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PEACEFUL USES OF EARTH-OBSERVATION SPACECRAFT

Volume II: Survey of Applications and Benefits

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Infrared and Optical Sensor Laboratory
Willow Run Laboratories
THE INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

PREFACE

A major objective of programs of the National Aeronautics and Space Administration is to investigate and implement the adaptation of space technology for peaceful uses. As a part of one program, the Federal Systems Division of the International Business Machines Corporation has conducted a comprehensive study of the requirements for conducting an integrated set of experiments in a series of manned earth-orbiting laboratories which would lead to the realization of such peaceful uses of space. The Willow Run Laboratories of The University of Michigan's Institute of Science and Technology was asked to assist in this work and, as a subcontractor to IBM, has conducted a three-month study to survey potential applications of observation spacecraft in a number of important scientific and economic activities and to consider the program of ground-based and orbital experimentation required to develop this capability.

The results of the first phase of this investigation conducted by the Willow Run Laboratories are reported in this three-volume report. Volume I is an introduction and summary of the work performed. Volume II contains a comprehensive survey of potential applications of earth-observation spacecraft and the anticipated benefits. Volume III describes some of the requirements to be met by the orbital sensing devices and the manned earth-orbiting experiments proposed for developing the orbital sensing capability.

This investigation was conducted by the Infrared and Optical Sensor Laboratory under the supervision of Mr. M R. Holter, Head of the Laboratory, and Mr. D. S. Lowe, Principal Investigator. Staff members with major responsibility for the project were I. J. Sattinger, Research Engineer and Project Leader, and F. C. Polcyn, Associate Research Engineer and Project Leader for Experiment Definition Studies.

Since the material in this report was produced through the efforts of people in many disciplines with only a limited time available, the statements made herein are based on their judgments and do not necessarily reflect the endorsement of NASA, IBM, or The University of Michigan. Acknowledgment of the work of the many individuals who participated in or contributed to this study are included in the appendix to Volume I.

ABSTRACT

Earth-observation spacecraft have many potential applications in the fields of geography, agriculture, forestry, hydrology, wildlife management, oceanography, geology, air pollution, and archaeology. Substantial scientific and economic benefits could result from the use of sensors carried aboard earth-orbiting spacecraft for earth mapping, collection of agricultural census data, forest inventory, wildlife habitat assessment, detection of sea ice, measurement of sea surface temperatures, and many other uses.

Types of sensors to be considered for these purposes include photographic cameras with focal lengths ranging from 0.5 to 20 ft, infrared scanners, multispectral sensing systems, noncoherent and synthetic-aperture radar, microwave radiometers, and laser altimeters. The development of operational systems of observation spacecraft would require a research and development program which included preliminary ground-based and airborne experiments followed by a series of manned earth-orbiting experiments. The preliminary experiments would provide information on sensor characteristics and capabilities for observing natural and cultural phenomena on the earth's surface which would be necessary for design of experimental orbiting sensors and planning of orbital experiments. The objective of the manned earth-orbiting experiments would be to ascertain the optimum conditions for sensor operation and to demonstrate the feasibility of future operational systems. In the manned earth-orbiting experiments, predicted characteristics of the atmosphere would be checked, individual sensors calibrated, sensor performance measured, and imagery and other data collected over both land and water, which would be analyzed to determine the feasibility of detection and identification of earth-based objects and the best methods for employing future operational earth-observation spacecraft.

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1 INTRODUCTION

1.1. BACKGROUND

The use of earth-orbiting satellites as platforms for remote sensing of the earth's surface has unique advantages over the more conventional ground-based or airborne methods of observation. Because of the great altitude and rapid movement of the satellite, it can be used to observe large areas of the earth's surface in a relatively short time and at moderate expense. Detailed studies are therefore being made at the present time by public and private organizations, under the aegis of the National Aeronautics and Space Administration, to consider the potential applications of observation spacecraft for both scientific and economic purposes, and to define the experimental program which would be required to achieve the technical capability for earth observation to fulfill these applications.

1.2. OUTLINE OF STUDY PROGRAM

The Willow Run Laboratories of The University of Michigan's Institute of Science and Technology has been engaged in this study program as a subcontractor to the Federal Systems Division of the International Business Machines Corporation. The results of the investigation by Willow Run Laboratories have been documented in this report, of which this is Volume II.

The other volumes of this report provide detailed treatments of other aspects of the study. Volume I presents an over-all summary of the work performed. A major portion of the project, reported in Volume III, was directed toward the selection of types and characteristics of sensors to be included in future experimental and operational spacecraft. Preliminary studies were also made of the pre-orbital and orbital experiments which would be required to develop an operational capability.

This report is devoted to a detailed discussion of possible applications for observation spacecraft in many technical and scientific fields. For each field discussed, the current state of development is described and the major existing problems are reviewed with particular attention to those problems in which the need for improved data collection is evident. This is followed by a detailed discussion of a number of applications of orbital sensing techniques to the acquisition of needed data, with estimates of resolution, repetition frequency, and other performance requirements placed on the sensing devices. For some of the applications, qualitative and quantitative statements are presented giving the estimated value of anticipated benefits.

Applications of observation spacecraft to the field of geographic studies are discussed first, since this discipline provides a broad overview of the subjects treated in later sections.

2
GEOGRAPHY

2.1. INTRODUCTION

This section discusses the significance to geographical research of observation spacecraft and the data they are capable of gathering relating to earth surface features and earth environments.

2.1.1. SUBJECT AREAS OF INTEREST IN GEOGRAPHICAL RESEARCH. Geography is the study of systems of interaction between man and his environment, between groups of animals, and between related human activities. It is also concerned with the interplay of these systems and the extent of the interaction manifested in the spatial distribution and patterning of phenomena (land use, transportation networks, settlement patterns, etc.) over the face of the earth.

The primary point of view of geographers is spatial. Relative position, arrangements, densities, and edges or boundaries are the static manifestations of the pertinent variables for many phenomena in any geographical problem. Examples of elements investigated include city shapes, region-wide natural vegetation zones, transportation lines or rivers, cropping patterns, population distribution and so forth. Table I suggests this classification of phenomena. At any chosen scale, decisions must be made regarding the sorts of information necessary to the study. These include consideration of site, situation, movement, and dimensional exchange. In-place characteristics such as topography, soil type, and resource endowment are referred to as site elements. Situation involves the relative position and interrelationship of elements in the landscape.

Dynamics enter the study of geography by pragmatic observation of movement and dimensional exchange. Dimensional exchange refers to the manner in which, for example, a real phenomena such as food production units are linked with points of consumption such as cities or export points. The observable pattern and intensity of such a dynamic system is a spatial expression of the human organization present. Information on the topology and intensity of such movement patterns may be available by remote sensing at lower cost than by other methods for many parts of the earth.

Some general themes in geographic literature suggest remote sensing applications. One such topic is the study of diffusion of an innovation from a community to a region. If the innovation is a new land use type or other such visible phenomena, it may be observable by remote sensors.

TABLE I. THE SCALE AND DIMENSION OF GEOGRAPHICAL PHENOMENA

Dimension \ Scale:	Local	Regional	Global
Point	house	town	city
Line	path	road	river
Area	field	cropping system	vegetation type

Other geographic phenomena in this same potentially observable class include the pattern of regional transportation systems including topological properties, such as density in area and total length; and dynamic properties, such as periodicity and intensity of flow.

Population distribution may be studied through related observable phenomena such as land-use patterns and possibly even man-induced energy emission. Many geographical problems deal with changes in the distribution over time of the elements described above. Periodic, synoptic observation of these elements at all scales would add significantly to the fund of information available to geographers.

The study of the geographical elements and their relationships may lead to the development of predictive theory. For example, the study of food production, distribution and consumption systems should eventually enable remote sensing of the environment to be used to predict certain types of naturally and culturally induced famines with sufficient advance notice to allow their prevention.

2.1.2. BENEFITS. The acquisition of data by remote sensing from spacecraft would benefit geography in several ways. Some of the more obvious benefits would be:

1. Savings in time over conventional data-gathering methods.
2. Acquisition of data impossible to obtain by conventional means.
3. World-wide uniformity and compatibility of data.
4. Economy of acquiring and storing data needed for multiple purposes.
5. Serendipity effect—synoptic coverage of the earth may reveal land use or other patterns and relationships not indicated by conventional mapping techniques.

2.1.3. APPLICATIONS. Two general methods of using remote sensing for geographic studies would be:

1. Basic Surveys for the entire surface of the earth providing uniform mapping and other local and regional units. Data gathered by conventional means is at present uneven in that most of it has been collected for the developed regions of the world. Data regarding developing countries are scanty, and in some cases, almost nonexistent.

2. Periodic Surveys of particular data would indicate rate of use, frequency of events, or changing patterns over time. Depending on frequency of observation, such surveys might indicate the nature of events, the timing of responses, or show small changes in surface phenomena that might not be detected using conventional data-gathering methods.

Specific applications of remote sensing to geography are listed under four major areas of interest:

Spatial Structure of Human Activities—includes all geographic problems which study man-to-man relationships, as manifested in the spatial distribution of man's activities, rural and urban settlement patterns and land use, transporting networks and dynamic analysis in terms of flows and spatial processes.

Patterns of Resource Use—includes all problems arising from man-environment interaction, such as the utilization of resources with respect to their availability at present and in the future. The effect of environment (terrain, climate) on man's activities (agriculture, commerce, and industry) would be one problem. Conversely, effects of man's activities (e.g., industry) on the natural environment (e.g., air and water pollution) would also be research topics.

Physical Geography—is a study of the interaction of the elements of the natural environment (hydrosphere, lithosphere, atmosphere, biosphere) and the effect of this interaction on surface features and surface activities. Man's role in altering the natural landscape is also a consideration.

Cartography—is concerned with the compilation, classification, generalization, analysis and graphic presentation of environmental data. The graphical representation of data that are distributed spatially facilitates visual and nomographic analysis of patterns of interaction. Maps are used by geographers to test and to formulate theories after sets of data have been collected. Two types of maps are used: (a) base maps, which show direct positional information such as land configuration, elevations, hydrography, and distribution of cultural activity, and (b) maps which show patterns derived by analysis of environmental information of diverse types.

Applications of remote sensing from orbit to these four areas of interest are discussed in the remainder of Section 2.

2.2. SPATIAL STRUCTURE OF HUMAN ACTIVITIES

A geographical point of view is a highly appropriate method of analyzing human activities. Geographical attributes of human systems are often the most and sometimes the only visible manifestations of social organizations. Static attributes of a geographical nature which reveal a human system include the shape and arrangement of facilities and land use. The structure of human systems is also revealed by the spatial relationships exhibited by the flow of people, carriers, and materials between discrete locations or by the network and capacity of channels used by these flows. Detailed and specific observation of land use patterns and transportation and communication networks should therefore be major objectives in remote sensing programs attempting to contribute to the geographer's study of man-to-man relations.

Systematic monitoring of these elements will be significant to a much broader group than geographers and other urban or settlement specialists. The potential utility to businessmen, public policy makers, and planners is very great. The scientific utility may in fact be secondary to the value of such information for operational and investment decision, both public and private. The breadth of utility will depend upon the quality of the information obtained and the effectiveness of the processing and delivery capabilities of the information gathering system.

If a real-time capability is achieved, the data are potentially valuable to operators of the human systems. Surveillance would be desirable for fire detection, air pollution warnings, or other environmental emergencies.

Another data capability range would make available information for planning purposes. Examples of purely social processes for which remote sensing information would be valuable are: projecting municipal services required for an expanding urban fringe; analyzing agricultural markets by estimating annual crop plantings; and planning regional or urban organization by analyzing changing patterns of land use. The potential for rational decision making is greatly increased by availability of timely and lucid information.

Data required for scientific study could be accumulated from operational and planning data. Periodic and comparative study information would result. Inventories would be useful for analyzing the relative importance and extent of various land uses, etc. Cross-cultural studies would benefit from synoptic information. Scientific analysis would benefit from the use of data collected on a comparable basis over large sections of the earth especially where information is poor at the present. From this scientific use of data, better economic, political, and social forecasting may be expected because regions are better understood.

2.2.1. SUGGESTED SUBJECTS FOR REMOTE SENSING OBSERVATIONS.

2.2.1.1. Studies of Static Land Use Pattern. Certain studies of static land use pattern seem immediately useful and feasible. The growth of slum areas in world metropolitan regions is a critical problem. An inventory of high density slum areas in great world cities such as Rio de Janeiro, Calcutta, New York, and Cairo would be helpful. A comparative statics analysis of these slums over a long period of time would be very significant in assessing a world problem which is likely to become a crisis in coming decades. The slum areas are likely to be identifiable by their texture using instruments having good resolution capabilities. Furthermore, only small areas of the earth would have to be monitored in each orbit.

