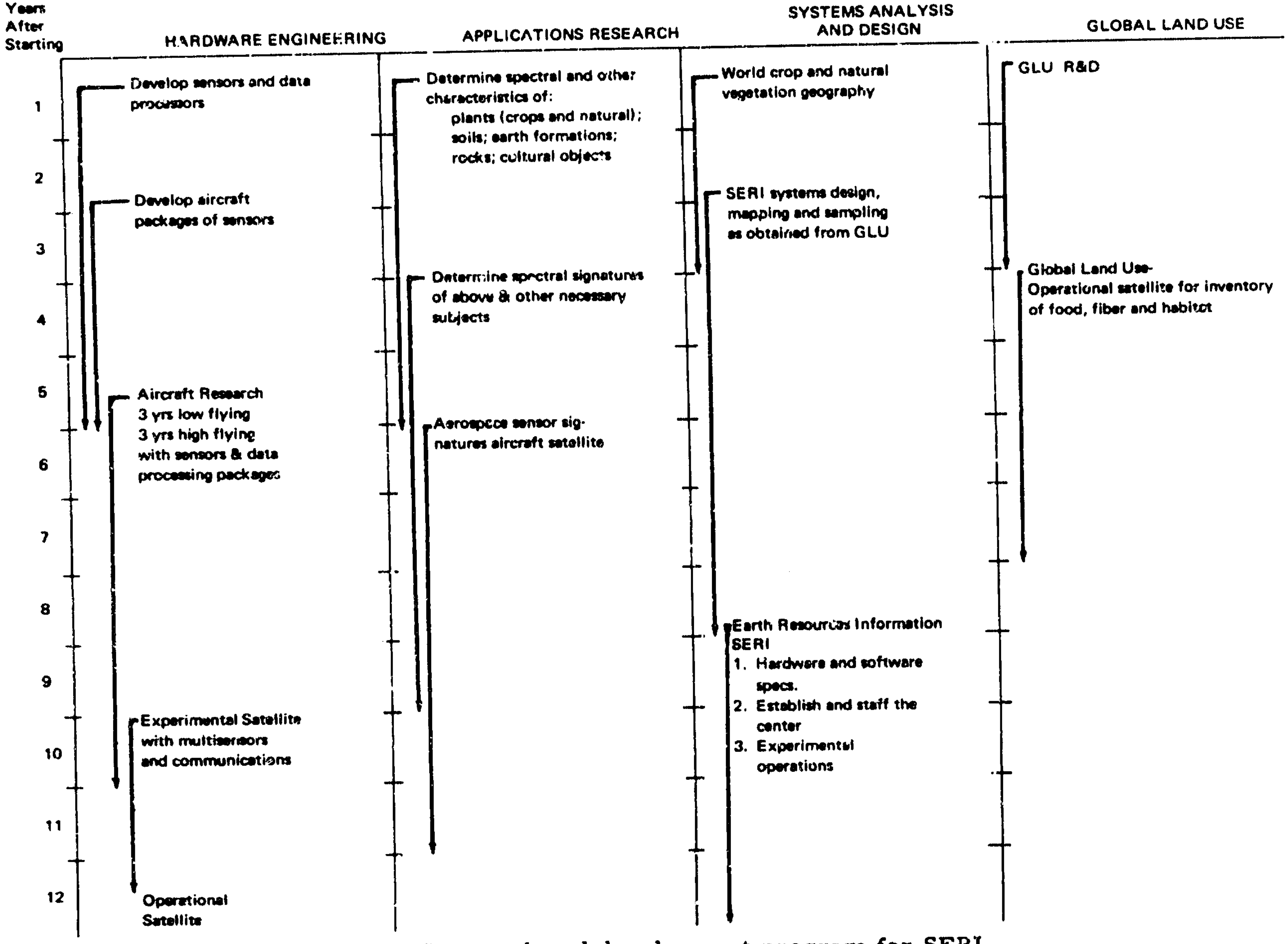

FIGURE 1.3.4 Research and development program for SERI.

In the hardware-engineering area, multichannel, multisensor systems will be required to span the entire electromagnetic spectrum. Long-wave, infrared and visible-band systems will require development as separate entities and integrated packages. The 5-year goal is to have available aircraft-ready packages for operational use in the R&D program and which include computer read-out and interpretation of discriminated imagery.

The aircraft part starts with two low-flying aircraft and adds two high-flying aircraft during the seventh year.* During the eighth year these aircraft, plus two more, are considered operational for the experimental phase of application technology, and to provide repetitive data as the GLU program is phased out. During years 10 and 11 the operating combination of satellites and aircraft is determined.

Much of the day-to-day information needed for irrigation and water resource management of lands in arid and semi-arid regions and in snowpack zones may ultimately be provided on a regional basis by satellite sensors. However, it is likely that in situ ground measurements of soil moistures at selected root-zone depths, water content of mountain snow pack, moisture content of forest litter, and certain micrometeorological measurements will be necessary. The number of devices equipped for telemetering their measurements to a data-collection satellite will be determined by technological developments that are expected to reduce present costs and provide alternative methods. However, for planning purposes it is estimated that 6,000 devices will be needed for world-wide coverage of agriculture and forestry.

Applications research must provide basic information on reflectance, emissivity, and radiance spectra of vegetation and soils, and must relate changes in these phenomena to season, vigor, stress, time of day, and the like. Spectral characteristics of cultural objects such as building types and road types must also be determined. In close coordination with hardware engineering, spectral signatures for aircraft and space altitudes must be obtained, for operational use. Spectral-signature research will relate multisensor, multiband data via computer discrimination and readout to identify some 100 to 200 different crop and forest species. These crop and forest species will be growing in varying densities and in combination with diverse soil backgrounds; their spectral characteristics vary as the plants grow during the season or over the years, as nutritional and moisture conditions change, and as insects or disease increase or diminish. Remote-sensing conditions change with time of day and condition of the atmosphere. Exploratory research to date predicts success for this venture, but success measured in terms of a practical and economic SERI rides on a continuing, intensive, and effective research program. This research area requires new spectrometer instrumentation for field use, particularly for pilot and field studies. An important part of the early research is to develop low-cost ground-truth "packages" for operational test sites.

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*It is recognized that research aircraft are now flying, but they are not flying proven, flight-tested instrument packages on an operational basis which fully supports the R&D program.

In the systems development area (including systems analysis and design) initial work seeks to stratify the earth's cultural and natural vegetation, and compile existing geographic information relevant to the programming of the GLU operation. In the third year, work with sampling and mapping systems for GLU serves as first-order systems design for SERI. This research is responsible for studies of international agreements, and for developing international programs, using other agencies as required. In the eighth year, aircraft data provide more input for the test operations of SERI. Hardware and software are completed and equipment purchased. Training of staff is begun.

The sequence of system development for SERI is shown in the time schedule in Figure 1.3.5. This illustration shows the two major decision points built into the R&D progress to date. At 8 years the decision for the major SERI commitment can be made. It is therefore possible to start the SERI R&D program without making the final commitment for the full operating system.

There is a major need for world-wide crop-reporting information now. There is also an almost unlimited demand for urban and regional planning information. In fact, it is felt necessary to start a pilot informational system to provide needed information, to begin early pilot testing of information systems, and of greatest importance, to begin to produce immediately, SERI-type information for the "user" agencies and businesses. The suggested pilot area is the 140,000 sq mi, three-state area of Illinois, Indiana, and Michigan. This covers a major segment of the corn belt and one major urban corridor from Detroit to Chicago. An estimated $2.5 million per year of the R&D program in systems development is for a pilot high-altitude photo system of this area, on a sampling basis. It is recommended that the Central Review Committee consider high priority for this part of the SERI Program so that benefits can be realized, and their significance evalutated immediately, and the full measure of demand for SERI-type information be developed.

3.2.3 Costs

SERI costs for this study and for general evaluation of the SERI program are projected in Table 1.3.4 for the three R&D areas. Pending the complete study of data systems and instrumentation requirements, this part of the summer study of space applications shows estimated levels of effort rather than detailed cost breakdowns.

The R&D program is scaled up slightly during the first 4 years, yet the total for this period is just $50 million. About one half of the hardware research funds are for equipment development and purchase.

At an appropriate time within the initial period a program review can be made, to revise budget allocations for the next 4 years, as appropriate.

In the second 4 years projected costs total $80 million, and include aircraft acquisition and the aircraft research and signature program. Year 8 provides the program-review point to commit SERI to satellite acquisition plus an application information center or centers.

The total program, which provides a system in full operation at the end of 12 years, is estimated to cost $397 million. This cost is separate from and in addition to the GLU cost of $127 million.

Annual operating costs after year 12 can vary from $25 to $75 million depending on actual data and information output requirements and the proportion of SERI operational costs passed on to the ultimate user.

TABLE 1.3.4

SERI R&D Cost Estimates

(in millions of dollars)

Year	Research Area			Total
	Hardware Development	Applications Research	Systems Development	
1	4	3	4	11
2	4	3	4	11
3	6	4	4	14
4	6	4	4	14
5	8*	5	6	19
6	8	5	6	19
7	10*	5	6	21
8	10	5	6	21
9	60**	8	30	98
10	10	8	25	43
11	10	8	25	43
12	50**	8	25	83
Totals	186	66	145	$397

*Acquisition of 2 aircraft

** 50 million for satellite and sensor purchase

4.0 SENSOR-SIGNATURE RESEARCH

Sensor-signature research appeared time after time during the brief study by this panel and others as the single, most important pacing element on which progress depends. Specifically needed are reputable data for, and exploration of, variations in emission and reflectance properties of biological and physical materials. These are the simple keystones on which sensor-signature research must be based.