Another useful study would be the analysis of rural settlement patterns in various parts of the earth. Systems of villages and towns identified by their size and transportation connections could be used to verify spatial organization and to make population estimates essential for planning and policy-making. Existing population estimates of many countries are in error by literally millions of people. Synoptic coverage of the country coupled with sample ground truth studies could yield much more reliable population estimates.

A third study which may be feasible with low resolution capability would be to establish the extent and shape of urban areas around the world. Again, this is important in assessing the extent of world urbanism and would be especially useful for cross-cultural comparison of the rate of urbanization. Boundaries could be observed directly by textural changes and/or tone changes exhibited by varied land use in the vicinity of cities. An urbanized area might also be defined by cultural features such as the density of road intersections or density of housing. In this case, the boundaries of urbanized areas would be defined by the gradients of the density surfaces generated.

2.2.1.2. Dynamic Patterns. Dynamic information on many features of land use change can be achieved by comparative statics such as those achieved with time lapse photography. These might be seasonal ebb and flow of natural or human activity associated with climatic changes or spatial growth trends of urbanized areas. Recurrent synoptic observation of the location of ships at sea could be used to define trade routes and densities of traffic flow on ocean routes.

Analysis of other flow data might require sophisticated equipment. A measuring device which could assign a vector to a moving object giving instantaneous speed and direction would find great application in the control and planning of transportation systems.

2.2.1.3. Proxy Measurements. Spacecraft remote sensing might also be used to establish proxy measures for indices of level of activity and degree of economic organization. Gross national product and per capita income, for example, are currently used as measures of the level of economic organization and the intensity of economic activity. These measures are imprecise and are especially suspect when comparison of one country to another is required. It has been suggested that if total man-induced energy radiated from the surface of the earth could be measured with reasonable accuracy, it might prove to be a useful indicator of the level of social or economic organization. Gross national radiation or per capita radiation, especially if classified by spectral region to indicate differences in temperature of radiating elements, might thus be useful indices of economic development. Such indices of the level of economic organization would have several advantages. They would not be tied to arbitrary unit areas such as countries, states, or nations. Any region of special interest could be distinguished, for example Appalachia or the suburban fringes of megalopolis. Another advantage would be that after calibration cross-cultural comparisons would have more meaning.

Other indicators of level-of-living and level-of-development would be the type and density of transportation networks, and urban/rural land-use ratios. Accurate, readily available indices of the type described would facilitate the development of geographic and economic theory, would allow better strategies of development in foreign areas, and would help to make more rational long-range planning relating to world demographic problems.

2.3. PATTERNS OF RESOURCE USE: MAN-ENVIRONMENT RELATIONS

Man's level of living is dependent upon his physical environment. Such dependence finds expression in systems of resource utilization which result in man's alteration of the landscape, and in turn, his adjustment to natural conditions. Interaction between groups of humans and the environments which they utilize results in tangible patterns on the earth's surface. These patterns may be in the form of transportation networks, variations in land-use, or differences in population densities and types of livelihood activities. In every case, there will be associated phenomena capable of observation from spacecraft which are indicative of the character and intensity of the man-land interrelationship.

Until the development of remote sensing techniques and automated data handling systems, the magnitude of this relationship (which can be though of as a continuum of resource management) has prevented a rational and holistic approach to the problems involved. The time has come, however, when methods already developed or in the developmental stage promise new ways of improving man's utilization of his total environment. An evaluation of the problems involved in applying spacecraft to geographic research concerned with such resource utilization has been presented by the Conference on the Use of Orbiting Spacecraft in Geographic Research held in Houston in January, 1965 (Ref. 1). The purpose of this discussion is not to repeat the materials presented at that time. Rather, five categories of research concerned with resouce utilization and involving important applications of remote sensing techniques will be presented as a supplement to that report.

1. Resource inventories
2. Historical evaluations of resource systems

3. World food supply inventories
4. Disaster threat and evaluation systems
5. Air and water pollution surveys

2.3.1. RESOURCE INVENTORIES. The recording and evaluation of data indicative of the type, extent, condition, and availability of resources is important to many fields of investigation. Agriculture/forest management, fisheries, and soil conservation programs demand continuous information of this sort. At the same time, decision-making policy of a greater magnitude depends upon similar evaluations. Price support programs, foreign aid activities, and planning at regional, national, and international levels, all require detailed and reliable information about the resource base of the political units involved. Data pertinent to this type of problem are most available and most accurate in the developed nations and least available and most suspect in underdeveloped areas, yet conventional means of obtaining information are most expensive in those places where the need is greatest. Data collection by remote sensing techniques could provide a solution to this paradox.

The arrangement of data by geographical coordinates presents an additional approach to problems of world-wide resource inventories. Presentation of materials in this form will facilitate basic geographic research relating to the intensity and type of resource utilization and the geographic spread or contraction of both beneficial and harmful practices. Once information relating to resource use is available on a comparable and comprehensive basis, the viability of resource policies throughout the world can be evaluated with greater accuracy.

Resource inventories are further discussed in Sections 3 (Agriculture), 4 (Forest Resources), 5 (Water Resources), 6 (Wildlife and Fisheries Resources), and 8 (Geology).

2.3.2. WORLD FOOD SUPPLY INVENTORIES. This category of information, while subsumed under the cateogories discussed above, is important enough to warrant special consideration. Growing concern with the adequacy of local, national, and world-wide supplies of food in view of increasing populations make vital the need for accurate, rapidly available estimates of food supplies. While eventual world-wide famine may someday plague humanity, local famines due in large part to the inadequacy of transportation and distribution systems will be of major importance for the next generation. Comprehensive surveys of food availability based on data gathered by remote sensing devices and correlated to transportation network extent and adequacy will do much to alleviate this problem and allow more time for the solution of the entire Malthusian dilemma. This application is discussed further in Section 3 (Agriculture).

2.3.3. HISTORICAL EVALUATIONS OF RESOURCE SYSTEMS. Many questions concerning the population carrying capacity of specific geographic areas have arisen in recent years. Evaluation of population potentials are often based in part on historical records of previous numbers of inhabitants. Obviously, this interpretation of such literary and archaeological materials is subject to wide variation. Examination of critical areas at suitable scales should indicate the accuracy of previous evaluations. For example, semi-arid areas of the Near East and North Africa are often cited as having previously supported much larger populations. Only comprehensive investigation of these areas can accurately indicate the extent of previous cultivation and settlement and former limits of water availability. This task is one which seems well suited to the techniques of remote sensing. In a specific case, aerial photography in parts of North Africa, have already revealed optimum spacing for olive orchards as empirically derived in Roman times. Many similar applications should be forthcoming when newly developed techniques are applied to these and other of the world's marginal lands.

2.3.4. DISASTER THREAT AND EVALUATION. Natural disasters such as floods and droughts may serve as trigger mechanisms for famines and other calamities. The ability to predict and/or evaluate the effects of such natural disasters permits adequate warning needed for supplying relief and recompense to the affected population. Beyond this immediate response, the avoidance of long-term consequences deriving from natural disasters make research in this field of great importance.

Among the many possible causes of natural disasters which might be sensed and evaluated from space are depletion of soil-water supplies on a regional basis, the too rapid melting of snows or build-up of excess waters in the catchment basins of river systems, and the spread of plant diseases. The social and political benefits of rapid response to human predicaments attendant on such conditions justifies further investigation of such warning and evaluation systems.

2.3.5. AIR AND WATER POLLUTION SURVEYS. Urbanization and industrialization are basic components of the developing world. Corollary to such phenomena is an increasing threat to the waters and atmosphere not only of single industrial sites but of whole areas such as the Washington-to-Boston megalopolis. The wide-spread nature of pollution of air and water makes its study on a comprehensive basis difficult and expensive. A capability for synoptic coverage on a repetitive basis from orbiting laboratories would promise new and less expensive means of coping with regional problems of pollution. As the world becomes more crowded, the tasks of supplying fresh water in adequate amounts and maintaining a pure atmosphere will take on increasing international importance. Earth oriented sensing equipment may contribute to the solution of this problem.

2.4. PHYSICAL GEOGRAPHY

Physical geography is concerned with the spatial and temporal interaction of natural processes, particularly as they focus on the earth's surface as the home of man. Thus, geographers are interested in studying the evolution of natural landscape through the integrated (rather than discrete) behavior of the diverse environmental elements which affect the earth interface. Necessary consideration must, therefore, be given to the multitude of processes which act independently within the realms of atmosphere, hydrosphere, lithosphere, and biosphere, but which act interdependently as surface-forming agents.

It follows that much that interests the geographer also falls within the purview of other earth sciences such as hydrology, oceanography, geology, and meteorology. There are many advantages to be gained from this overlapping of disciplinary interests, not the least of which is the possibility of sharing the same kinds of scientific observations. Using the same data, each discipline approaches the material from a different point of view, with different methodologies, and with different objectives; the potential harvest of scientific information, new theory, and practical applications is thus increased manyfold.

In the past, unfortunately, this has worked better in theory than in practice. Data collected by investigators in one discipline have seldom been available to workers in other fields. In fact, they are seldom available to workers in the same field. Access to the data has instead been restricted largely to its condensed appearance in scholarly articles and books which usually present a particular specialist's approach to the material—yet these same data could be most valuable if analyzed for different purposes by investigators in other fields. The use of remote sensors for environmental research provides an opportunity to overcome this communication and data processing block. Spacecraft observation of the earth, if properly stored and processed, can provide the first comprehensive survey of earth envoronments. At a larger scale and on a sampling basis, particular problems can also be attacked. The many advantages of a universal earth-sensing program include:

1. Uniform methods of collecting and storing data. Previous efforts have been haphazard and influenced by the needs of a particular investigator or agency.

2. Elimination of duplicated observational and intellectual efforts through the use of a single sensing and storage system. Wastage of human resources through duplication of effort is socially and economically inefficient.

3. An increase in scientific productivity in several fields due to the universal availability of data.

4. Economic benefits resulting from the elimination of separately funded projects which duplicate observations of the same phenomena.

2.4.1. APPLICATIONS OF REMOTE SENSING METHODS TO PHYSICAL GEOGRAPHY. Potential applications of remote sensing methods to physical geography can be categorized under the major headings of (1) energy exchange and water balance, (2) soils geography, (3) plant geography, and (4) geomorphology. These subjects were discussed and evaluated in terms of research needs, sensing resolution and coverage, and specific proposals at the Conference on the Use of Orbiting Spacecraft in Geographic Research. Detailed reports were submitted by the three panels concerned with natural environment and include several score suggestions for earth-oriented spacecraft research (see Ref. 1). Summary statements of the panel reports are quoted below. Many of the suggested applications are considered in detail in later sections of this report.

2.4.1.1. Energy and Water Budget. Studies in climatology can be greatly aided by spacecraft sensing to provide synoptic information on surface temperature and on energy transfer by convection and evaporation supplementing presently available measurements. Wind effects can also be observed over large areas by such indirect indications as smoke plumes and cloud patterns. Studies of energy and water budgets should be concerned not only with natural phenomena, but the effect of man's activities on climate, including such processes as forest clearing, crop cultivation, urbanization, and air pollution.

2.4.1.2. Plant Cover and Soils. Studies of plant cover and soils made possible by spacecraft sensing on a worldwide basis would provide information of great scientific value. These studies would contribute to the verification of theories of the formation and distribution of various types of soils and vegetation. From the improved theoretical understanding gained, existing trends and future developments in the ecosystem of various portions of the earth could be confirmed and our capability for predicting the effect of specific events improved. For these purposes, it would be highly desirable to obtain a vegetation map of the world, indicating types and distributions of plant cover. In particular, the amount and the distribution of chlorophyll-green in observed vegetation would indicate soil characteristics, climate, and availability of moisture. Direct economic benefits would be derived from being able to predict the yield of various types of crops throughout the world and to select optimum uses for agricultural and forest lands.

2.4.1.3. Geomorphology and Glaciology. The advantages of spacecraft sensing for investigations of geomorphology and glaciology include the ability to provide synoptic, small-scale and repeated observations. Coverage to obtain maximum seasonal contrast would be valuable.

Projects of special interest include observations related to

1. Glacier mass budgets, both mountain and continental, with observations of accumulation, ice flow, flux of icebergs to the sea, etc.
2. Glacial, secular, and periodic climatic problems related to fossil and active sand fields, dunes, and sand trains.
3. Composition of solid-earth surfaces; rocks, alluvium, beach sands, and other accumulations.
4. Gross patterns of lineaments, with emphasis on jointing, faulting, and other deformational features.
5. Effects of wind and waves on coastal beaches and topography of shallow water bottoms.

Studies of many other topics would be of interest provided present sensing capabilities can be extended.

2.4.2. ANTICIPATED BENEFITS. While the Houston Panel reports provide an excellent framework for discussion of possible earth spacecraft sensing programs, some further discussion of the needs and benefits associated with the individual proposals is warranted. Discussion is focused on four of the major research areas that interest physical geographers—categories which have import not only to earth science-oriented geographers, but also to students of man-environment relationships. These studies are: (1) Naturally-induced energy, (2) World water balance, (3) Vegetation and soil distributions and boundaries, and (4) Physiographic regionalization.

2.4.2.1. Naturally-Induced Energy. The ramifications of energy exchange at the earth's surface are, to laymen, among the least appreciated factors in the environmental scheme.

Scientists have recognized for years that a knowledge of the temporal and distributional characteristics of energy fluxes is needed to premit a realistic understanding of climatic variation; weather forecasting; processes of condensation, vapor transfer, and evapotranspiration; soil moisture exchange; photosynthesis; and a multitude of other phenomena which are not fully understood. If the earth's energy budget were mapped and understood, the potential in scientific terms would be tremendously amplified by the social, economic, and political benefits that would, as a result, accrue. These would include, for example, improvements in agriculture through proper understanding of irrigation needs, better growing season management of crops, and predictive knowledge of snowshed melting potential. Even in advanced industrial societies, man's ability to cope with his environment and master it is woefully inadequate—and the question of energy is at the heart of the problem.

Yet most of our knowledge of interface energy exchange is based on a very small sample of expensive and tricky spot measurements. In sparsely settled regions and in developing nations such information is practically nonexistent. Man is presently unable even to make a reasonably accurate map of the world's surface temperatures, a most critical and necessary measurement. This might be accomplished on a world-wide scale with infrared sensors operating from orbiting spacecraft.

If humanly-induced energy can be separately detected and measured, a valuable by-product measurement would be made available. The spatial and temporal variations in man-made energy could serve as important indices of human activity, level of living, etc.

2.4.2.2. World Water Balance. The above discussion of energy has indicated that water flux and energy flux are interdependent variables of our environment; discussion of one must necessarily include discussion of the other. If energy is understood, so too can the earth's water balance be mapped in space and time. The mapping, understanding, and possible control of our water resources is one of the most immediate and significant challenges facing man. In most medium-to-heavily settled industrial and agricultural regions of the world, allocation of water resources has already become a critical issue. Domestic, industrial, hydroelectric, and agricultural demands are ever increasing and population projections give no solace. Yet climatologists must admit that they do not really know where it rains nor when! It is necessary that rainfall, soil moisture, snow and ice water storage, and runoff be mapped sequentially through the year so that our dwindling per capita water supplies can be put to intelligent and significant uses. The potential returns from increased crop yields, averted famine, accurate flood prediction, etc., have tremendous social and economic implications.

2.4.2.3. Vegetation and Soil Distribution and Boundaries. The significance of vegetation and soil mapping to regional and land use planning should be reiterated. As the world's exploding population places greater demands on agricultural, watershed, and timber lands, regional and government planners have a greater need for a comprehensive resource inventory. Since large parts of the world are either physically, politically, or economically inaccessible with present surveying techniques, spacecraft sensing again seems the most efficient and economic method for obtaining the information. Many areas that have not been previously mapped may in fact be revealed as potential lands for settlement and exploitations; certainly, population trends indicate the need for such a safety valve. Also, in terms of regional planning in the developing nations, the availability of soil and vegetation maps should bring political as well as humanitarian returns.

2.4.2.4. Physiographic Regionalization. Although geographers are interested in the delineation of physiographic provinces for purposes of environmental and man-land studies, this subject has been fairly well covered within the capabilities of present mapping techniques. The use of radar sensors does, however, promise new insights into the history, structure, and origin of these physical regions. While geographers encourage spacecraft sensing and refined mapping of these gross landscape patterns and will wish to draw upon the results, it is believed that this program will be of particular benefit to geologists.

2.5. CARTOGRAPHY

Maps traditionally provide the most convenient method of recording inventories of geographical information. Maps showing the distribution of people, of land use, of transportation flows, or of other features of the cultural, social, economic, or natural environment are of great importance to many fields including geography.

Inventories of geographical information are indispensable for a large spectrum of practical problems, a few of which have been cited in the previous pages. Theoretical studies in geography also suggest types of information to be mapped and use maps as sources of data to test theoretical hypotheses. The theory and practice of geography consequently often require advanced methods of cartographical analysis, or require derivative data instead of the direct observational information (e.g., second derivatives of geographical density functions rather than simple location of objects).

The most easily identified cartographic benefits to accrue from orbiting sensors are topographical base maps, and coverage of photographic, infrared, radar or other imagery.

These are of very great practical importance and the benefits are readily recognized because of the magnitude of the current effort in these fields. Other currently active projects, such as the world population map or the world land use map, are of equal or greater importance, but are more difficult to justify in an accounting sense; they are not as clearly a part of the national budgets since much of the effort is voluntarily contributed by scientists throughout the world. It is also important to note that the major theoretical interests cannot be served adequately unless the data acquisition system is accompanied by an analysis and processing capability of at least comparable magnitude.

2.5.1. PRESENT STATUS OF WORLD MAPPING. Many areas of the world still remain inadequately mapped. Those portions of the industrialized nations that are most important economically have been mapped for many purposes, but this does not imply that there is no need for new maps. In the underdeveloped regions of the earth, detailed mapping is almost nonexistent. It is estimated that less than 50% of the land area of the world has been adequately mapped. There remains a few areas for which even reconnaissance maps are lacking (particularly the arctic, antarctic, and the ocean regions), but large gaps exist in the current coverage of detailed maps. The largest scale for which complete coverage of South America is available, for example, is 1:1,000,000 (1 inch on the map is 16 miles on the ground). This series of maps was undertaken in the 1920's, not in South America but in New York City, and relied in parts on vague accounts of explorers and missionaries for some of its information. For some parts of South America these are still the best maps available.

The problems and needs for more accurate and current maps exist for both the industrial nations and the developing countries of the world, but for different reasons.

2.5.1.1. Industrial Nations. In the industrialized nations, increasing attention is being devoted to the solution of regional, resource utilization, and metropolitan problems (for example, Appalachia). Regional planning requires the intensive study of large areas. The analysis is often hindered by the inherent differences in the positional accuracy, specifications of available maps, or by map obsolescence.

There has been an increase in the amount of economic, social, and cultural information identified with the aid of maps by latitude and longitude coordinates. This form of location identification allows direct computer analysis in greater volume and at less cost than methods previously employed. Without the accurate positional information provided by maps, this work would be seriously hampered.

2.5.1.2. Developing Countries. Mapping of all types is urgently needed in many of the underdeveloped and remote regions of the earth. The data collection is generally very slow and laborious due both to economic and technical problems. The time involved in data collection, completion, and publishing is so long that even adjacent maps produced by the same agency cannot be used for comparisons due to the time interval between them.

Travel, business, and political stability in these areas are hampered not only by the lack of transportation, but also by insufficient or obsolete knowledge of the current conditions of the transportation facilities. The magnitude and distribution of forests, agricultural areas, mineral resource deposits, water resources, and urban facilities often are only vaguely known.

2.5.2. TOPOGRAPHICAL BASE MAPPING. Topographic maps provide the basic cultural and environmental data for a wide variety of problems. Upwards of $400 million per year is spent on activities related to topographic mapping by agencies of the United States government (U. S. Geological Survey, U. S. Coast and Geodetic Survey, Army Map Service, Aeronautical Chart and Information Center, Oceanographic Office). This does not include agencies which have a secondary activity in mapping (Forest Service, Soil Conservation Service, Bureau of the Census). Also not included are state, county, and city efforts in mapping. The maps produced range in scale from 1:2,400 to 1:5,000,000 with the major series at scales of approximately 1:25,000; 1:50,000; 1:250,000; 1:500,000 and 1:1,000,000. The mapping activities of other countries are similar to those of the United States but vary considerably in scope. Some countries have more active programs and are better mapped than the United States, whereas many others lack the economic and technical capability to produce adequate maps.

It is estimated that only 70% of the United States has adequate topographical map coverage. The present plans of the U. S. Geological Survey are to complete mapping for the entire continental United States at a scale of 1:24,000, within the next two decades. The major task after this period will be revision of the maps. Each map currently takes about two years to complete, costs between $10,000 and $20,000, and has a useful life of between five years (urban areas) and twenty-five years (desert and mountain areas). The current practice is to maintain maps at smaller scales by correcting them from information collected for the large scale maps. The critical item needed in periodic revision of the maps is not the topographical information, but the cultural information (roads, built-up areas, vegetational cover).

2.5.2.1. Cartography and Photographic Imagery. With the advant of aerial photographs and their use in the cartographic field, the quick and accurate mapping of much of the world has been greatly enhanced. Aerial photography came into its own during the 1930's and consistent progress has been made in the application of aerial photography to map compilation. Aerial photography is relatively inexpensive costing from $2.50 to $4.00 per square mile for scales in the 1:20,000 range (Ref. 2). Costs vary considerably depending on the amount of coverage, type of film, scale requirements, and type of terrain for which the photos are required.

Aerial photographs can be used as map substitutes in certain instances. Many photographs together can be made into a mosaic. In much regional planning work today photographs, mosaics, and maps are needed. Maps are accurately made and emphasize certain important features (visible or not), while photographs and mosaics record all information in the visible (and near infrared) range of the electromagnetic spectrum. Photographs and mosaics are usually not nearly as accurate in positional location and they do not have place names, jurisdictional boundaries, or route numbers.

The amount of aerial photography required for small scale maps is quite large and makes the compilation of such maps from photographs impractical. Therefore, existing larger scale maps are used and the required information is abstracted and reduced to fit the format of the smaller scale maps. The accuracy of this process is only as good as the original source used and the correct portrayal of current cultural features must be ground-checked. It should be pointed out that aerial photography solves many, but not all, of the problems associated with data collection in the cartographic field. Ground control and checks are still necessary. The use of aerial photography does pose limitations as to what is economically feasible in repetitious coverage of the same area for purposes of updating existing maps. For example, many cultural features of importance to geographers change quite rapidly. Except for unusual circumstances, it is not economical to obtain monthly or even annual photographic coverage to measure these changes. Furthermore, in the developing nations of the world, economic and technical problems make the use of aerial photography impossible.

2.5.2.2. Current Status of Air Photo Coverage. Reference 3 summarizes the status in 1960 of air photo coverage throughout the world. North America is the most thoroughly covered of all the continents. Approximately 100% coverage exists, much of it obtained within the last 10 years. Photo coverage of about two-thirds of South America exists, but much of this dates to the early 1940's. The coverage is also limited by the fact that is is discontinuous within photographed areas. Photography exists for about 80% of the area of Europe outside of Soviet control; almost all of this dates back to World War II. Little photography over the areas of Eastern Europe or Asia is known, but this may be due in part to inaccessibility of such information. Approximately half of Africa is covered with photography of various ages and approximately two-thirds of Australia and New Zealand, almost all before 1950. Thus, it is clear that as of 1960, large areas of the world did not have air photo coverage, and that much of the existing coverage was 10 to 30 years old.

2.5.3. ADVANTAGES OF A SPACECRAFT TO THE CARTOGRAPHIC FIELD. The spacecraft offers important advantages for cartographic application. For the first time, large areas of the earth can be covered in a short time interval. Many underdeveloped areas of the world might be mapped for the first time. Assuming that the spacecraft imagery can be related to a geodetic control network on the ground (which it must!) the actual position of any item will be known with respect to all other items. Repeated coverage over large areas of the earth with short time lapse intervals will be possible. This may make extremely small changes in phenomena measurable.

Many specific advantages can be obtained from an orbiting spacecraft. The existence and accurate location of many important natural resources can be mapped on a world-wide basis. The accuracy of current knowledge can be improved, not piece-meal and at different dates, but all at once. This knowledge will be extremely valuable in the economic and cultural analysis of important region of the world.

Specific benefits for mapping programs to be gained from the use of orbiting platforms will occur in connection with (a) map revision; (b) mapping of areas now poorly covered; (c) improvement of positional accuracy (upon occasion map makers must "move" important islands and mountains as much as twenty miles to their correct location); (d) preparation of small scale maps; and (e) recording new types and configurations of information. Reduced costs per square mile for obtaining map data are likely. Further major economics can be realized if world-wide imagery obtained by a single operational system can be used jointly for many different scientific or economic purposes.

Obtaining topographical information would involve substantially more complicated sensors than for only planimetric information. This latter would suffice, however, for the majority of needs of map revision and reconnaissance of poorly mapped areas. In terms of scale, revision of maps would benefit if the step of combining hundreds of large scale maps into one small scale map could be circumvented by obtaining small scale imagery for a large region all at one time. Considerable effort has been expended in recent years in this direction, using aircraft flying at higher and higher altitudes. Orbiting altitudes provide the logical extension. The advantages for mapping of areas not now covered are great.