A signature in this context is defined as any remotely sensed parameter which directly or indirectly characterizes the nature and/or condition of the material under observation. Although there are a number of means of sensing remotely, such as by acoustics, seismics, static electric and magnetic fields, gravity, particles of various sorts, among others, the principal practical means used today employs electromagnetic radiation in the ultraviolet, visible, infrared, passive microwave, and radar wavelength regions for all but the shortest observation ranges. The four principal characteristics of electromagnetic radiation which are available for providing signatures characterizing materials and their conditions are: variations in reflectivity and emissivity with wavelength (i.e., spectra); variations in reflectivity and emissivity with spatial position (i.e., shape); polarization introduced by the material or its condition; and variations of reflectivity and emissivity with time either rapidly, so as to cause doppler shifts, or more slowly, in diurnal and seasonal cycles. Existing technology is not capable of exploiting all of these to the same extent.

Sensing and data-processing theory and methods of implementation are quite adequate to capitalize on spectral signatures. For this reason there is an immediate and critical need for information regarding spectral signatures, their statistical variation at each instant, and their mode of variation with time. The theory and analytical methods presently available for automatic shape recognition are inadequate to handle anything beyond trivial cases. The need in this area is more for additional theoretical progress than for signatures, when automatic processes are contemplated. Where human beings are employed to perform the shape recognition there is of course a need for additional keys and signatures of the classical type, and for training of human interpreters in their use. The extent to which polarization can provide more or less diagnostic clues as to materials type and/or condition is, as yet, largely undetermined. There are, however, enough clues to indicate the merit of additional exploratory investigations. Therefore, the immediate need for signatures should be considered with the understanding that further developments may radically increase the need for spatial and polarization signatures.

Obtaining the basic data from which spectral signatures are to be extracted involves three classes of measurements. First are laboratory measurements of individual natural materials under a variety of conditions, including different illuminating and viewing angles, different temperatures, different stages of growth and health (for the botanical materials) and so on. The purpose of these laboratory measurements is to obtain a fundamental understanding of the relationships between the radiation and the types and conditions of the individual materials. Second are field measurements to extend the understanding gained in the laboratory to more natural conditions, where several materials will be simultaneously within the instrument field of view, and where the sources of incoming radiation are more varied, i.e., sunlight plus skylight plus scattered and emitted cloud radiation plus radiation from nearby surface materials, to include the effects of wind, evapotranspiration, etc. Third are measurements at greater range, from aircraft and satellite platforms, to obtain more nearly operational viewing angles and total fields of view, to include longer atmospheric paths, which will modify the signatures to some extent, and to obtain much larger and more widely distributed samples.

Instruments to make such measurements can be designed and built with existing technology, but those needed for the field and air/space-borne measurements are in a very early stage of development. There is a need for quantities of specially adapted radiometers, spectrometers, and multi-wavelength calibrated imaging devices whose many channel outputs are synchronized in space and time and in electronic form, for ease in automatic processing.

These measurements must then be subjected to analyses of the amounts and modes of their variance for various materials and materials conditions. The signatures will stem from these analyses. Because of the many sources of variability in the real world, these signatures will be statistical in nature.

Having the signatures, it will be possible to specify or develop the processing methodologies to identify materials types and conditions. Only then will it be possible to go back and specify the desired characteristics of the operational sensors on the one hand, and on the other to answer the question, "What can and cannot be seen remotely?" so that realistic system performance and (ultimately) system costs and benefits can be derived and put on a sound basis. Also, only at this stage will it be possible to specify what sampled ground and aircraft measurements, and what data from other sources will be required to supplement the data sensed remotely from orbit. Accompanying these measurement and analysis activities there is a need to establish standard nomenclatures, standard measurement procedures, uniform instrument-calibration methods, uniform data formatting, and other housekeeping procedures.

It is in this sensor-signature research that physical scientists, engineers and biologists must work together. Since biological and physical phenomena in a wide array of complex and changing patterns are the targets, understanding of these phenomena is needed to build the models required in this research.

5.0 ECONOMIC BENEFITS

A number of studies of the potential benefits to agriculture and forestry permit us to project cost savings and benefits in hundreds of millions of dollars.

Westinghouse, for example, indicates a gross benefit from an initial EROS system, to operations of the Department of Interior, of $70 million per year, plus an ever greater benefit to the private sector.*

The Center for Aerial Photographic Studies at Cornell has identified several billion dollars of potential savings to agriculture and forestry.**

The Demeter study at Stanford University projected estimates of cost savings for agriculture, forestry, pollution, and hydrology to be $62 million for the United States and $242 million for the world.*** Comparable user benefits were estimated to approximate $700,000,000 for the United States and $2,800,000,000 for the world by 1975.

All of these studies emphasize the limitations of data, lack of methodology, and caution against use unless all assumptions are carefully considered.

The 3-week Summer Study could concentrate on only one limited aspect of the economic benefits - that of improvements in data systems. (Even then, it could not analyze all current systems). The methodology and results of that study follow. Though no analysis was made, it appears fairly obvious that comparable benefits in areas of urban and regional planning, as described in Appendix B, would be equal to or greater than those projected for agriculture and forestry.

5.1 Summary

The data expected from the projected systems divide readily into two categories. Some will replace agricultural and forestry data currently collected, while other information to be gathered offers natural extensions of current data. For reasons explained more fully below, benefits from data which replace those currently collected are assessed at current costs of collecting the data to be replaced. Benefits from new and improved data are assessed by forming a subjective estimate of their usefulness relative to data currently being gathered.

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*EROS Application Benefit Analysis. Final Report to the U.S. D.I. Geological Survey, Westinghouse Defense and Space Center, Aerospace Division, Baltimore, Maryland. December 8, 1967

** Potential Benefits to be Derived from Applications of Remote Sensing of Agriculture, Forest, and Range Resources. The Center for Aerial Photographic Studies, Cornell University, Ithaca, N.Y. December 1967.

*** Demeter, An Earth Resources Satellite System. Stanford University School of Engineering, June 1968.

The following resulting figures provide hints of the general order of magnitude of such benefits for the United States and for the world (including the United States).

	Annual Benefits*	
	U.S. ($ millions)	Total World ($ millions)
Agriculture	7.5-11.25	18-45
Forestry and Related Resources	7.5-10.5	26-36
Total (Agriculture plus Forestry)	15.0-22.0	44-81

5.2 Introduction

Except for rare special cases, the application of new technical developments in our economy produces manifold, interrelated effects whose impacts can be only vaguely anticipated, even by the best efforts of well-trained specialists. Typically, some prospective changes can be outlined in a qualitative fashion, and for some of these changes hints regarding possible dollar values can be obtained.

Even when one considers the simpler problem of assessing economic benefits of past technical innovations, there are enormous uncertainties, due to the complicated and incompletely understood interrelationships among the activities, plans, and commitments of the people, businesses, and government agencies comprising our economy. These uncertainties are compounded many times when one makes prior assessments of prospective applications. The difficulties of forecasting are then added to those of interpreting economic effects.

Among the elements most difficult to forecast are the developments that may be expected to follow the application of new techniques. Application of some knowledge typically stimulates searches for both new knowledge and new applications. Thus it would be clearly unwise to decide on possible applications entirely in terms of visible benefits.

There does, however, seem to be substantial merit in appraising visible benefits as carefully as circumstances permit. When the visible benefits seem to cover a large fraction of prospective costs and the bases for the appraisal are strong, people who hold quite different conjectures on possible benefits of more distant developments may still find themselves agreeing on a current decision to apply the new techniques. Also, careful examination of visible benefits may sharpen one's conjectures about distant prospects.

In what follows, a very hurried look is taken at visible benefits from agricultural and forestry data gathered by the remote-sensing systems described in Section 3. Certainly these should be checked by more careful studies (which will necessarily be more time-consuming) that make more effective use of analytical economic tools. Some analytical suggestions are presented later.

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*Newport assumed responsibility for estimating the dollar benefits to forestry. Hildreth and Wallace collaborated in making benefit estimates for agriculture.

To obtain even crude quantitative hints it is necessary to make rather specific assumptions about the data that might be expected to emerge from the systems. Briefly, for agriculture and forestry we assume that the systems will provide useful information on broad land-use classes, on acreages in major crops (perhaps 8 to 12 of the more than 60 crops now covered), on forest areas by broad types, on indicators of forest and crop conditions at selected times of the year, on incidence and extent of certain plant and tree diseases and pests, on some aspects of soil condition (perhaps moisture, erosion, salinity), on the extent of special disasters (including forest fires), on livestock types and numbers, on wildlife numbers and habitat conditions, and on recreational use.

Regarding accuracy of the data, it is assumed that information directly comparable with information currently gathered will be of similar accuracy. For data not presently compiled we have formed rough subjective judgments of probable accuracy after talks with sensor experts.

What will actually be possible in extent and accuracy of information will depend on the success of the R&D program. As integral parts of this program, economists should be called upon to indicate the areas in which accuracy is most important for potential application. Statisticians, especially sampling statisticians, should work with sensor experts in the translation of technical indicators of accuracy into estimated error variances of tabulated data.

As a simplified example of a kind of problem that will arise, consider the following discussion, based on consultations with an aerial photography expert.

If we photograph an area containing a square field, sharply defined, the measurable accuracy of a side of the field is X ± R/5, where X is the true length of a side in linear feet and R is resolution in feet. If the experiment is repeated a large number of times, about 2/3 of the measurings will lie within the limits described above. If, as is typical, the errors in measuring length and width of a given field are highly positively correlated, the range of error for measured area is approximately $(X + R/5)^2 - (X - R/5)^2$, which reduces to 4/5 RX.

If we assume normality of the measure of area and assume that 4/5 RX covers the central 2/3 of the distribution, then the standard error is $\sigma = 2/5$ RX.

And the coefficient of variation is C.V. = $\left(\frac{\sigma}{X^2}\right) = (2/5)\left(\frac{R}{X}\right)$.

For an example, suppose we are measuring a 40-acre-square field with 100-ft resolution.

Then the coefficient of variation would be C.V. = $(2/5)\left(\frac{100}{1320}\right) = 3\%$.

Note that as we try to measure smaller and smaller fields with the same resolution, our error increases. Note also that, for a given size field, the coefficient of variation is proportional to resolution--as we increase resolution (i.e., go from 100 ft to 10 ft) we improve statistical accuracy (reduce the error variation). However, as we increase resolution, the quantity of data to be analyzed goes up as an exponential, so for a given task there would be a balance between benefits (accuracy) and costs (equipment plus data processing).

Returning to the problem of assessing benefits of the new systems, this is divided into two parts: replacement of current data and benefits from new and improved data. Our procedure in each case is based on a key assumption.

In assessing replacement of data we have estimated the decrease in public expenditures that could be effected by the replacements. This is done on the assumption that the present data system represents a pretty good adjustment of amount of data collected to the cost of collection using current techniques. In the theory cited at the end of this section one would say that the existing quantity of information is close to the efficient quantity.

For new data, the problem is even more difficult and subjective. We have assumed that new data will be sufficiently like existing data and used for sufficiently similar purposes that crude estimates and subjective judgments of its amount in relation to existing data will not be grossly misleading. Certainly anyone would want to improve on this aspect of our approximations in a more extensive study. Some possible analytical tools for this purpose follow our discussion of the order of magnitude of benefits.

5.3 Replacement Saving in U.S. and World Agriculture

As discussed previously, one of the benefits that can be ascribed to the remote-sensing system is the cost of those currently existing functions that can be replaced by the new system. Through conversations with people in various agencies involved in collecting and disseminating agricultural data in the United States, we have arrived at some crude estimates of the replacement benefit for federal agencies. Recognizing that other agencies within the United States are also involved in this activity, we make an extrapolation of our figures. And, to the extent that the system under discussion furnishes data in world agriculture for the use of other nations, we make a further extrapolation to benefits to foreign nations based on a rough dichotomy of developed versus underdeveloped countries.

Various agencies exist at the federal level whose responsibilities include gathering, interpreting, and distributing U.S. agricultural data on a periodic basis. These include the Statistical Reporting Service (SRS) of the U.S. Department of Agriculture and the Census of Agriculture in the Department of Commerce. Also, other agencies such as the Agricultural Research Service, the Economic Research Service, the Agricultural Stabilization and Conservation Service (ASCS), and the Soil Conservation Service collect data for special purposes such as providing information to help control pests and crop diseases or to plan erosion measures.

After our hurried survey, we estimated that about $0.6 million of the $0.8 million spent annually by these agencies on aerial photography could be replaced by data from SERI. We estimated that, in addition, expenditures on periodic surveys could be reduced by about $1.6 million, and that field work and surveys in connection with investigations for disease and pest control, land-use planning, erosion control, and the like could be reduced to the extent of about $2.3 million.

The resulting figure of $4.5 million annually represents a fairly small proportion of the concerned agencies' budgets. This seems reasonable because, first, the agencies gather a great deal of data that cannot be gathered by the new system, and, second, much of the budget is allocated to such activities as processing and analyzing data and writing and distributing reports.*

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*For example, the 1966 appropriation for SRS-USDA was about $14 million, only part of which was allocated to the primary collection of data. And the SRS collects not only acreage and yield data on crops (which the new system will eventually replace to some extent) but also such data as price information, characteristics of farm operators, and planting intentions.

On the other hand, we realize that our figure of $4.5 million annually is low since our contacts were with federal agencies only and many of the states have agricultural data-gathering agencies. Also, primary agricultural data are sometimes collected by commodity associations, farm organizations, and private businesses. Making a rough assumption that the activities we failed to survey amount to 1/3 to 2/3 of the activity that we did locate, we estimate that from $6.0 million to $7.5 million of benefits would accrue from the new system in the form of replacement of current data collection in U.S. agriculture.

5.3.1 Replacement Saving in World Agriculture

Having had no access to data collection in world agriculture, we must base an estimate on an extrapolation from the U.S. figures. Since the underdeveloped countries in varying degrees have not established elaborate agricultural reporting, we will only consider the more developed areas of the world in this section. This is not to say that the underdeveloped countries will find data from SERI useless; indeed the greatest relative benefits may well be derived in those countries. However, in this section we are only concerned with benefits in the form of replacement of conventional data gathering by SERI. Hence we confine our extrapolation to parts of the world whose agricultural development is comparable to our own. The areas of the world in addition to the United States that we are thus concerned with here are Canada, Europe, and Oceania.*

The following gives some idea of the relative importance of agriculture and general economic activity in the United States and in what we have defined as the remainder of the agriculturally developed world.**

	1964 GNP (millions)	1964 Population (thousands)	1964 Arable Land (1,000 Hectares)	1964 Cereal Production (million metric tons)	1964 Meat Production (1,000 metric tons)
United States	681,200	191,000	183,000	163.4	14,850
Canada, Europe, and Oceania (incl. USSR)	585,159[a]	475,000	461,000	200.6	22,000

[a] GNP data excludes USSR.

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*This leaves out countries that have made considerable progress in agricultural development, such as Mexico, Japan, and Israel, and includes some countries in Eastern Europe and Oceania whose agriculture may be somewhat short of developed. The choice is arbitrary and based on existing data aggregates in the source material.

**Data were compiled from Production Yearbook, Food and Agriculture Organization of the United Nations, Vol. 19, 1965, Rome, Italy, 1966, and Agricultural Statistics, U.S. Department of Agriculture, Washington, D.C., 1965.

Indeed, some of the figures such as arable land area could be construed as indicating that agriculture is twice as important in the rest of the developed world as it is in the United States. But one should note first that the Soviet Union has been included in the European data and second that many quality measures such as agricultural income and land value are missing from our data. It is likely that the Soviet Union is contemplating a SERI-type application, and it is also likely that all the qualitative measures would favor the United States relative to the remainder of the developed world. So in the absence of a better indicator, we assume that SERI would provide a replacement benefit to the remainder of the developed world roughly equal to the benefit accruing to U.S. agriculture. Clearly from the above table, one could infer that agriculture is at least as large in the rest of the developed world as it is in the United States.

In summary of this section, we have obtained a crude hint of $12-15 million annually from the SERI system as world benefits accruing in the form of replacement of current data gathering in agriculture. Roughly half of this amount would accrue to the United States. We assumed that the state of data gathering and processing was so little advanced in the underdeveloped countries that we should not impute a replacement saving other than to the more developed regions.

5.3.2 Benefits from New and Improved Data from SERI

The expected improvements from SERI can be categorized into several groups. First, remote-sensing data should provide some additional information to be used in crop-yield forecasting in advance of harvest. Crop forecasting in the developed part of the world is currently done using crop reporters and sample surveys, knowledge of soil moisture, and past trends in crop yields for specific crops and areas. Having additional and periodic observations from SERI on acreages and density and vigor of crop stands should prove useful as additional information for making forecasts. In the underdeveloped parts of the world's agriculture, the SERI information should have more net predictive contribution for this purpose than in the developed world.* To the extent that world crop yields can be successfully forecast, the advanced information would be useful to farmers in adjusting their plans to conform with either high or low prices depending on whether the harvest is to be meager or bountiful. And, to the extent that crop conditions in one hemisphere can be known in advance, farmers of the same crop in the other seasonal framework should be able to make plans even before planting. Crop forecasting has uses at other levels of decision also. For example, to the extent that the world is committed to alleviating starvation, better knowledge of crop conditions in the world would allow for advance planning of concerned governments and organizations. The extent of the benefit accruing from possible improvements in crop forecasts, as do other potential benefits discussed in

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*The basis for this statement is that one would expect the SERI data to be correlated to some extent with existing data on which crop yields are forecasted in the developed agricultural regions. Hence the net predictive value of SERI data would not be so great as in regions where little is known about past yields, soil moisture, and related phenomena. Note that this discussion is in terms of predictive efficacy not economic value.

this section, depends upon the empirical realization of accuracy. Hence to make a reasonable assessment we would have to predict now the outcome of considerable research that will be carried out under the SERI program.

A second category of potential benefits from SERI is in the area of early detection of crop stress. This includes stress resulting from, for example, unfavorable weather, soil conditions, plant diseases, and insects. It is unreasonable to think of SERI ultimately providing repeated coverage of every farm via remote sensing—the data flow would be too staggering to contemplate. However, the spectral techniques that develop through the SERI program may prove complementary to visual inspection and laboratory techniques in determining crop stresses and their causes. And remote sensing would provide a panoramic view of crops, and hence some hints of large stress areas. In this context, remote sensing would in some instances give clues of where to look on the ground.