The sophistication of present mapping was brought about primarily through the use of aerial photography and its related skills. An orbiting spacecraft imaging system with a multispectral sensing capability would provide new and different imagery for study. The benefits accruing to the geographic field with this possibility may far outweigh the more obvious benefits of easier and quicker methods of supplementing current operations.

2.5.4. TYPES OF COVERAGE DESIRED.

2.5.4.1. Small Scale (1:10,000,000 and smaller). Imagery of the earth's surface at this scale will greatly enhance the ease of preparation of small scale maps. A capability of updating the information at frequent time intervals should be economically feasible. With multispectral sensing capabilities there is a possibility of observing new terrestrial phenomena. A new and different "look" at the earth may reveal ideas, problems, and concepts heretofore unknown or unobserved.

2.5.4.2. Small Scale (1:1,000,000 - 1:5,000,000). The advantages of this scale are similar to those listed for the 1:10,000,000 scale; in addition other practical uses become important. Maps with scales in this range are used for navigation and for national planning. The completion of the International Millionth Map of the World, begun in 1909 and now being coordinated by the United Nations, would benefit considerably from imagery obtained from an orbiting spacecraft. Similarly, such imagery could be applied to the preparation of an international millionth mosaic. Also, there is in preparation at present, a world atlas at a scale of 1:5,000,000 (Ref. 1). The international nature of these maps require uniform standards and would readily lend themselves to using data obtained by a spacecraft.

2.5.4.3. Medium Scale (1:250,000 - 1:1,000,000). Many different types of maps and charts are presently produced at scales of 1:250,000 to 1:1,000,000. The 1:250,000 scale has the advantage of being large enough for relatively detailed studies of an area, while being small enough for comprehensive planning over large areas. Maps of this scale are also used for navigation by airlines and military forces. As mentioned earlier, the major problems are to keep the existing maps up to date and to increase the areas covered. With rapid time-lapse coverage, a complete world-wide updating of this series of maps would make possible a world-wide standard or base map. For such a map, geographers, regional planners, agriculturists, foresters, geologists, and many other specialists could extract the information of interest to their respective areas.

2.5.4.4. Large Scale (1:25,000 - 1:250,000). Imagery in this scale range may be used for detailed analysis of any selected area. A scale of 1:60,000 appears feasible for the photographic negative. The study of urban growth, transportation patterns, industrial activity, and the changes that take place in these phenomena will be greatly enhanced by accurate and current imagery at this scale. With an orbiting spacecraft repeated coverages over the same area as often as once a month should be possible, if necessary.

Initially, only one or two such study areas would be possible at the largest scale. However, considering a multiple spacecraft program, comparison between different areas may be possible. Simultaneous coverage of two cities with different economic and social patterns would greatly aid the study and analysis of various types of metropolitan problems.

Maps of the changes in these phenomena would provide a ready reference of past activity to compare to present activity. From an analysis of these changes, future changes may be predicted, and long range planning activities would be more reliable. Accordingly, utilization of our resources would be much more efficient and beneficial to mankind.

2.5.5. DATA REQUIREMENTS—STORAGE, RETRIEVAL, ANALYSIS. For mapping purposes almost all details obtained will have use. Geographers consider obtaining as much information as possible from the spacecraft a sine qua non. The time dependencies of useful information vary, however; one type of data may be needed one day and a totally different type may be required at another time. This necessitates a comprehensive storage, retrieval, and analysis system. Ideally, the direct return of photographic or sensing imagery is preferred. Once obtained on the ground, the information would need to be put into an electronic computing system.

For mapping projects of small scale, the discrimination of 16 levels of graytone is a minimum requirement. For larger scale projects, discrimination of 64 measurements of phenomena will be possible. The types of imagery and resolution available will determine to a great extent the use of the data.

Much of the data used in mapping the earth would be of direct value to many specialists in a wide variety of fields. It can be assumed that processing of the data and imagery necessary to bring it into a map or mosaic format will be similar for many fields. The storage and retrieval of this information should be based on a system of complete locational, temporal, and topical cross referencing. The wide dissemination of the information assumes this as a prerequisite. The planning of the data bank should also give consideration to the best compromise between storing large quantities of data and reacquiring data as needed.

3
AGRICULTURE

3.1. INTRODUCTION

It appears that the potentially useful applications for remote sensing in agriculture are such as to warrant immediate interest in, and adequate support of the needed research and development and the establishment of a working remote sensing system. These applications are expected to provide not only more and better agricultural information, which will be of economic value in the United States, but also permit securing new and reliable information about agriculture in other countries, particularly for the developing regions. Such information from regions of economic and political interest to the U. S. is taking on an increasing significance from the point of view of world population growth and the decrease in per capita arable land resources available to supply the world's food requirements.

United States population projections for 1975 range from 215 to 240 million and from 270 to 380 million for the year 2000. World population by 2000 is expected to rise to about 6.28 billion people. In 1955 the arable land per person was about 1.25 acres; by 2000, arable land per person will decrease to a little more than one-half acre per person. From this view of the future it is clear that performing agricultural research and obtaining agricultural information on a world basis must be vigorously pursued.

Our interests are not entirely cultural and humanistic; our concerns are also economic and political. In indicating the combination of our interests, it is useful to quote from Phillips (Ref. 4): "Helping our neighbors at home and abroad has become a tradition among Americans. . . . But there are reasons other than good neighborliness for our interest in such activities—reasons that we might group under the phrase 'enlightened selfishness'.

"Bringing plant and animal pests and disease under control in any country reduces the danger of having them brought to the United States.

"As economies of other countries are strengthened, the possibilities of trade are enhanced, including better outlets for our agricultural products."

For the solution of any present or potential problem, sufficient information must be acquired to understand the problem and to make wise plans directed toward achieving a desired end. It is believed that remote sensing techniques can add a significant dimension in the acquisition of world agricultural information.

3.1.1. PROCEDURE AND ASSUMPTIONS. Twelve applications in agriculture for an operating remote sensing system have been described in Section 3 in terms of its use within the continental United States. Rather than repeat the discussion for other developed countries and for the world's developing regions, the presentation has concentrated on the domestic uses and then has indicated the order of economic value for these applications in other parts of the world. In considering each of these 12 applications we have attempted to define the functions to be performed by the sensors, the desired recurrence rate of the sensing and the resolution required to perform the function. Naturally, these rates and resolutions will be subject to review as the development of a workable system progresses. The potential benefit has been studied for each application within the U. S. and benefits have been considered separately for other developed countries and for the developing regions. For the latter, it appears that there will be not only direct benefits to these regions but also benefits to this country that were partially outlined by Phillips as quoted above.

For the area of application of agriculture as a whole, some assumptions and limitations that we have employed should be indicated. First, not all of the desired applications have been included. For example, obtaining information about numbers of livestock or about livestock enterprises has not been considered. From orbital altitudes, it was assumed that the resolution would not permit counting farm animals in pastures, on the range or in feedlots. We have selected the major sensing functions to be performed as those that will permit identifications of agricultural crops, measurement of areas of fields in such crops and determination of yield indications plus general assessment of water availability.* In directing attention to applications utilizing these functions, it has been assumed that technical sensor capabilities would not restrict the performance of these functions and that the data processing techniques would make the desired information available when needed.

It is believed that the economic value of the agricultural information now collected and disseminated by the agencies of the U. S. Government far exceeds in value the cost of collecting this information by present methods and procedures. Yet improvements in the precision, timeliness and accuracy of this information are continually being sought. Thus, it seems that a comfortable margin exists in which the benefit of additional remotely sensed information will be highly favorable in relation to the cost of securing this added information.

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*Insects and diseases affecting crop production may be considered as negative yield indicators when remotely sensed. Snow and water survey will be discussed further in Section 5, (Water Resources). Some of the applications considered can utilize additional functions; See Table III.

For the purposes of this study, it has seemed relevant to use agriculturally associated expenditures from the 1966 Budget of the U. S. (Ref. 5) to bring out the degree of interest of governmental agencies, the farmers, and the consuming and taxpaying public in adequate and timely agricultural information. Since this Budget is referred to frequently in the subsequent discussion, selected items from the Budget are presented in tabular form in Section 3.2.4.

The matter of benefit analysis must be approached indirectly. "Goods and services" are not directly produced by expenditures to obtain more or improved agricultural information. These decisions may result in the production of more "goods and services," or in the shifting of resources to alternate more productive uses. It seems clear that for any of the applications in agriculture described below, a remote sensing system will provide additional information, availability of the information will be enhanced in time, and the information obtained will be improved in accuracy and provide its own measure of precision. It must be emphasized strongly that this statement of services to be obtained from a remote sensing system depends heavily on the solution of the data processing problem.

Because of the inherent uncertainties in arriving at estimates of anticipated benefits and the limited time available for study, we have made considerable use of informed judgment in arriving at estimated benefits. Such judgment still includes subjective elements, and since the figures must be regarded as tentative, we have tried to give a probable range of benefits for each application. We have tended to be conservative in assessing benefits for the U. S.

Because of the limited time frame of the report, it has not been possible to obtain the desired review and approval or concurrence of interested individuals and agencies. The preparation of this section on applications in agriculture has been much improved through consultation with staff members of The University of Michigan, Purdue University, and the U. S. Department of Agriculture. Such consultation does not imply, however, any concurrence in the content of this section. The authors assume full responsibility for the presentation as given here.

3.1.2. MAJOR APPLICATIONS AND POTENTIAL BENEFITS. There appear to be three major domestic applications for remote sensing in agriculture. These applications are in the Agricultural Census, in support of our Agricultural Programs and for the Agricultural Statistics Programs of the Statistical Reporting Service of the U. S. Department of Agriculture. Outside the U. S., the principal application is for improvement of the agricultural censuses. Further needs exist in the developing regions for agricultural resource surveys and then for the preparation of current agricultural statistics.

In terms of estimating actual domestic benefits of a remote sensing system, a range of \$20 to \$50 million appears realistic. For other developed countries it has seemed reasonable to consider the potential benefits of these services to be equal to those for the U. S. For the developing regions of the world, these services clearly have great value since all that is now available for many of these regions is information which is insufficient and of unknown accuracy and reliability. A modest amount of \$10 to \$20 million expended annually for remote sensing may return many times its cost in the efficient use of U. S. foreign aid. In addition to U. S. contributions major effort is required on the part of the people of developing regions themselves to achieve adequate food production. This effort will also benefit from the availability of adequate information. Thus, the total benefit of applications of remote sensing to the developing regions of the world would accrue directly to the U. S. in providing needed information for monitoring and evaluating our aid to foreign agriculture (stated here as \$10 to \$20 million annually), to the developing countries in helping to solve their food production problems, and to the world at large in contributing to its social and political stability through the solution of its serious current and future food supply problems.

3.1.3. OPERATIONAL CONSIDERATIONS. The introduction of aerial photography on a large scale in the 1930's added a new dimension in agricultural research and in obtaining agricultural information. This new tool, aerial photography, gave particular support to the development of the agricultural programs, soil conservation activity and our desire to obtain improved agricultural statistics. Now it appears that new advances in technology may add significantly to our ability to perform remote sensing of agricultural activity. Multispectral sensing techniques open up new methods of identifying various crops and of assessing crop maturity and health. These methods, when combined with the capabilities for rapid synoptic coverage by orbiting spacecraft, provide a capability for improving the agricultural information situation.

There are techniques still to be developed for satellite wide-band remote sensing. We have to sort out what can be done best at the earth's surface, what can be done best using aircraft and what can be done well by satellite in securing agricultural information. We also need to investigate the complementarity of ground, aircraft and satellite methods.

In collecting agricultural information, two kinds of data are obtained, physical data (such as areas and yields), and economic data (such as prices received and prices paid by farmers). Hence, a system limited to obtaining physical data can only partially replace or supplement the present system.

In collecting agricultural information there will be applications requiring a regular or routine employment of a remote sensing system while, on the other hand, there will be some applications for agricultural research or special uses arising from time to time. Put in another way, we may say that there are applications in which there is a recurring use of the system while other applications will place non-recurring demands on the system or may be described as needs arising at random (in time and space). Also, applications will differ in that some will require 100% coverage of agricultural areas while others may fulfill their requirements by sampling the agricultural area of interest.

There are also considerations of required scale and resolution. Since it seems reasonable to expect some improvement in sensor capabilities in the 5 to 10 year system development program envisaged, it is assumed for the purposes of this report that sensor capabilities will not limit the requirements of any of the agricultural applications.