Going on to a third category, land-use maps produced from SERI should prove valuable to agricultural agencies in designing sample surveys in more optimal strata. This is especially true in the developing nations for which good land-use maps are not so readily available.

Fourth, SERI data on land use and inventory come in a form that allows various aggregation and disaggregation. As indicated in the previous example of the coefficient of variation for measuring land areas in a specific crop, the reliabilities of farm, county, state, and national aggregates could be worked out fairly accurately for the SERI data, whereas in putting together a number of sample surveys carried out by different people in different areas one might get fairly reliable aggregate estimates but uncertain estimates for smaller aggregates.

In trying to put a number on the dollar benefits to SERI in terms of benefits from new and improved data we are faced with a problem of sheer speculation. In extrapolating to developed countries we are guided somewhat by a conjecture that if the new and improved data were as valuable in a marginal sense as data currently collected then we would see some attempts to collect the new data via conventional methods. Hence we are willing to make a conjecture that the new and improved data will be worth from 1/4 to 1/2 of the value of costs of collection of current data that will be replaced by the new system. So, for the developed agricultural countries, we arrive at a somewhat constrained guess that the new data will be worth from $3 million to $7.5 million. For the underdeveloped countries we feel that some data that will beprovided by the new system are currently furnished in the more developed countries by other means such as sample survey, aerial photography, and volunteer respondents. Again, we feel that at the current level of agricultural development of the less-developed countries such data are not worth as much as they are in, say, the United States. Otherwise one would expect to see more activity in collecting the data via conventional means. To make a projection to the less-developed countries we must look at some relevant comparisons of the importance of agriculture in those countries with the more developed parts of the world. To do this we refer to the table on the following page.

	1964 Population (thousands)	1965 GNP (millions)	1964 Arable Land (1,000 hectares)	1964 Cereal Production	1964 Meat Production
Developed regions (North America, Europe, and Oceania)	669, 200	1, 266, 359	644, 286	364. 2	36, 500
Less-developed regions (Latin America, Asia, and Africa)	2,610,900	342,551	812,714	657.3	30,800

It appears from the above table that by several measures we could say that agriculture is at least as important in the underdeveloped as in the developed world. Allowing for the fact that considerable investment in processing and distributing data would be required in underdeveloped agriculture, let us assume that 20 percent of the value of SERI data to the developed world can be imputed to the agriculturally underdeveloped regions. This would yield the estimate that we could expect SERI to benefit the underdeveloped regions from $3.0 million to $4. 5 million annually. The above guess takes the state of data processing, analysis, and application in the underdeveloped world at about its present level. Perhaps this is unduly pessimistic. The fact that the systems under consideration are not expected to be fully operating for a decade or more suggests that one should also make a guess about benefits to underdeveloped countries under the assumption that substantial improvements are made in data processing and analysis for underdeveloped countries. Again we are faced with sheer conjecture.

An extreme assumption would be that these developments proceed sufficiently far to make benefits to less-developed countries equal to those of developed countries. The range would then be $15-22. 5 million.

It must be noted that when one makes optimistic assumptions which will be realized only after considerable time, the future benefits should be appropriately discounted before being compared with costs that must be incurred at earlier dates.

5. 3. 3 Summary of Dollar Benefits for Agricultural Data

The following table summarizes our rough initial approximations of the benefits that one might expect from an agricultural collection system similar to the one under discussion.

	Millions of Dollars Annually
1. Benefits to developed countries in the form of replacement of old data	12-15
2. Benefits to developed countries in the form of new and improved data	3-7. 5
3. Benefits to the underdeveloped countries	3-22. 5
4. Range of total benefits	18 -45

5.3.4 Benefits to Forestry, Range, Recreation, and Wildlife Management

The benefits of SERI to forestry, range, recreation, and wildlife management activities have been estimated by methods similar to those used above for agriculture. The potential benefits from SERI are assumed to have value equal to the expenditures now being made or planned to be made to obtain the same information by conventional methods. To this is added the value of new information not now being gathered but which SERI will provide and which can be expected to have utility. The two principal kinds of numerical data used for these estimates were variable costs per acre of the several activities to be replaced by the SERI system and the acres of forest or other land classes by country or by continent.

Numerous state and federal agencies and private institutions, companies, and individuals collect information about forestry and related wildland resources We have limited this analysis of benefits to those who are directly involved and make or plan to make expenditures for collecting data similar to those expected from SERI. At the federal level, the agencies considered in this estimate are as follows:

- Department of Agriculture
  - U.S. Forest Service
  - Soil Conservation Service
- Department of Interior
  - Bureau of Land Management
  - National Park Service
  - Fish and Wildlife Service
  - Bureau of Outdoor Recreation
  - Bureau of Indian Affairs
  - Bureau of Reclamation

- Tennessee Valley Authority

These agencies use information for three purposes: to disseminate as a public service, as a basis for policy making and program planning, and as a basis for action programs on public lands such as national forests or on public resources such as ducks and geese. The U.S. Forest Service, for example, uses timber-resource information for all three purposes. Its Forest Survey inventories and reports periodically on the total U.S. timber-resource situation. The Forest Service uses this same information to plan programs of assistance to forest-land owners and to conduct research. The national forests are protected and managed by the U.S. Forest Service, and it conducts inventories and gathers other information to carry out action programs on these lands. Other federal agencies make similar use of resource information of the type to be produced by SERI for the United States.

Each forested state has one or more agencies involved in wildland resource data collection and/or protection and management. Large forest- and range- land owners and universities were also considered in estimating expenditures for information.

The types of information to be collected and reported by SERI have been described earlier. The nature, accuracy, and suitability of the information expected from SERI were estimated for the performance expected of (GLU) and of SERI, respectively. This was necessary because SERI is expected to perform much better than GLU which will use the present state of the art for satellite and sensors.

Information on current and planned expenditures was obtained from the various agencies. Judgment estimates were made of the portion of the expenditures for aerial photography, photo interpretation, photo map making, and so forth.

The total U. S. expenditures for forestry and related information that could be obtained by GLU (hard-copy photos to users) for publishing and for protection and management activities are estimated to be from $1 million to $2 million per year when the system becomes operable. When SERI becomes operable, it is estimated that it would provide information similar to that now collected by other means that is costing users from $5 million to $7 million per year to obtain under present methods.*

5. 3. 5 Expenditures for Forestry and Related Resource Information in North and South America

In the Western Hemisphere, SERI would provide information now being gathered by United Nations FAO, OAS, the countries, and by private companies or institutions. Canada and its provinces spend a considerable amount of effort in gathering timber-resources and related information, because forest land is such an important part of her economy. FAO has assisted several South and Central American countries in making initial inventories of their forest resources using aerial photography. These include Mexico, Panama, Ecuador, Colombia, Guatemala, Nicaragua, Paraguay, and Venezuela. These initial inventories include costly map making which will not have to be repeated when these countries are reinventoried 10 or 15 years from now. Similar synoptic information for making forest-type maps of the remaining nations will be needed when they are first inventoried. Subsequent inventories (by present methods) will be less expensive after the first forest-type maps are completed.

The total present expenditures for North and South America, including the United States, for information that could be supplied from GLU (hard-copy photos) is estimated to be from $2 million to $3. 5 million per year when the system becomes operable. When SERI becomes operable, it is estimated that it would provide information for North and South America that presently is costing $10 million to $12 million per year.

5. 4 Expenditures in the Rest of the World

In Europe the intensity of forest-land management and the ready accessibility of the forests leaves little to be gained by remote sensing from GLU or SERI. Some benefit was estimated in the analysis as the result of surveillance for protection and rapid assessment of losses under SERI.

In Africa, the FAO, U. S. AID program, the African nations, and private firms are now and will be making expenditures for information on forestry and related resources. As in the case of South America, the estimated future expenditures do not include the cost of forest-type maps and certain other aerial-photo uses for those areas already covered by a satisfactory

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*All benefit figures quoted for SERI represent totals for the system, not increments beyond those obtained from GLU.

first inventory. These will, of course, show benefits when reinventories are made at 10-15 year intervals. For countries not yet inventoried, expenditures were assumed to include forest-type mapping.

For Asia and the South Pacific areas, the same procedure used in South America and Africa was used to estimate the cost-value of information. Thus existing information for well-developed nations made the benefits of GLU very low, while the benefits to the developing nations were higher for that system. The Soviet Union (in both Europe and Asia) and China were excluded from this analysis on the assumption that the information was already available and that it was not financially feasible to transfer their expenditures as a "credit" to SERI.

The total present expenditures for the world (excluding the Soviet Union and China) for information that could be supplied if GLU were operational, is estimated to be \$4.5 million to \$5.5 million per year. When SERI becomes operable, it is estimated that it could provide information that is presently costing from \$13 million to \$18 million per year.

5.5 Benefits of New Information Not Now Being Obtained

In addition to supplying information of the kind now being obtained, both GLU and SERI will provide new information that will have value. The same agencies, institutions, companies, and individuals discussed above can be expected to pay for this additional information as a basis for increasing the efficiency and/or output of their particular products, be it information for others or hard goods and services from forests and related lands.