The volume of data that must be recorded and transmitted to earth is very large. Hence, the ultimate operating system will require essentially on-line, real-time processing. The processing will need to be automated to a high degree; only with such developments can the requirements of some of the agricultural applications be satisfied.* It is realized that such processing requirements are in contrast with present procedures of the USDA and other agencies for data processing. Storage and retrieval for the vast volumes of information recorded will be an associated problem.

3.2. DESCRIPTION OF APPLICATIONS

There are substantial differences in the needs for remote sensing in the U. S., where aerial photography is presently fulfilling our requirements, in other developed countries, and in the developing countries, where the size of the job is much greater. Because of the differences of the applications in these three areas, they are treated separately in the following discussion.

In the material presented below, a number of potential applications are discussed. Table II gives a list of these applications. The list is based largely on the applications suggested for aerial photography (Ref. 8) plus those that seem feasible from other sensor capabilities (Ref. 9). Each of these listed applications is discussed below, first in terms of domestic application, i.e., within the Continental United States (CONUS). Less detailed discussions in terms

*There appear to be developments on the horizon in man-machine communication that will make possible rapid summarization of identification and area information (Ref. 6 and 7).

TABLE II. FUNCTIONS TO BE PERFORMED BY SENSORS IN AGRICULTURAL APPLICATIONS

	Application	Function
1.	Agricultural Census	Area Measurement Crop Identification
2.	Agricultural Programs	Area Measurement Crop Identification
3.	Agricultural Statistics	Area Measurement Crop Identification
4.	Resource Surveys	Area Measurement Resource Identification
5.	Soil Classification and Mapping	Mapping and some Soil Identification Soil Boundary Delineation
6.	Conservation Programs	Area Measurement Mapping
7.	Agricultural Geography	Mapping Activity Identification
8.	Changes in Land Use	Area Measurement Land Use Identification
9.	Economic Studies	Mapping Land Use Identification
10.	Damage Detection and Assessment	Area Measurement Identification of Damage Cause
11.	Snow Surveys*	Area, Depth and Density or Equivalent Water Volumes
12.	Water Supply Prediction*	Soil Moisture and Water Areas and Volumes

*These two applications are also considered in Section 5 (Water Resources).

of the specific nature of the applications follow for the other developed countries and for the developing regions, although several of the applications have their greatest potential benefits when employed for these regions. Before discussing each application, an overall tabular review of the applications and functions to be performed is given here from the point of view of the domestic applications (Tables II and III).

The subject of benefits is discussed in connection with each application. Neither the present methods of collecting agricultural information or a projected spacecraft system for assisting, improving and adding to the present information system will produce directly recognizable "goods and services." The output will be essentially non-marketable although, if not available through public means, private agencies would endeavor to secure some of the information or possibly contract to obtain it. In view of this non-marketable output, the benefit analysis presented is of a general nature.

Conclusions concerning the applications to agriculture are summarized in Section 3.3.

3.2.1. DOMESTIC APPLICATIONS

3.2.1.1. Agricultural Census. The present Agricultural Census is conducted by the Bureau of the Census, Department of Commerce, at five year intervals in the years ending with the digits 4 and 9. It would be desirable to secure this information annually. Such annual coverage would permit better measurement of the current status of the agricultural economy and substantially improve assessment of all agricultural programs and activities.

Both physical and economic data are secured by a supposedly 100% coverage of all farms and farm land. For certain purposes of the Agricultural Census, physical data must be related to the operating units, individual farms, which would require special and elaborate processing. Such processing could be combined, however, with Application 2, below. A simple Census would need only summary totals by minor civil divisions (i.e., towns, townships, and parishes).

Both area measurements and crop identifications are required. Coverage required is 100% of agricultural areas. Desired area resolution is a single acre (about 200 ft × 200 ft) although a four acre unit (about 400 ft × 400 ft) would be adequate for many needs. An accuracy of ±1% would be satisfactory.* To accomplish crop identification, annual sensor repetitions required would range from 2 to 4. Assuming that area measurement and crop identification are accomplished by separate sensors, the resolution needed for the latter is only that which permits

*Coefficient of variation of 1% for a minor civil division.

TABLE III. TABULAR REVIEW OF APPLICATIONS IN AGRICULTURE FOR REMOTE SENSING SYSTEMS

Application	Coverage	Units	Resolution (expressed in feet)	Repetition Intervals***	Processing Time
1. Agricultural Census	100% of agri. areas	Minor civil divisions*	Area Measurement 20' - 40' Crop Ident.** 20' - 40'	1-2/yr 2-4/yr	2-4 months
2. Agricultural Programs	100% of agri. areas	Farms	Area Measurement 4' - 8' Crop Ident. 20' - 40'	1-2/yr	2 months
3. Agricultural Statistics	Sampling fractions of $f = \frac{1}{200}$ to $\frac{1}{100}$	1/4 Sections to Sections	Area Measurement 20' - 40' Crop Ident. 20' - 40'	Monthly	3-4 weeks
4. Resource Surveys	Variable: counties or watersheds up to several states	Sections to Townships	Crude Area Measurement 40' - 60' Resource Ident. 50' - 100'	Occasional	4-6 months
5. Soil Classification and Mapping	Both sampling and 100%	1/4 Sections to Sections	Mapping 8' - 20' Soil Boundaries 20' - 40'	5-10 years	6-12 months
6. Conservation Programs	Variable: counties or watersheds up to several states	1/4 Sections to Sections	Mapping 10' - 20' Area Measurement 8' - 20'	Occasional (before and after)	3-6 months
7. Agricultural Geography	Both sampling and 100%	Minor civil divisions to counties	For sampling 8' - 20' For 100%, 50' - 100'	Initial plus occasional (1/5 years)	6-12 months
8. Changes in Land Use	100% of agri. areas	Minor civil divisions	Area Measurement 4' - 8' Use Ident. 10' - 20'	Annual or Biennial	4-6 months
9. Economic Studies	Selected small areas: 100% Large areas by sampling $f = \frac{1}{1000}$ to $\frac{1}{10}$	Farms to minor civil divisions	Mapping 4' - 8' Crop or land use Ident. 20' - 40'	Occasional	3-6 months
10. Damage Detection and Assessment	Selected Areas 100% Some sampling	Sections to Townships	Area Measurement 4' - 8' Ident. 10' - 20'	2-5/yr	3-4 weeks
11. Snow Surveys	Snow areas: 100% or by sampling	Townships, counties and watersheds	50' - 100'	2-3/yr	1-2 weeks
12. Water Supply Prediction	Both 100% and sampling	Townships, counties, watersheds and lakes	50' - 100'	2-4/yr	1-2 weeks

*Towns, townships and parishes.

**Ident. = Identification. The resolutions shown in this table for crop identifications are based on the problems of identifying crops where strip cropping, terracing and contour farming are present and fields appear as long narrow strips. Text discussion of resolution for each of the applications is based on square or rectangular fields.

***Some of the applications will utilize more frequent sensing if made available because of the needs of other applications. Examples are Applications 6 and 7 using the outputs from Applications 2 and 3.

positive crop identification for a one acre or a four acre unit (field). Availability of summary data in two months would be desirable although four months could be tolerated.

The Census of Agriculture is published by the Bureau of Census as a national summary volume, as individual volumes by regions or single states and in terms of separates comprising special summaries or tabulations. Other interested agencies are Department of the Interior, Army Corps of Engineers, and most divisions of the Department of Agriculture.

Advantages of remote sensing by satellite may be indicated in terms of both cost considerations and additional information obtained. Aerial photography is not now used directly in support of the Agricultural Census operation because of cost and feasibility considerations. Even if only summary totals were compiled by area measurement and crop identification from remote sensing, a positive and direct check on information collected from farm operators and land owners would be available. Present checks are indirect and incomplete. If processing problems can be resolved, the use of satellite observation could materially assist in taking an annual agricultural census. Check information on specific crops also would become available. Further, the annual census for the preceding year would provide an adequate basis for current season crop forecasts based on sampling procedures (refer to Application 3, below).

Expenditures for obtaining the Agricultural Census are estimated from 1966 Budget data (Sec. 3.2.4) to be about $20 million once every five years. By providing check information at the time of taking the census and by providing up-to-date information at annual intervals during the five-year period, it is estimated that the value of the agricultural census could be increased from a minimum of $4 million per year to, perhaps, $6 to $8 million per year, an increase of $2 to $4 million per year. If a decision were made to prepare a complete census every year, the contribution of orbital sensing would be even greater than the figures just cited.

3.2.1.2. Agricultural Programs. Agricultural programs are administered by the Agricultural Stabilization and Conservation Service (ASCS) of the USDA. The functions of these programs are production adjustment, conservation assistance and price and market stabilization. Specifically, for production adjustment, marketing quotas are established, acreage allotments are made and farmers obtain stabilization payments for crops in abundant supply, e.g., cotton, tobacco, rice, peanuts, wheat, corn, and other feed grains. In order to carry on these activities, contractual agreements are entered into by the government with individual farmers. These contracts provide for acreage allotments, acreage diversion to other uses and cropland conversion. Further, these contracts provide for benefit payments to farmers or in some cases penalties due to failure to fulfill the contract requirements. Thus, it becomes necessary for the Service to check on contract compliance, in terms of acreages and kinds of crops grown by contracting farmers.

In assessing compliance, the need arises for crop area measurements and crop identifications. Aerial photography is now used in this work to provide a means of checking areas of fields whose crops have been identified by field visits or farmer reports. It is estimated that the annual cost of the field work is about $40 million.

If multi-band sensing provided positive crop identification and area measurements, a significant dimension would be added in improving the compliance check work. Even though not all farmers participate, a 100% coverage of all agricultural areas would be required since areas under contract with the government will not be concentrated but rather randomly scattered in any state or county. For ASCS area measurements resolution as good as 2 or 3 feet is required to obtain an accuracy of ±1% for small fields. Such capability is required because each individual farmer's compliance must be determined. Complete coverage for area measurements for most crops is presently obtained not oftener than every six years; such measurements obtained every other year would be a substantial advance over the present methods. It should be recognized that area measurement calls for 100% coverage with high resolution cameras. On the other hand, the sensing for crop identification would require only a resolution that would permit identification for a unit of say one acre in size. The sensing would have to be repeated, however, two to four times per year, to obtain adequate crop identification. Some parts of the country, such as western Kansas, would require only two passes, but other parts, such as California, would require four passes. Ground reference locations must be visible on the imagery or geographic coordinates must be associated with the crop identifications and area measurements in order to connect these data with the correct minor civil division and individual farmer. In stating these area and identification requirements, it must be recognized that a crop such as tobacco, which is planted in small fields, could be only partially assessed by a remote sensing program.

Processing speed is not critical for the ASCS programs, but since the remotely sensed information would need to be distributed to the county level, the processing problem is a special one. Thus, it seems best to tie the processing procedure to Application 1, the Agricultural Census placed on an annual basis. Data and images need to reach the county in about two months. Further, the processing procedure must have a storage system from which the area and identification images can be retrieved systematically and rapidly in order that a check can be made with a farmer's sketch and his contract.

As already indicated, other agencies will be interested in the information obtained. These agencies include the Bureau of Census, most other divisions of the USDA, and state and federal game agencies.

Through combination of the agricultural Census and needs of the ASCS programs, remote sensing by satellite may become a practical possibility. Aerial photography is now available but it is not being used on an annual basis for these two requirements. An operational satellite system might be lower in cost than aerial photography and provide identification information not now obtained. Thus, an individual farmer's compliance could be checked remotely with an accuracy not now available; in addition, overall information newly made available would permit better planning and guidance for the adjustment programs. It is realized that the processing needs may be difficult to meet but if successful it is believed that the present annual field work cost eventually could be reduced from the present $40 million so as to yield gross benefits in the range of $10 to $20 million annually.

3.2.1.3. Agricultural Statistics. The Statistical Reporting Service (SRS) of the USDA is charged with the preparation and issuance of current crop and livestock estimates. These estimates comprise statements of crop forecasts, crop and range conditions and estimated harvests. While much of the SRS activity is economic in nature, we shall be concerned here with only the information that is physical in nature. As an example, we may consider the corn crop which is significant in nearly all states. An "intentions to plant" in terms of acres is issued early in the season, in March; June 10, a planted acreage estimate is made; July 10, condition of crop is reported; another condition report is issued for August 10 with a preliminary yield forecast; further yield forecasts follow for September 10, October 10 and November 10; then an estimated yield and total harvest report appears in December.

Altogether, a similar procedure is followed for about 80 primary crops with number of estimates for each crop depending on the nature of the crop (Ref. 10). Not all of these crops are as widely distributed as corn; some are significant in only one or two states. Concentration of the crop in its area of economic significance also varies by nature of the crop. These considerations affect the degree of coverage required for the sensors. Widely distributed crops such as corn and wheat can easily be handled by a sampling procedure with a low sampling fraction, perhaps 1/100 or even 1/200. For certain concentrated crops, however, 100% coverage by the sensors of their areas of concentration might be required in order that the desired estimates could be prepared by the SRS. Perhaps, some crops could not be satisfactorily dealt with by remote sensing.

It does not appear that the resolution requirements would be difficult to meet for widely distributed crops. If the sampling system could be demonstrated to be unbiased, then an adequate sample size would readily provide the needed precision. For the more concentrated crops, area and identification needs would pose a demand for resolution of one-acre units (approximately 200 ft × 200 ft). Significant gains over present techniques could be achieved with resolution of four-acre units (approximately 400 ft × 400 ft). It is believed that if crop identifications can be made correctly with high probability, 0.99 or better, then acreage estimates can be made easily with resolutions that can be provided. Determination of crop yields is highly desirable and appears feasible but much research still needs to be done. The assessment of (1) moisture in the plants above ground level, (2) density of stand, and (3) the chlorophyll-green conditions should make yield predictions possible. Ground recorded temperatures during the growing season might be added to improve forecasts.

From the above discussion for the corn crop, it is clear that a capability would be required to sense the agricultural areas of the U. S. at a rate of once per month during the growing season. Such a need seems to bar procedures for using film and bringing this film to earth by capsule. Instead, telemetering techniques should be employed.

With respect to the processing speed or rate at which the data must be made available, the SRS requirements are the most stringent of any of the agricultural applications to be considered. The Crop Reporting Board, a unit of the SRS located in Washington, D. C., is required by law to issue these crop forecasts and estimates for major economic crops on specified dates (Ref. 11 and 12). By custom, additional dates have become established for statistics on other crops. Thus, it appears that a telemetering technique must be combined with some form of automatic processing to produce numerical results in three to four weeks time from the "sensing period."

It is noted that the SRS now maintains 43 field offices which are engaged in the collection, summarization and review of agricultural statistical information (Ref. 11). From these field offices, the information is forwarded to the Crop Reporting Board for further review and issuance of the "official estimates." If a remote sensing and automated processing system is developed, it will still be desirable to distribute the results to the interested field offices for review in order that gross errors which enter from time to time into any numerical procedures may be detected and appropriate adjustments made.

Interest in these special needs of the SRS will range far outside this agency. There is a close relation of the SRS work to the Agricultural Census (Application 1) and the ASCS work (Application 2) described above. If an integrated system is developed that meets the needs of the SRS, then it is clear that many other applications will be aided or fully met.

Although aerial photography is now used in support of the SRS work, it is almost obvious that the frequency of coverage and variety of sensings which may be required for adequate crop identifications will preclude the use of conventional aerial photography for fulfilling this mission. Not only would the cost be great, but the processing bottleneck might not be resolved. On the other hand, the availability of a satellite system with a suitable variety of sensors aboard appears to offer hope for meeting the frequency of sensing need at a reasonable cost. Coupled with suitable automated processing, the time frame for needed estimates could also be met.

Accurate and timely forecasts and estimates of agricultural production are needed for the protection of farmers and the food consuming public. All the in-between elements of the links between food production and food consumption need this information on volume and location which determines prices. These elements include transportation, storage, processing, speculation, financing, marketing and wholesale and retail distribution.

The direct cost of the Agricultural Statistics Federal budget (SRS) is $14 million for 1966. Related expenditures are made in ERS and other parts of the USDA. Many of the 43 field offices of the SRS cooperate with the State Departments of Agriculture or other agricultural offices of the states where these field offices are located. A total annual expenditure for agricultural statistics activities of $20 million seems conservative. (Of these activities, however, about 50% of the expenditure is related to livestock estimates and economic information.) It seems likely that a moderate reduction in cost could be achieved by using spacecraft to supplement the present methods. A 5% reduction in cost, for example, would amount to $1 million per year.

An added benefit, and one potentially worth much more than that just mentioned, would result if spacecraft observation provided improved methods for forecasting. Important economic decisions which depend on these forecasts involve sums far exceeding the cost of the data. Improved forecasting could comprise more accurate forecasting of total crop yeilds, determination of the precision of the estimates, and more rapid acquisition and distribution of the data. Hence, gross benefits could range from a minimum of $1 million annually to as much as $10 million.

3.2.1.4. Resource Surveys. Search for new agricultural resources in the CONUS is of limited extent at present. No doubt currently available aerial photography has fulfilled and will continue to fulfill most sensing needs in this area. It is possible, however, that remote sensing with other sensors might reveal resources of value to agriculture that are at present unknown. Examples of the latter might be location of economically valuable deposits of fertilizer or other soil treatment materials. In studying areas for drainage, conversion from forest or cutover

Thus, there does not appear to be a continuing domestic requirement for remote sensing of the earth for this application. It is recognized that non-photo sensing may aid soil survey progress in various ways not yet defined, but it is not expected that such possible uses will place a specific additional need for a remote sensing system to operate on a regular basis. Instead, the multi-band sensors used for the major agricultural applications (1, 2, 3, above) should fulfill soil survey needs simultaneously.

Soil classification and mapping is an activity of the Soil Conservation Service. The total budget of SCS is about $200 million for 1966. An allocation of 0.5% of this budget for obtaining improved agricultural information would provide $1 million per year for support of remote sensing. If improved methods and/or more economic methods of soil classification by multi-spectral sensing were achieved, gross benefits of $1 to $5 million annually should be realized.

3.2.1.6. Conservation Program. Sensing of the earth's surface is a material aid in planning and later in measuring the effectiveness of a particular agricultural conservation program for an area or a region. Aerial photography is now used as a base frame of reference in considering the planning of a program. Essentially, the photo is a map, but more than a map, in that it shows general topography, terrain details, specific land features and presence or absence of vegetative cover. The sporadic nature in both space and time of these program needs does not pose a requirement for a regularly operating remote sensing system. Presently available aerial photography has been meeting these requirements satisfactorily, and will continue to be an appropriate way for supplying most of these needs for CONUS. If coverage of a desired area by a remote sensing system with a variety of sensors were available, it is likely that such coverage would be consulted from time to time for some special purposes. Examples of such purposes might be sensing of geologic and/or soil information, e.g., limestone out-croppings or types of soil layers exposed by gullying or sheet erosion. A further possibility would be an erosion survey for a complete watershed and the relation of this information to the siltation of reservoirs in the watershed or possibly direct assessment of the silt accumulation behind a dam. In extreme drought periods, such as took place in the years 1934-1938 in the Great Plains area of the U. S., remote sensing with a variety of sensors might contribute materially to understanding and assessing the magnitude of the disaster. The disaster assessment problem is further discussed in Application 10, below.

Thus, the Conservation Programs by themselves do not pose a general domestic requirement for remote sensing. Therefore, the requirement is considered a marginal one. If a satellite system were in existence and provided remote sensing information of various types, some of this information would be used in support of Conservation Programs in the planning stage, to some extent during development of the program and from time to time in assessing a program's progress or effectiveness. It is estimated that such utilization of the system could provide gross benefits annually ranging from 0.2 to 1.0 million dollars.

3.2.1.7. Agricultural Geography. Geographers interested in the agricultural aspects of their subject need descriptive information that will indicate broad patterns of land use and associated agricultural activities. Generally such patterns change slowly so that the information about them need not be updated frequently. Present aerial photography with U. S. coverage repeated every five to ten years has provided a large volume of geographical data. In fact, for domestic agricultural geography studies, a major problem is the extraction of the geographical information from the aerial photos. Occasional special geographical needs will occur, however, that will not be filled by the present time spacing of U. S. photo coverage. Some types of geographical information relevant to the storage, movement, and marketing of agricultural products can be obtained only by more frequent sensing such as already described for the application, Agricultural Statistics. Information of this kind is also relevant to studies in agricultural economics.

These additional needs for information on agricultural geography will arise from the requirements for interpreting existing broad land use patterns and for use in planning new programs for which large changes in land use are envisaged. Some examples that may be cited are contour farming, strip cropping, terracing and irrigation. The last may be of special interest if the combination of large nuclear power plants and desalinization facilities proves economical. Resulting major shifts in land use may be preceded by agricultural geographic studies.

With presently available aerial photography, it is unlikely that agricultural geographers will need any additional 100% coverage of the U. S. Some 100% coverage for selected regions may be needed from time to time plus sampling of these selected regions or other areas to secure more detailed information. As examples, full coverage at 1:62,500 or even 1:250,000 may be desired for areas such as Appalachia or Alaska. With these large areas, sampling at large scale would provide sufficient detailed information. There is no premium on processing speed for such studies. Availability of information within six months seems adequate.

Agricultural geographic information for the world outside the U. S. would be of considerable value at the present time. These interests will be considered later. It is sufficient to remark here that non-western agriculture, i.e., in the developing regions, exhibits patterns and configurations totally different from westernized, particularly U. S., agriculture. So far, geographers have not been able to study these land-people associations in an effective manner. It is expected that remote sensing will contribute much to these studies.

Agencies interested in geographical information within the USDA would be the Forest Service, Soil Conservation Service and Office of Rural Areas Development. Other interested groups would be agricultural research institutes, geography departments in the universities, and other universities engaged in agricultural research and teaching.

An existing spacecraft system for sensing the earth's surface would be a tremendous aid to geographers in providing an observation point of view not attainable with reconnaissance aircraft. Small scale images could show agricultural patterns not now discernible in composite mosaics showing large areas. Vegetation identifications provided by a multi-band equipped spacecraft would enhance the interpretations of geographers.

It is realized, however, that the total effort devoted to studies in agricultural geography in the U. S. is limited. The benefits from such studies may increase considerably in the future, particularly if remote sensing results can be processed and analyzed. Further discussion of geographic applications is found in Section 2.

3.2.1.8. Changes in Land Use. A continual reduction in the land available for agricultural purposes is taking place in the CONUS. Among the causes of these losses are super-highway construction, airports, urbanization (or spreading of suburbia), strip mining for coal and other near surface geological deposits, oil drilling and new industrial sites established outside of incorporated areas. It is difficult to collect and aggregate current facts on these changes in land use.* If sufficient data were available, a constructive control program for this variety of activities might be established. It is clear that these losses cannot be stopped, nor should they be, but their adverse effect could be reduced by selective allocation of less productive lands to some of these non-agricultural uses.

Availability of a remote sensing system for other applications already described above would fulfill the requirements for this application. In particular, Application 1, the Agricultural Census, could provide as an auxiliary output information on losses of agricultural land by diversion to other uses. Coverage required would be similar, i.e., essentially 100%. The resolution needed might have to be somewhat better than for other applications discussed. Measurement of rural settlement and spreading of suburbia would require detection and identification

*Approximations and estimates have been prepared at five year intervals by the USDA, see Ref. 13.

(perhaps, by use of several sensors) of cottages and small homes. An annual survey would certainly be adequate. Perhaps, a biennial report would be adequate. Thus, no great processing speed would be required. A separate processing for this application would not be economical, however, so land use change data could best be accumulated by minor civil division or county as processing was carried out for an Agricultural Census. Distribution of the summarized information to Federal and State agricultural agencies and to the Congress and State Legislature would provide adequate dissemination.

Availability of a satellite remote sensing system along with appropriate processing techniques to obtain 100% coverage of the CONUS would provide a unique method for assessing the land area losses from farming at a moderate cost in conjunction with other uses of the system. With aerial photography available no more frequently than once every five years, such information is not now compiled on an adequate basis. Partial information may be obtained from a variety of sources, but current overall estimates are not available of the changes in land use (Ref. 13).

This application is a part of the whole area of land use, and is thus related to applications in geography, forestry, hydrology and, perhaps, other areas. Further material on this application may be found under these other areas in this report but the viewpoint taken here is related in the main to agriculture.

A single sum total of land loss by counties, states, etc., would be sufficient from the agricultural viewpoint, i.e., land going out of farming, but for other subject areas sums of land loss might be desired for each of the uses such land is going into. The variety of these uses need not be listed here; it is likely that 10 to 20 categories would be required.

3.2.1.9. Economic Studies. In making economic studies, attention is often directed to 100% coverage of small specially selected areas or to larger areas by use of sampling surveys. When sampling is used, the sampling fractions may take a wide range depending on the nature of the study; the fraction might be as low as 1/1000 to as high as 1/20 or 1/10. In support of such studies, some physically sensed information could be quite helpful. The desired kinds of information will include data on crops and land resources. Aerial photography in terms of its mapping function has been and is being used in support of such studies. More use would be made of aerial photography if the desired information could be more easily extracted and if the coverage were available more frequently. With wide band remote sensing available, it is expected that Economic Studies will expand their use of physically sensed information. Specific examples lands to farming, return of presently farmed land to forest or range use, and irrigation, it may be of considerable value to employ additional sensors outside the visible light band.