The new information will be of two types: a general kind of information about new or remote places and more detailed information about old places. As an example of the first type, GLU might provide general information on the extent of hardwoods in the Amazon area. Yet we already know more about hardwoods in the United States than GLU can provide. As an example of the second kind, SERI might provide information about forest-fire hazard in the United States not previously available by present methods.

In the absence of firm estimates of the resolution, definition and accuracy that GLU and SERI will be able to provide, and without any certain knowledge of the future needs for new information, it is difficult to estimate the value or benefit of such new information. For all the world we can guess that the dollar benefit probably is not more than the cost-value of expenditures for presently gathered information as estimated above. On this basis, the total benefits of SERI for the world would be the present expenditure for information (\$13 million to \$18 million), plus another \$13-18 million estimated value of new information, for a total of \$26 million to \$36 million per year when SERI becomes operational.

For the United States, where detailed information about the forests is already available, we estimate that new information will have somewhat less value. If new information were valued at 1/2 the value of current information the total benefit of SERI for the United States would be \$7.5-10.5 million dollars per year.

5.6 Relation of Assessment to Theory of Public Expenditures

The above evaluations can be crudely related to the theory of public expenditures as developed by Lindahl, Samuelson, Musgrave, and others (see the articles by Paul A. Samuelson in The Review of Economics and Statistics, November 1955 and November 1958 and the literature cited therein) by classifying agricultural and forestry information into relatively homogeneous types and regarding the flow of each type of information as a public commodity.

In this theory the basic difference between a public commodity (bridges, highways, public schools) and a private commodity (wheat, shirts, automobiles) is that each individual buys whatever amount he prefers of each private commodity at prevailing market prices while he has access to the same amount of each public commodity. For private commodities, the prices and quantities exchanged are determined by factors summarized in familiar supply-and-demand relations. For public commodities the government must reach a decision on the quantity to provide, and this is available to all users.

In discussing questions of public policy, economists have frequently found the concept of an "efficient allocation" of resources useful. The allocation of economic resources is said to be efficient if there is no possibility of improving the economic position of any one person in the economy without simultaneously damaging the position of another. In other words, all possibilities for economic benefit that do not simultaneously impose penalties on some members of society have been exploited. By using this concept of efficiency, economists are able to discuss efficient use of resources without raising questions of how economic benefit or income are to be distributed among individuals.

Samuelson has shown that to achieve an efficient allocation of resources in the above sense, the government must furnish that quantity of each public commodity that makes the marginal cost of the commodity (cost of providing one additional unit) equal to the sum of the marginal valuation of each individual. The marginal valuation of each individual is the amount he would just be willing to pay for an additional unit of the commodity if each could bargain separately for an additional unit.

For a commodity that is homogeneous and infinitely divisible, the determination of the efficient quantity may be represented diagrammatically as in Figure 1.5.1. Vertical units are dollars, horizontal units are of a

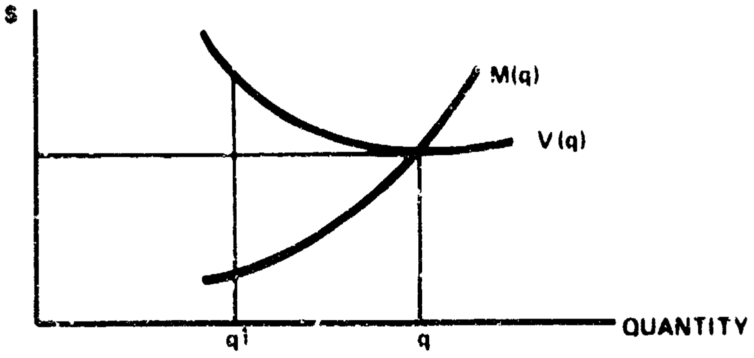

FIGURE 1.5.1. Determination of the efficient quantity.

public commodity. V(q) is a curve whose height above the Q-axis at any point is the sum of the individual valuations of an incremental unit assuming that the indicated quantity is already available. For $q > q^1$ it is usually assumed that $V(q) < V(q^1)$, since users are better supplied at q—their most pressing needs may already be filled. M(q) represents the marginal cost corresponding to each point on the Q-axis. At the point lettered q in the figure, it would cost the government as much to increase quantity as the sum of the individual valuations of the increase, so q is the efficient quantity.

Suppose an economy starts from the position of Figure 1.5.1 and then there is a technical improvement which makes it possible to lower the marginal cost curve as indicated by $M^1(q)$ in Figure 1.5.2.

If the government were to adopt the new technique and provide the new efficient quantity, q^{11}, a reasonable assessment of benefits of the change would seem to be the sum of shaded areas above $M^1(q)$. This would have to be compared with the cost of establishing the new technique to see if a change were desirable.

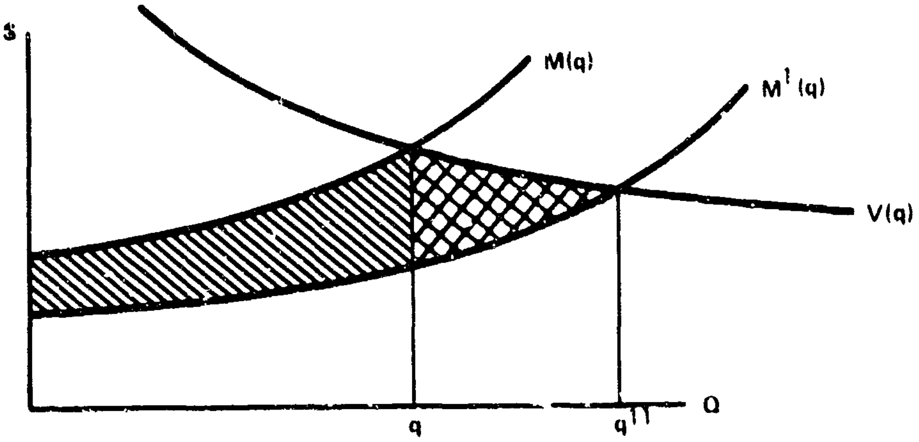

FIGURE 1.5.2 Effect of lower marginal cost.

The shaded area to the left of q represents the reduction in variable cost of furnishing the old quantity with the new technique, while the shaded area to the right represents gains due to the provision of an additional quantity. The latter represents the difference between what users would have been willing to pay if each unit increase could be negotiated separately with each user and the added cost to the government of increasing quantity from q to q^{11}.

The earth-resources information that we are considering is a public commodity, but the theory outlined above does not apply precisely because the information is not homogeneous (we know of no natural unit in which to measure the quantity) and not infinitely divisible (given a collection system, minute variations in quantity are not practical). Nevertheless, there is a fairly close analogy between the problem we have considered and the simplified theoretical problem sketched above. The shaded area to the left of q represents reduced expenditures in gathering existing types of data; that to the right of q represents benefits due to extensions. Figure 1.5.2 may depict reasonably well the result of shifting from traditional data gathering to sensors carried by aircraft or the shift from one aircraft system to a more efficient one. In considering a shift to a satellite system we have the further facts that, once the system has been instituted certain data may be gathered at negligible marginal costs, but increases beyond the capacity of the system are impossible or prohibitively expensive. Furthermore, only part of the original quantity is replaced by the new system and part is gathered by traditional means. The situation accompanying a shift to satellite sensing is shown therefore more accurately in Figure 1.5.3.

The theory could be elaborated to correspond more closely to the technical circumstances by formulating an algebraic version not dependent on diagrams. This would seem a possibility worth pursuing in more extensive studies of these problems.

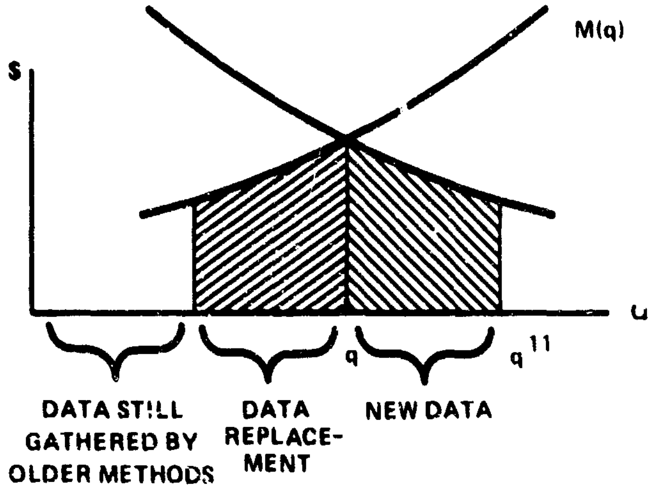

FIGURE 1.5.3 Effect of shift to satellite sensing.

5.7 An Alternative Analytical Tool

Another line of investigation worth considering is illustrated by the recent work of Griliches in assessing benefits of research and extension activity in U.S. agriculture. Griliches' first study was concerned with social returns to the research costs incurred in developing hybrid corn.* In this study, research expenditures on hybrid corn from 1910 to 1955 were arrived at via a mail survey and other data. Returns were estimated on the value of increased corn production adjusted for price changes. His procedure led to the estimate that at least 700 percent per year was being earned, as of 1955, on the average dollar invested in hybrid corn research.** In a later paper, Griliches presents an estimate of the rate of return to total research and extension expenditures in agriculture.*** Taking a different approach, Griliches estimated a production function for American agriculture based on state data on outputs and inputs for 3 years covered by the Agricultural Census. He included state agricultural research and extension expenditures in dollars as one of the inputs in the production process and concluded: "This finding implies the fantastically high gross rate of return of about 1300 percent for social investment in agricultural research and extension."****

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* Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 419-431, Oct. 1958.