Even so, if these potential uses should be developed, it is not apparent that a few large demands or even a modest continuous use for such remote sensing would be required in the CONUS. It is recognized, of course, that such remote sensing for agricultural resource assessment in other countries would be of great value. This need will be discussed below.

For Resource Surveys, it does not appear that a definable item of the 1966 budget can be attributed to this application. The U. S. has a continuing program of re-assessment of agricultural resources. This program is concerned with watershed and river basin studies which places a requirement for new photography and/or other imagery for a number of areas of the U. S. each year. Spacecraft observation could materially aid such studies. Overall planning studies of total needs for cropland and the resulting cropland diversion programs also depend on a re-assessment of our total agricultural resources.

From a broader point of view, this application, Resource Surveys, and the four following applications may be associated. These applications form a part of the whole subject of Geography and Natural Resources. Separation, therefore, is difficult and partly arbitrary. For Agriculture, a soil survey is a specific resource survey but it has seemed useful to consider the application separately. The same procedure has been followed for the next three applications. As a consequence of this separation, no specific allowance for benefits of remote sensing for Resource Surveys is made here. The subject of benefits is considered further in the following applications.

3.2.1.5. Soil Classification and Mapping. Aerial photography is now used for this application. The mapping is utilized in two ways: (1) Reconnaissance mapping of land areas at small scales, e.g., 1:62,500 down to 1:500,000, and (2) detailed soil mapping in which large scale photos, i.e., 1:15,840 or 4 inches to the mile, are checked on the ground by reconnaissance and by actual soil identifications using stream banks, erosion evidence and soil borings with hand augers. In some cases, augered samples may be taken to a soil laboratory.

It appears that aerial photography has fulfilled the needs for soil classification and mapping remarkably well. Availability of the aerial photos has made possible great savings in time and cost for soil surveys. There does not appear to be a requirement for much further reconnaissance mapping in CONUS. For further detailed soil mapping of areas in the U. S. not now so mapped, presently available aerial photos can supply most of the needs.

that can be suggested are the swampy parts of Florida, coastal areas of the Carolinas, forested northern areas, or arid western regions that are suitable for agricultural development.

Like Resource Surveys, no definite item for Economic Studies is found in the agricultural budget for 1966. Expenditures for Economic Studies may be included in the budgets for the Forest Service, Economic Research Service, Soil Conservation Service, Farmers Home Administration, Rural Community Development Service and the Federal Crop Insurance Corporation. Within the ERS alone, it is estimated that about $10 million is allocated to Economic Studies. Use of agricultural statistics and aerial photos for Economic Studies in these agencies is in a sense a second use of information already collected for a prior purpose. However, considering that the use of observation spacecraft will probably expand the availability of up-to-date photo type coverage, a range of $0.5 to $2.0 million appears reasonable as a measure of the gross benefits spread over these several agencies.

3.2.1.10. Damage Detection and Assessment in Agricultural Areas. The types of damage to agricultural production may be listed as due to flood, windstorm, drought, fire, weeds, insects and diseases. Knowledge of the extent and degree of damage is particularly important for planning and programming disaster relief. Such information is especially needed in flood, drought and fire situations. Availability of the information may be thought of from the viewpoint of two phases of the situation. There is the immediate need in the case of floods and fires in order that relief needs for farmers and animals can be met promptly. Following on, there is the second phase of determining the total damage in crop loss and its economic value. This latter knowledge determines the development of the full disaster relief program, and consideration of alternative catch crops still possible in the same season. Further, such knowledge will aid the planning on a world-wide scale that will be needed to assure future food requirements; a crop loss in one hemisphere may be compensated for by additional plantings in the other hemisphere.

Unfortunately, meeting of the immediate need for information may be hampered by weather conditions, cloud cover, smoke cover, dust storms, or atmospheric moisture content. Photographic reconnaissance, or other band sensing, may not be feasible under such circumstances. Radar sensing from aircraft could be effective in some of these circumstances. It does not seem reasonable to include the radar band for sensing in an unmanned remote sensing vehicle for this limited agricultural use alone; but if such a system could serve other purposes as well, it might be justified economically.

The second phase needs may be especially suitable to assessment by multi-band sensing. Some remarkable potentials for insect and disease damage have already been indicated. Windstorm damage in citrus fruit areas or flattening of grain and corn in the Middle West from cyclonic winds or aftermaths of hurricanes also should be subject to assessment by multi-band sensing.

Coverage required would ordinarily be limited to regions no greater than two or three states at most and often only part of a state. For example, the floods during the winter 1964-65 in the West affected northern California, Oregon, Washington, and small parts of Idaho. Occasionally, need would arise to cover large areas because of continued heavy rains or prolonged drought. Considerable flooding occurred in the midwest in 1947 from heavy rains, and in the 1934-1938 period, drought effects covered 2/3 or more of the area from the Appalachians to the Rockies. Both sampling and 100% coverage of a specified area would be needed; coverage demanded would depend on the type and spread of the disaster.

Only moderate resolution would be required for most disaster sensing in terms of detection and identification. A unit, 800 ft × 800 ft, or about 16 acres resolved and identified would appear to be adequate. When detection and identification has been made, however, a need may arise for a follow-on survey to support the SRS (Application 3, above) in bringing the effect of the disaster into the current crop forecasts and estimates.

Processing time must be kept short to make information on disaster extent and effects rapidly available. In order to be fully useful, the allowable delay in making information available should approximate that for the SRS (Application 3). Certainly, no longer than a month should pass before the facts are available.

Most divisions of the USDA would be interested in disaster sensing information with some agencies showing greater interest in certain kinds of disasters. For example, the ARS would be most interested in "insects and diseases" along with the SRS. Interest would extend to the Agricultural Census in fully assessing the economic effect of any particular disaster. Distribution would often need to be made to the State and County levels of the USDA agencies, i.e., to extension offices and associated cooperating agencies. Many state and local relief or cooperative agencies and societies would be aided by such physical sensing of disaster of a reliable and quantitative type. Not only would the directly involved divisions of the USDA utilize the disaster information, but all marketing and economic units would be aided by the rapid and reliable availability of such information.

There is no doubt that much fuller knowledge of agricultural disasters could be obtained by sensing from aircraft, but it is not being done. Partially, the problem is one of cost, of course, but the irregular occurrence and broad dispersion over the country have contributed, perhaps, to the lack of organization of an activity for adequate assessment of these effects. Availability of a satellite system with appropriate sensors for the purposes outlined above would inevitably lead to its use for study and measurement of the disaster effects. Many kinds of information not at all available now, or only poorly assessed, would become available rapidly with acceptable reliability.

The importance of damage assessment can be judged in terms of the magnitude of damage which must be dealt with and the funds expended for disaster relief. "Approximate Damages by Floods in the United States" have been tabulated by years for the period 1927-1953 (Ref. 14). These damages range from low values of 3, 10, 10 and 14 million dollars for 1931, 1932, 1934, and 1939, respectively, to $1,029 million for 1951. The figure for average annual damage is given as $160 million of which a considerable portion comprises damage to farm crops.*

In contrast to the flood situation, we may look at the drought situation in the 1930's. Evaluation of the economic effects of this drought period might be made in several ways. As a consequence of the abandonment of seeded acreage due to the drought conditions, large areas of seeded acreage were not harvested. The annual economic loss directly associated with the abandoned acreage for wheat amounts to $20 million to $40 million, on the basis of a rough estimate of $2 per acre for the seeding of the crop using data taken from Ref. 10. Similar substantial losses occurred for a number of other crops. Indirect losses are associated with the loss of income of the farmers affected by the drought and the higher prices paid by consumers for the reduced supply of food.

The losses due to floods and droughts pale by comparison with those due to insects, crop diseases, spread of noxious weeds and poor cultural practices in controlling weeds. So far, it has not been possible to prepare good estimates of the effects from these causes. In Ref. 15, which describes a preliminary appraisal published in 1954, the aggregated losses from these causes were about $7.5 billion in the U. S. alone. Expressed in another way, elimination of these losses would add to current production the output of at least 90 million acres. It is expected that satellite observation could aid materially in improving these estimates, detecting the presence of known pests, diseases and weeds in new areas, alerting us to new or previously unknown

*The subject of observation of flooded areas is considered further in Section 5.

threats to production in any area, and planning control or elimination programs. Hopefully, such observation would enable us to predict potential disaster so that resources could be directed to control or alleviation before serious losses occurred.

As indicated in the U. S. budget, the Federal Government expands substantial sums for damage assessment and disaster relief. Famine Relief, an explicit item, is principally for developing countries. In the ASCS budget, we find Emergency Conservation Measures (land damaged by natural disasters) with an average annual expenditure of about $4 million. Parts of the SCS budget can be regarded as the consequences of Damage Assessment, e.g., Watershed Protection, Flood Prevention and Resource Conservation in the Great Plains. From these items, perhaps $50 million of the combined budgets might be related to Damage Assessment. In the exposition of the budget of 1966, the President referred to "Disaster Relief." Expenditures were programmed at $56 million and $57 million, respectively, for 1965 and 1966. Undoubtedly, state and local expenditures greatly increase these total figures.

Damage assessment, as now carried out, could be much improved. Rapid and accurate information would contribute to making sound decisions concerning immediate steps to provide relief and protection to farmers and to minimize economic loss. Within the limits of man's ability to control the situation, moderate reductions in damage and loss could be anticipated, ranging from $1 to $10 million annually. Even more significant benefits would arise from the availability of accurate knowledge as to location and extent of a particular loss to agricultural production. Accurate knowledge leads to positive and appropriate action. An informed legislative body and public will more often take the action needed to support and direct the research and action programs needed to reduce or essentially eliminate a loss of needed food and fiber production.

3.2.1.11. Snow Surveys. Snow depth measurements are now made by the SCS of the USDA. Knowledge of the snow cover is important to many of the irrigation districts in the Western U. S. Knowledge of snow cover also is needed in the Eastern and Northeastern U. S. Utilization planning for water use in the summer season will become more dependent on the knowledge of the snow cover. It is understood that experiments to date show a potential for snow surveying by measurement of the passive microwave emission from the earth's surface. This radiation is affected by the depth of snow cover. It is expected that much research and experimentation still needs to be carried out in order to develop, establish, and measure reliability of a suitable snow surveying system based on remote sensing. This development period may require 10 to

20 years in order to accumulate sufficient data for correlation and prediction. Because of this time frame, the research and development program should be gotten underway as soon as feasible.

Initial coverage required for an operational snow survey system would be for the western half of the U. S. Coverage also would be desirable for the northern part of the remainder of the country. It is believed that sampling could be used for many watersheds but 100% assessment of some areas would be needed.

Since knowledge of the technology of passive microwave emission is limited at present, it is difficult to specify an appropriate resolution. This resolution must be determined both for area measurement and depth and density of snow measurement. Initially, it seems that useful information might be gathered for units no smaller than 20 or even 40 acres (the latter is 1/4 mile on a side), but eventually better areal resolution would be desirable.

For agricultural purposes, several measurements during the winter season would need to be made. Final assessment would probably be made in late April or early May of each year with some areas sensed as late as early June. These requirements are convenient since they are partly complementary to other agricultural needs for remote sensing.

It would be desirable for agricultural purposes to have the results of snow surveys available in two weeks so that crops, crop acreages and water use can be programmed for irrigation districts where water supplies are essentially rationed. The snow survey results would need to be summarized by watersheds and distributed to the water control agencies in each watershed. Other interested agencies would be the Bureau of Reclamation, Army Corps of Engineers, and USDA units such as ASCS, SRS and the FCIC (Federal Crop Insurance Corp.).

The preceding discussion provides only a general review of the subject of snow surveys from the viewpoint of application to agriculture. Additional more detailed discussion of snow surveys is given in Section 5.2.1 under Water Resources. It is appropriate here to give an indication of the potential benefits to agriculture alone. According to Reference 13, about 17 million acres are irrigated with surface water in the 17 western states. Nonirrigated crop lands in these partially arid states comprises an additional 152 million acres. It should be noted, too, that about 14 million acres are irrigated from ground water, i.e., from wells or by pump irrigation.

To what extent could these crop lands support snow surveys? Snow surveys would have their greatest value for surface water irrigation areas. At five cents per acre, a figure of $850,000 would be obtained for the 17 million acres. Taking one cent per acre for the nonirrigated areas in these 17 western states, we obtain $1.5 million. From these considerations it appears that gross benefits from snow surveys could easily range from $1 to $5 million annually. In unusual years of heavy snow or light snow, accurate knowledge would yield much larger benefits.

3.2.1.12. Surveys for Water Supply Prediction. In part, this application has already been considered under Snow Surveys (Application 11, above) Estimation of equivalent water volume from snow surveys for irrigated regions of the CONUS is a major part of the water supply prediction problem. It is expected, however, that in some cases multi-band sensing might yield information on the available soil moisture for crops outside the irrigated areas.