** Griliches, ibid., p. 419.

*** Zvi Griliches, "Research Expenditures, Education and the Aggregate Agricultural Production Function," *The American Economic Review*, 961-974 (Dec. 1964).

**** Griliches ibid., p. 968. In qualifying the above statement, Griliches arrives at a 300 percent rate of return figure. -Ed.

It is somewhat unfair to the spirit and intent of the Griliches' papers to quote him out of context as in the above paragraph. A careful reading of his papers indicates that his purposes were in part to call attention to some major methodological gaps in economists' attitudes toward research and development. However, his results, even if discounted heavily, do lend a sanguinity to the benefits from past public expenditures on research in agricultural industry.

Further, the purpose of presenting Griliches' results is not to suggest that we could automatically expect comparable benefits from the data-collection system under discussion here. First, his results are descriptive of the past and in the case of hybrid corn were an investigation of a singularly successful public research venture whose payoff was somewhat obvious prior to the investigation. Second, the later study is quite aggregative in nature, tending to treat together public research and extension expenditures which surely include some specific instances of bad investments. However, Griliches' studies lend credibility to the notion that there may occur substantial returns to public investments in a rather broad sense.

To apply this approach to the problem of satellite sensing one would have to classify kinds of information developed in the past into more homogeneous inputs and associate potential productivity of sensor-gathered information with the historical types with which it is closely comparable.

APPENDIX A

OPERATIONAL AND STATISTICAL USE OF A SYSTEM FOR EARTH RESOURCES BY FARMERS AND RANCHERS

T. J. Army and J. Ralph Shay

Need for global agricultural statistics, crop-yield forecasts, and land-use evaluation by governmental and international agencies has been well defined. The value to the producers and agriculture business is often overlooked.

During the next decade, concomitant with the development of SERI, domestic agriculture will continue to undergo rather drastic change. These changes all suggest larger units, more capital investments per farm, and a highly sophisticated, technologically oriented business approach to crop production. The farmer will become more of a manager than an operator.

With greater capital investment and increased technological inputs, risk will be materially increased. Timing of operations such as planting, pest control, and harvesting becomes critical where cost inputs are high and maximization of profits is needed. Timely, accurate information on crop and weather conditions and forecasts of weather and pest infestations will be required to minimize these risks. A System for Earth-Resources Information (SERI) with current inputs of the satellite weather systems could supply much of the data and interpretive reports needed by the managers of American agriculture for production stability and risk minimization.

A. 1 General Economic Facts of American Agriculture

At the present time 30% of the U.S. farms now have gross sales of $10,000 a year or more. They account for 80% of the nation's food and fiber control 60% of the cropland, and buy 70% of the farm supplies. The larger farms, 13% of the total, have gross sales of over $20,000 and account for over 55% of the total farm sales; they control 40% of the cropland and purchase 45% of the farm supplies. Specialists project that over 50% of the farms will fall into this category by 1980. Commercial farmers today are highly efficient, profit-oriented businessmen. They are substituting, at an increasing rate, capital for labor, and their efficiency must be continuously improved.

A. 2 Remote-Sensing Production Operations

Operational information from aircraft and from space pertaining to the five following key operations, or major decision points in a commercial crop-producing unit, would be of value. Specific operational inputs would be related to advanced weather information at SERI.

1. Land preparation: Moisture conditions—present and expected—are critical to prevent adverse effects on soil structure and to minimize erosion by wind and water in some areas.
2. Planting operations: Both moisture and temperature prior to and following a seeding operation are critical to stand establishment. All crops are influenced to some degree but some like cotton and small-seeded vegetables are more sensitive than others like corn or wheat.
3. Pest-control operations: Advanced agriculture is moving toward the production of food and fiber in a pest-free environment. Systemic insect and nematode-control chemicals are under development in public and private laboratories. Preplant herbicides are already in common usage. These are designed to give maximum weed control through critical stages in crop development.

The effectiveness of this higher-cost technology is often governed by moisture and temperature prior to and after incorporation into the soil or application to the plants. Early detection of pest problems is an absolute necessity. Research on spectral signatures of diseased versus healthy crops suggests that early detection via remote sensing is feasible.

4. Fertilization: Farmers are moving toward heavy application rates of bulk-applied fertilizer materials. These are usually applied prior to planting in large tonnages by large heavy trucks or tractor-drawn distributors. Soil-moisture conditions are critical if serious soil compaction or bogging down of equipment is to be prevented.

A 2-week weather forecast is considered desirable for effective scheduling of equipment.

Micronutrient deficiencies (Zn, Cu, and, for example, B) are becoming increasingly important as the application of major nutrients (N, P, K) is increased. Remote sensing could lead to early detection of micronutrient needs and permit remedial applications to the growing crops.

5. Harvesting: Serious damage and financial loss often occurs at or prior to harvesting. Many of these could not be eliminated or even minimized by advanced crop-condition reports. However, crop-condition reports prior to harvest and expected weather, especially moisture, would permit greater flexibility in harvesting operations and could minimize losses in a multicrop farm operation. Hail is also a particularly important contributor to crop loss, especially as the crop approaches maturity. It appears that weather modification offers the possibility of hail control or minimization of storm severity. Hail suppression would find immediate use in much of the Great Plains and in some fruit-producing areas.

Similar operational information will be needed by agriculture in developing countries as their agriculture moves from a subsistence level to a commercial structure. In fact, such operational inputs could hasten the conversion to commercial agriculture in politically and socially favorable national environments.

The use of remote-sensing techniques for on-site use (a fallout from space technology) by individual operators also offers opportunities for development of new management tools, for example, irrigation needs and pest problems. If the nutritional status of specific fields could be continuously or periodically monitored with sensing devices located adjacent to the growing crop, data could be transmitted to a central control unit for use in managing the crop-production unit.

A. 3 Remote Sensing for Statistical Information

Profits from any business, including agriculture, are a function of two quantities—the profit per unit sold and the total number of units sold. The extent to which the American farmer can increase his production at a profit depends not only upon domestic and foreign markets, but also on competitive foreign production. With the assistance of government, state, and private agencies, he must be able to interpret and relate events in distant lands to his own farm operation. Examples of such needed advance interpretation are the impact of Puerto Rican pineapples on Hawaiian farmers, African tobacco production on farmers in our Southeast, and the now increasing production in oil-seed crops in Russia and other countries that will compete in the world markets.

The proposed System of Earth-Resources Information would be aware of and keep domestic producers informed of all foreign competition, progress, and reorientation in crop production, including crop failures or bumper yields that would affect domestic planting. The information from SERI could be channeled through conventional government agencies, but it should be obvious that new techniques for data processing to ensure timely communication will have to be developed.

The list of crops to be monitored via remote sensing are listed in Table 1. A. 1. Initially only the most important food crops--wheat, corn, rice, soybeans (because of export value also)—need to be monitored, but the list would be expected to expand as technology developed.

Remote sensing in determining these crop species (corn, wheat, alfalfa, and others) and status or vigor of crops as influenced by disease, weed infestation, drought, and other phenomena causing crop loss should be designed from the outset to take advantage of all phenomena associated with the objects to be sensed. These provide significant discrimination clues and valuable decision data.

A. 3. 1 Stages in the Developmental Cycle of the Crop

Annual spring-planted crops are planted at times appropriate to their requirement for soil temperature and moisture. Seedlings emerge and development proceeds so that within 4 to 5 weeks the crop covers about 1/4 of the area of the soil. During this early period the spectral characteristics of the soil predominate, whereas from this point on to the harvest the characteristics of the crop predominate. The crop spectral characteristics may change markedly with onset of flowering, fruit maturity, senescense, and harvest. Similar periodicities occur in perennial crops, particularly during foliation, flowering, and maturation. Blossoming of fruit orchards is a dramatic example. It is obvious that a single multispectral signature for a given crop is useful only for the developmental stage in which it is measured, and that signature will change continuously during the season. However, it also follows that such changes may provide a period in which the spectral signature is unique such as the bright green in early spring, of winter-planted cereals

TABLE 1. A. 1

HARVESTED AREA OF PRINCIPAL CROPS OF THE WORLD

Crop	Area	Share of Total Cultivated Area
	(millions of acres)	(percent)
Grains	1, 628	71.2
Wheat	506	22.1
Rice	290	12.7
Corn	261	11.4
Millet and sorghum	231	10.1
Barley	150	6.6
Oats	114	5.0
Rye	76	3.3
Oilseeds	164	7.2
Soybeans	52	2.3
Peanuts	36	1.6
Rapeseeds	20	0.9
Sunflowers	17	0.7
Sesame	12	0.5
Copra	12	0.5
Castor beans	3	0.1
Palm kernels	12	0.6
Roots and Tubers	115	5.0
Potatoes	61	2.7
Sweet potatoes and yams	36	1.5
Cassava	18	0.8
Pulses	111	4.9
Fibers	108	4.7
Cotton	82	3.6
Flax	19	0.8
Jute	5	0.2
Hemp	2	0.1
Fruits and Vegetables	84	3.7
Sugar	34	1.5
Sugarcane	18	0.8
Sugar beets	16	0.7
Beverage Crops	23	1.0
Coffee	17	0.7
Cocoa	4	0.2
Tea	2	0.1
Tobacco	9	0.4
Rubber	9.7	0.4

against the brown of all other vegetation; the progression bloom of plum, pear, and apple orchards; the tasseling of corn in early August, the yellow flowers of wild mustard weed in grainfields, and others. Sensing measurements at these times can be nearly absolute in accuracy.

A. 3. 2 Weather Extremes

Year-round repetitive observations on a daily schedule can take full advantage of unusual events to improve accuracy of basic data on a crop-production region. Bright weather immediately following a blizzard or very heavy snowfall displays all brush and tree-covered drainage ways in sharp contrast to crop and pasture areas. Ratios of wooded lands to tillable acres determined at these times would be highly accurate. Intense and heavy rainstorms on level lands contribute to ponding in low areas of fields. The location and extent of these areas can be readily plotted due to the spectral contrast between pond water and wet soil. Cumulative data on crop losses from drowning can provide economic data for decision on correction through land leveling or improvement of regional ditch-drainage networks.

A. 3. 3 Sun Angle and Polarization

A space platform in geosynchronous orbit would provide for frequent daily observations of crop areas and make maximum use of sun-angle effects on spectral signatures of crops. These effects would likely vary in degree with crop geometry. Polarization properties of crops may be important in discrimination. Instruments designed to measure polarization can take advantage of these characteristics.

APPENDIX B

Four brief papers which examine various aspects of the possible importance of remote sensing in urban and regional planning

Other references of interest:

Barraclough and Rosenberg, "The Ault System," Photogrammetric Engineering, September 1966 (pp 842 et seq).

"A Sinister Urban Crisis" (Calcutta), New York Times, July 17 1968

EXAMPLES OF URBAN AND REGIONAL PLANNING REQUIREMENTS FOR REMOTE SENSING

R. Keith Arnold
University of Michigan

Following are examples of urban and regional planning and urban problems which illustrate the complexity, as well as the many interactions, of man and environment which are becoming increasingly critical in today's society. These examples are from an almost unlimited array of urban problems, regional problems and programs, rural-urban interactions—all involving the quality of environment—which require new, synoptic, timely data.

Proceedings of the Federal Mapping Coordinating Conference* highlight many areas which suffer from lack of synoptic data—particularly in map form. A small sample of examples follows:

"In Appalachia. . . our next greatest need is for flood-plain mapping" (p 17)

"There are billions of dollars of Federal Funds distributed on the basis of Census results, and our data collection program for 1970 is intended to provide the kind of information for this. In order to do an adequate job, we need a set of accurate maps—certainly a lot better than we have ever had in the past" (page 24)

"Riot control and civil defense together represent a major requirement for having our urban area maps up to date." (page 27)

"Urban development is galloping headlong so fast that it will be a monumental task to keep them (maps) up to date" (page 30)

"We need mapping in all areas of the United States. It follows that our pressing need is for completion of the coverage of the United States, and secondly for the updating of that coverage." (page 37)

Other specific examples are found in the articles copied below, which describe the complexity of transportation and land-development data.

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* Proceedings of the Federal Mapping Coordinating Conference. Sept 18-19, 1967. Washington, D. C., U. S. D. I. Geological Survey.

THE INFINITE VARIETY OF LAND RESOURCES*

(an expanded summary)

William A. Fischer
U. S. Geological Survey

For all resources, expansion in effective use depends on enlarged knowledge of their distribution and character. Just to maintain the United States and world economies at their present levels requires continued discovery and development of new resources. During the last 30 years, the United States alone used more minerals and fuels than did the entire world in all previous history, and it will double its present consumption of most minerals within 15-25 years. The supply problem is literally compounding with growth in population and rise in per capita consumption of raw materials and energy.

To match the acceleration in demand for resources, the means must be found to accelerate acquisition of knowledge concerning them. The development of aerial photography and of airborne geophysical surveying techniques has already increased the rate at which new knowledge of the world's resources can be acquired, but even with far wider use of presently available methods, the work cannot progress in pace with needs. Fortunately, it appears that the acceleration required can be obtained through the use of "remote sensing" devices mounted in satellites, provided that means may be found to reduce the data in an efficient and expeditious manner.

Maps are fundamental to all resource investigations; small-scale (1:250,000 and smaller) maps are essential in regional land-use inventory and planning, and in the study of distributions of gross features, such as large cities or major structural features.

The compilation of small-scale maps by current practice is a slow, laborious process of assembling thousands of observations and subjecting them to photogrammetric processing. As a result, small-scale maps are neither uniform nor timely—in fact, today 70% of the world's maps (at scales of 1:600,000 or smaller) are judged inadequate and the remaining 30% are obsolete (Doyle, 1967).

"Orbital" photographs of proper design are near-orthographic—in effect, they are "instant planimetric maps" and require no complex photogrammetric processing. It is this quality of near-orthography, coupled with the great speed of spacecraft, that opens to the earth scientist a new vista of resources surveys.

It is not unusual for compilation of a 1:1,000,000 scale map to take 10 years or longer; assembly of "space photos" (from a properly designed system) into an equivalent-area map format would take perhaps 10 minutes, and the space-photo map would contain much more detail, be more accurate, and up to date. These qualities are not achievable for conventional maps as they are prepared today.

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*Presented at IEEE International Convention - March 1968

The quality of near-orthography coupled with the great speed of spacecraft makes it possible for earth scientists to have up-to-date base maps and to include distributions of dynamic features.

Maps of dynamic features are the key to most benefits that will befall the resources community from our space program. They will include:

- maps of land use—compiled on an annual basis—for analysis of changes in land use and land-use planning.
- hydrologic maps showing the distribution of water and snow—as required for hydroelectric, irrigation, and waterfowl management and for study of anomalous snow-melt patterns as they relate to geothermal structure.
- maps of timber distributions and vigor for forest-management purposes.
- maps of range condition to help in range management and conservation.
- maps of effluent discharge into estuaries to aid the shellfish industry and help in design of pollution-abatement systems.
- maps of agricultural crops to aid in agricultural management and crop-yield predictions, and
- maps of wilderness areas, National Parks, National Seashores, and other recreation areas, to aid in assessing their use and in their conservation.

From a purely technical standpoint, all of these resource products, and more, are possible. Most, but not all, could be accomplished from aircraft data as well as spacecraft data. From an economic standpoint, however, space systems are the only practical way to meet the need for timely small-scale maps. The table, below, (Table 1. B. 1) suggests appropriate applications for both aircraft and spacecraft and contrasts the cost of a survey of North and South America by both methods.

I believe we may safely conclude that there is a need for timely resources surveys and that space observations offer potential for fulfilling this need. To my mind, however, we have but scratched the surface with respect to the contributions our technology can make toward effective use of the data. An examination of space as a vantage point for earth observations clearly demonstrates that space data are not only geometrically superior to aircraft data, for many mapping purposes, but they are also more uniform and repeatable. These qualities open the door to a host of automatic-processing and interpretation techniques that are difficult or impossible to apply to aerial observations—this is an area of opportunity and a challange for the combined effort of electronics scientists and earth scientists.

Reference

Doyle, Frederick J., 1967, Mapping of the land from space: 13th Annual Meeting, American Astronautical Society, May 1967

TABLE 1.B.1

COMPARISON OF AIRCRAFT AND SPACE SENSING DATA-GATHERING TECHNOLOGY

Altitude of Sensor Increases ↑

	Distinctive Characteristics	Example of Application	Cost of Data Collection (Land Areas of the Western Hemisphere)	Cost of Data Reduction and Compilation (Land Areas of Western Hemisphere)
Space Sensing	Coverage of large areas. Ease of repeated surveys for large areas. Effective use of narrow angle-of-view sensors. Reduction of variables within single observations.	Land-use map of North America. Grazing land surveys on public lands. Mapping of regional hydrologic features. Observation of regional dynamic features such as coastlines. Small-scale thematic maps such as forest types, soil, etc.	$30,000,000 Est. Cost of ERTS Satellite	$2000-printing 2000 photos $20,000-making mosaics $160,000-interpretation for a single purpose @ 1¢/sq. mi. (Average) Est. time for map completion 1-2 yrs.
High Altitude Aircraft Sensing Low Altitude Aircraft Sensing	Very high resolution for detailed mapping. Experimental Development of sensing instruments.	Standard large-scale topographic mapping. Detailed urban planning surveys. Spot surveys of specific problem areas. Detailed sensing of "Target" areas identified by space sensing.	$70,000,000-obtaining Black/White aerial photography (one time)	$2,700,000-printing 2,700,000 photos. $130,000,000-making orthophoto mosaics $160,000,000-interpretation for a single purpose @ $1.50/sq. mi. (Average) Est. time for map completion (Based on air survey experience in Latin America since 1944) 40 yrs.

EVALUATION OF PHOTO-MOSAIC OF WESTERN PERU

Edward M. Risley

Division of Earth Sciences
National Research Council

The Interagency Report NASA-87 "A Photo-Mosaic of Western Peru from Gemini Photography" has been reviewed by staff in the Division of Earth Sciences. It has also been commented on extensively by Division contacts in universities and industry and by representatives of National Research Council affiliates. The following observations summarize reactions to the referenced report and map.

The Peru mosaic is the first tangible evidence of the new facility for earth observation and mapping presented by the availability of spacecraft. It is reasonable to describe this photo-mosaic map as representing a breakthrough in cartography. For the first time, metric and other types of cameras can be used to photograph large areas from very high altitudes, thus permitting the use of narrow angles of view. This unique vantage point allows the acquisition of completely new data presented in a format comparable to small- and medium-scale maps. In actuality, the result is a photomap. The referenced photo-mosaic is a first example of a new means of obtaining large quantities of terrestrial data and displaying it with cartographic precision. There seems no reason why this technique should not be elaborated and further employed in the next few years. Within the decade, space-acquired mapping photography will almost certainly become a most important tool of many of the earth sciences.

The Gemini photography possesses built-in limitations which severely restrict its use in preparing a photo-mosaic map. The chart of Peru shows limitations caused by such factors as a choice of orbits, which presented a poor sun angle over much of the area covered. However, the U. S. Geological Survey, the contractor, and the cooperating U. S. Army mapping center are to be congratulated for the rectification and correlation task which they performed successfully using source material which was not designed for mapping purposes.

The report briefly but accurately describes the principal uses of small-scale photo-mosaic maps used to supplement now conventional aerial and surface-surveying and data-collection methods. The synoptic view provides a new overview of major topographic and geologic features. The report does not attempt to take the next step and point out the applications of some of these data. Improved delineation of fault structures has obvious use in mineral prospecting. Knowledge of snow-cover extent at any given time is critical to calculations of future run-off and water supply. The examples are numerous. Geographers, for example, believe that maps of this character will permit far more accurate description of land-use areas and more timely knowledge of changes in human-occupance patterns.

Interest in the field of remote sensing of environment from space has been developing over the past several years based in part on detailed investigations conducted by committees of the Division of Earth Sciences, such as those advisory to the U.S. Geological Survey and ESSA, and to study efforts performed for panels on geography, oceanography and other earths science disciplines. However, until the availability of the Peru photo-mosaic, real data have been lacking. The interest of researchers has noticeably picked up following briefings based on this map and report. Response has been widespread and enthusiastic among professional societies associated with the Division. For example, the Association of American Geographers has established a Commission on Remote Sensing which has been impressed by the possibilities for geographic research using this type of map.

The Director of the American Geographical Society, which has recently completed a map series of South America at scale of 1:1 million, noted that their time-consuming and expensive compilation job could have been significantly advanced by space photography. He also stated that the AGS map of Lake Titicaca is incorrect, a fact that became apparent only upon receipt of the rectified Gemini photography. Finally, an officer of the American Society of Photogrammetry pointed out that just as the transition from ground to aircraft survey during the past 20 years has revolutionized mapping speed and accuracy, so the next step to space can be expected to similarly advance their science. These three professional societies are all members of the National Research Council and represent a sampling of views.

In reviewing the report and in consulting with other earth scientists on the attributes of the Peru photo-mosaic, a number of observations were made which are summarized here.

1. The Peru sample demonstrates the desirability of obtaining coverage of the earth's land masses with photography convertible to maps at the scale of 1:1 million. The less-accessible portions such as the polar regions might be designated as first priority.

2. The greatest advantage of cartography from space will most likely be realized by photography suitable for maps at the medium scale of 1:250,000. A single series of maps based on up-to-date compatible (uniform source) data at this scale would be of inestimable value.

3. Studies show that the 70-mm Hasselblad camera should be replaced in future space flights by somewhat longer-focal-length cameras. Adequate 6-in and 12-in metric cameras are available to provide base maps of suitable accuracy, and improved-resolution TV cameras may be employed in long-life satellites to facilitate updating of thematic content.

4. Commentators have generally agreed that the Peru photo-mosaic would be useful as a new view, especially as periodically updated, of the United States. Applications would include both the service functions normally provided by government mapping agencies as well as a data source for private industry such as mineral- and oil-exploration companies. Maps of this type would also greatly improve the efficiency of U. S. programs for aid to less-developed countries where current maps are frequently inadequate or unobtainable.

5. The fact that the President of Peru has responded favorably to a presentation of the photo-mosaic of his country is believed, by some, to point the way towards achieving general political acceptability of mapping from space. From this example it seems evident that small- and (subsequently)

medium-scale maps will not pose serious problems such as claims of invasion of privacy. Certainly this material does not expose information of military value.

6. Members of the various professions making up the earth sciences were consulted on the general value of this type of data. Numerous practical advantages were pointed out, such as the value of accurate maps containing a high concentration of content directly exploitable for economic purposes. They also pointed out that, in addition (and of possibly even greater importance), the satellite approach for earth observations has value for science. This may be the only feasible means for obtaining global information necessary for studies of the world water balance, for example.

7. There has been a unanimous reaction to the Peru photo-mosaic among earth scientists that a systematic program for obtaining broad-area coverage should be instituted. The costs of such a program should be modest since only small automated satellites are required and the returns would be large, diverse and, in many instances, of unique character.

From inquiry both within the Division and in consultation with normal Division contacts it has been ascertained that space photography suitable for mapping has great potential value. The Peru example is considered impressive, even though based on photographs taken for pictorial purposes. In view of demonstrated state of the art and with the knowledge of marked improvements possible in the quality of future imagery, it is concluded that the U. S. Geological Survey, in collaboration with other agencies of the Government, should plan to obtain additional experience in acquiring and handling space photography for mapping. It is strongly recommended that the U. S. Geological Survey support the necessary steps to carry out a strong and unclassified program of mapping based on the use of satellites.

REMOTE SENSING - CROP PRODUCTION

T. J. Army and R. O. Aines
Growth Sciences Center
International Minerals & Chemical Corporation
Libertyville, Illinois

Users

1. Farmer

Need for better information systems becomes more critical as agriculture continues to move toward larger units, with greater utilization of technology and increased substitution of capital for labor.

The producer will use the information as a basis for decision in:

a. farming operations - includes weather effects
b. business management - crop types, market demands, prices, etc.
c. hedging in futures markets - future markets are already an important part of the operations of the larger units.

2. Agribusiness

This whole business complex is closely tied to the producer. Vertical integration is increasing (directly or indirectly) rather rapidly. The trend is to make the producer, the farmer, part of the overall input-output business enterprise.

The components of agribusiness now utilizing or requiring statistical information and condition reports are:

Suppliers of farm inputs -
    Machinery
    Seed
    Fertilizers
    Chemicals (pesticides, growth regulators, etc.)
    Petroleum
    Power (electric, gas)
    Finance (credit)
    Transportation
    Customer services (contract land preparation, pest control, harvesting)

Processors and handlers of farm products -
    Grain storage operators
    Livestock processors and Creameries (Relate directly and indirectly to crop production)
    Fruit and vegetable processors (canners, freezers, oil seeds, etc.)

Transportation
Commodity specialists

Transportation
Railroads
Trucks
Barge, ship
Air (this is expected to expand very rapidly and could materially change crop production in many areas now considered too far from the centers of population.)
Pipeline

Marketing organizations
Farmer marketing groups
Contract buyers
Retail distributors (food chains)
Commodity and future markets
Commodity analysts
Financial institutions

3. Public agencies (government, academic, international)

Regulatory functions
Research and extension
Planning functions
Security (Dept. of Defense)
Statistical reporting and estimating (crop reporting and census)

4. Private agencies (academic, foundations, consulting firms)

Research and extension functions
Planning
Teaching

Hierarchy of users

1. Public agencies
    a. Statistical reporting and estimating (crop reporting and census)
    b. Planning and regulatory (farm production control and defense)
    c. Research extension, conservation

2. Farmers (food and fiber producers)

Their needs and use of information are directly related to agri-business. Increasing specialization and vertical integration of inputs, production, and marketing of products is taking place rapidly in American agriculture.

3. Agribusiness

   a. Farm commodity and future markets
   b. Farm product storage, handling, processing
   c. Transportation
   d. Suppliers of farm inputs (chemicals and credit)

4. Other groups

   a. Research, development, teaching, planning, consulting, etc. - national and international in scope

Sophistication level

There is a breakdown in sophistication level. In general, the degree of sophistication in data accumulation and applications needed parallels the "hierarchy of users."

Breakdown by time scale in evolution application

Crop-production areas

Weekly basis during planting and harvesting seasons
Bimonthly during growing season
Crop information should be related to livestock operations on a monthly basis during grazing period. Bimonthly during critical periods
It is also assumed that weather reports with appropriate agricultural implications and warnings will be issued on a timely basis for all of agriculture.

Users' needs (type of information required)

1. Measurement of:

   a. Environmental items to be reported

      subsoil moisture
      topsoil moisture
      soil temperature
      air temperature
      precipitation
      winds
      sunshine
      winter snow cover
      depth of frost

   b. Operational and crop-condition information to be reported

      harvesting
      plowing
      land preparation
      seeding and crop identification
      stage of vegetative growth

weed, insect-disease infestation
drought conditions
crop mortality
severe storms
stage of maturity

2. Use.

The accurate measurement and reporting of this data would be used on a continuing basis to: (1) identify, define and describe the environmental factors that influence the demand for fertilizer and other farm supplies; (2) establish relationships between changes in these varibles and fertilizer consumption; and (3) facilitate projecting demand and gearing production, shipment, and sales to better serve the market.

3. Data form.

The data should be in a form that can be fed into the users' computers for analyses and interpretation specifically related to that users' interest and business needs. The basic data would eventually be expressed and disseminated in several forms.

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Under the terms of its Congressional charter the Academy is also called upon to act as an official—yet independent—adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

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Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

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