An example would be soil moisture available to wheat plants in the Great Plains region of the Western U. S. States included in this area are Texas, Oklahoma, Kansas, Nebraska, North Dakota, South Dakota, and parts of Minnesota, Montana, Wyoming and Colorado. Knowledge of soil moisture conditions in these states would add much to the ability to forecast and estimate the wheat crop. Part of this knowledge would come from snow surveys as already indicated.

In the more densely settled areas of the U. S., east and northeast, knowledge of the water supply at all seasons will become more important in the future and in some years critical. In the 31 humid area states, utilization of ground water and surface water for agricultural purposes has been increasing each year with consequent competition for and pressure on the supplies. Such irrigation is used for high per-acre value crops and to improve the seasonal distribution of the natural rainfall. Remote sensing may simplify water accounting for lakes and reservoirs otherwise not readily accessible. If soil moisture can be assessed in watersheds of interest, then flow into storage lakes and reservoirs, perhaps, can be estimated throughout the season. Thus, it is reasonable to expect that a combination of snow surveys and other detection of rainfall and soil moisture would improve the accuracy of water supply predictions.

It is realized that this problem of water supply estimation and prediction is an exceedingly difficult and complex problem. Many plausible techniques have not achieved the desired results. Nevertheless, much progress has been made in recent years by hydrologists and meteorologists in understanding the water balance problem. Thornthwaite and Mather have summarized much of this progress in Reference 16. Yet variability from season to season and within seasons remains a problem. It is hoped that remote sensing will add significantly in improving measurements and predictions of water supplies.

Coverage required will be 100% for areas of specific interest such as lakes or reservoirs, but sampling should be adequate for measurement of large areas. In terms of area, only modest resolution would be required, to handle units of 20 or 40 acres in size (latter 1/4 mile square)

About four to six surveys during the growing season would be needed to supplement the snow surveys. In addition, surveys of specialized areas would be required at times depending on each year's conditions, also surveys of selected areas with 100% coverage.

Fairly rapid processing of information on water supplies would be desirable. It is expected, as for snow surveys, that some type of integrating measurement system may be developed that would essentially automate the processing. Then processing speed should not be a problem. During the growing season, survey results should be made available in five to ten days. The water supply predictions would be distributed to all federal, state and local agricultural agencies. In addition, state and local agencies interested in water supply for industrial, navigational and domestic uses would utilize the survey results.

The possible benefits to agriculture of water supply knowledge supplied by satellites are difficult to estimate at the present state of the development. The ability to assess soil moisture and/or the water available to or in the plant cover would, as indicated above for wheat, assist materially in assessing crop conditions and forecasting yield. This benefit would contribute to Application 3. Possible benefits from knowledge of drought conditions have already been indicated in Application 10. If a working satellite system for the purposes indicated here becomes available, it appears that average annual gross benefits of $1 to $5 million could be obtained. Again, as for snow surveys, benefits likely would be greater in unusual seasons. These benefits would be spread in one way or another to over 400 million acres of cropland in the U. S.

Further discussion of the water supply prediction problem for agriculture is given in Section 5.

3.2.2. APPLICATIONS IN OTHER DEVELOPED COUNTRIES. In considering the application of remote sensing for securing agricultural information, it seems obvious that all modern nations can utilize all of the applications already described for the CONUS. In Canada, for example, agricultural production is organized in much the same manner as in the U. S. Except for some differences in agricultural programs (Application 2), the 12 applications listed and detailed above would be applied about as described. Even for Canadian agricultural programs, the basic sensing requirements likely would not be changed although processing requirements might be less complex and less time constrained. On the other hand, for soil classification and mapping (Application 5) considerably more large scale resolution sensing for mapping purposes may be needed. Such differences, however, do not appear to warrant separate discussion of each of the applications for Canada and other developed countries.

In certain other areas of the world, remote sensing would likely be employed in much the same manner as in this country. In North America we may, perhaps, include Mexico as well as Canada. In South America, Uruguay plus parts of Argentina, Brazil and Chile may be regarded as developed areas. All of Europe would be included in the developed countries. Next, Australia and New Zealand would be wholly included as developed regions. Only limited areas of Africa and Asia, would be included in the developed areas, e.g., Japan and the southern tip of Africa.

The amount of use or importance of each of the applications would vary from one developed country or region to another. Certainly, the agricultural census application would be a prime requirement in all developed countries and it is likely that sensing surveys for producing agricultural statistics (crop forecasts) would be the second requirement. Further listing or ranking of the requirements for the various applications by country would exhibit considerable variation.

The developed countries itemized above cover a total area of more than 10,000,000 square miles, and have populations totalling about half a billion people. Without attempting to perform individual analyses of each country, it is conservative to assume that the economic benefits for these countries would be equal to those assigned to the United States, or in the range of $20 to $50 million annually.

3.2.3. APPLICATIONS IN THE DEVELOPING REGIONS. One of the major problems facing the world today is that of increasing agricultural production to keep pace with the rapidly expanding world population. Much of the activity of the United Nations (in particular, the FAO) and more recently the U. S. Alliance for Progress has been concerned with the food supply and, hence, the agricultural problems of the developing countries. Publications of the USDA and FAO have indicated the degree of malnutrition present in most of these developing countries and the need to improve the food supplies by increased domestic production in each country.

Reference 17 states that "two-thirds of the world's people live in countries with nutritionally inadequate national average diets. The diet of people in these areas averaged 900 calories per day below the level of the one-third of the world living in countries with adequate national average diets in 1959-61, and 300 calories below the average nutritional standard for the diet-deficit areas. The daily consumption of protein was less than two-thirds of the level in the diet-adequate countries; the fat consumption rate was less than one-third."

According to Reference 4, the world population is expected to rise by the year 2000 to approximately 6,280 million persons, unless effective methods of population control can be introduced. The amount of arable land per person will have been reduced to just over one-half acre at the end of this century, compared with the 1.25 acres that were available in 1955 (Reference 18). "No matter how optimistic is our outlook, the countries of the world have to solve serious problems if their people are to get enough food in the future, even though, in some parts, surpluses of a few products create problems of a different type." (Reference 4).

The United States is greatly concerned with the humanitarian aspects of the situation, but in addition, we also have a great stake in finding a solution to the problem because of the tremendous political, military, and economic repercussions that will otherwise ensue.

It is recognized that food-production technology alone cannot solve the food problem. International cooperation will be required, and the developing countries themselves must take the necessary steps to provide political and economic stability and to educate their population in improved agricultural methods. If this basis can be provided, however, the necessary scientific knowledge is available to solve the problem of food production.

Studies of the problems of increasing world food supplies stress the need for adequate planning and supervision of the agricultural program. Reference 17 states that "if the developing countries are to speed up their rate of progress, economic and technical assistance will have to be expanded and used more efficiently. Especially, the developing countries need to do some long-range planning. Without such planning, economic and technical assistance frequently is not as effective as it should be."

In order to meet the desired food requirements, there will thus be a strong incentive to place the planning and management of world food production, storage and processing on a basis approximating the techniques used in this country. It is expected that individual developing countries may pattern their technical and administrative practices after those of the U. S. and ultimately pursue similar goals. Thus, there is a great need for obtaining information about food crops on a world-wide scale.

3.2.3.1. Types of Information Needed. The developing countries generally need the same types of information about their agriculture as the USDA currently collects for the U. S. Yet it is realized that the task of acquiring adequate data on the world's agriculture may take a long time; perhaps as much as one or two generations.

A prime need for each developing country is a current agricultural census of reasonable accuracy. Such census data combined with the continuing collection of agricultural statistical data will enable the country to monitor current production and predict crop yield, so that serious maldistribution or shortages of food can be counteracted in time.

Concomitant with this primary need, however, is the requirement for both complete and sampling surveys. Information obtained from such surveys should permit optimizing the use of the limited land resources available for agricultural production, and protecting and improving these land resources through appropriate conservation programs. The types of information required have been discussed in connection with applications described in Section 3.2.1 as:

- Agricultural Geography
- Resource Surveys
- Soil Classification and Mapping (Reconnaissance)
- Economic Studies
- Conservation Programs

An interesting example of the possibilities of resource surveys is provided in Reference 19. The campos cerrados is a scrub-growth savanna covering large areas of Brazil. There are roughly 22 million acres of this savanna in Sao Paulo State alone and "in a partially studied region of Central Brazil . . . it is estimated that there are 400 million acres of campos cerrados." Research has shown that the essential problem is one of high soil acidity which can be alleviated by adequate application of agricultural limestone and some fertilizer. This resource problem would be an excellent application, if a multi-sensor satellite could firm up these figures and check on the progress of rehabilitation of these areas.

In the developing countries, there is also a great need for improved damage assessment. Floods and drought are often more severe in their effects because of the lack of transportation. Famines occur frequently because of the combination of crop damage, poor transportation facilities and bare subsistence incomes. The current eradication campaign against the locust hoards in Africa and Asia illustrates the importance of damage inflicted by insects and diseases. Only by securing improved knowledge of such damage can the proper campaigns be initiated for alleviating these losses and thereby increasing the total food supply.

One other use seems to have immense potential. Consider a world survey of the chlorophyll-green condition! Such a survey would be equivalent to a world fertilizer survey! The need for increased fertilizer production in the USSR has come to the world's attention in recent years. Such a world survey of fertilizer needs would be worth many times its cost. The information would be of value for the chemical industry in both the U. S. and the rest of the world, it would be useful information for our Economic Assistance program, and it would help the developing regions in the stimulation of their own fertilizer production programs.

This fertilizer example points up the tremendous value of accurate information to private industry and industrial development related to agriculture and food production. Availability of an operating remote sensing system, which could be tapped by private firms or whose outputs could be made available upon request, would be of great use in planning and guiding investment decisions by both US-based and overseas companies interested in the economic and resource potential of these developing regions. The satellite surveys could assist in assessing the needs, finding the resources and determining optimum and efficient industrial locations.

In view of the large areas which need to be surveyed and the high cost of the required remote sensing using aircraft as the sensor vehicles, it appears that a spacecraft system is the most appropriate method for securing much of the needed agricultural information. Measuring current production and locating the agricultural resources available for future increased production will secure the information needed to increase the quantity and improve the distribution of the world's food supply.

3.2.3.2. Potential Benefits. The preceding discussion has emphasized the need for increased agricultural production as a world-wide problem. The United States also has other more direct interests in assisting the solution of the problem. One way of evaluating this interest is in terms of our public expenditures. The 1966 budget gives information about our programmed expenditures in areas relating to the agriculture of the developing regions. These expenditures are listed under a variety of headings, e.g.:

Economic Assistance
Alliance for Progress
Agency for International Development (AID)
Peace Corps
Food for Peace
Foreign Agricultural Service
Sale of Commodities for Foreign Currency (P.L. 480)
Grants of Commodities for Famine Relief

A grand total of about $4 billion covers the costs of these Foreign Related Programs.

Not all of the programmed expenditures are directed at the improvement of agricultural production, processing and distribution of food in developing regions but certainly a major part of the funds have this purpose. A rough estimate is that from $1 to $2 billion is directed to the improvement of agriculture in the developing regions.

Thus, improvements in the foreign agricultural situation can benefit this country in two ways: (1) by reducing the amount of our direct contribution to aid foreign agriculture, and (2) by enhancing the possibilities of foreign trade with other countries, providing an outlet for our own products.

A further area of our interest is the concern of the USDA is preventing the introduction of insects and diseases into the U. S. that may lower the quality and quantity of our own agricultural production. By knowing about damage from insects and diseases in other lands, we can keep alert to the dangers of introducing them into our own country.

The magnitude of obtaining even a single coverage of remote sensing from aircraft of the developing countries can be understood by considering that the total area of all developing countries is more than 10 times the area of the CONUS. A single complete survey, which might very well cost from $100 to $200 million, would be faced with many practical problems in its execution, and would take years to complete. The need for repeated coverage for crop estimates and predictions, even if limited to small sample fractions, would increase the cost still further. Nevertheless, such data would be extremely valuable in the planning necessary to reduce the world food deficit which it is estimated will attain a value of 1970 in equivalent U. S. prices of $6.8 billion (Reference 17.

The value of remote sensing data may also be judged strictly in terms of U. S. expenditures for foreign aid. As already noted, our budgetary expenditures related to the improvement of agriculture and food production for these regions exceeds $1 billion annually, and may be nearer to $2 billion. The larger figure would be obtained on the basis that the agriculture related programs comprise 40 to 50 percent of the grand total for these Foreign Related Programs. Now, how much should we devote to an annual assessment of the status of the developing world's agriculture for which the U. S. taxpayer makes such large annual contributions? By taking a conservative view, one percent gives us an allocation of from $10 to $20 million, say $15 million per year. Surely, such amounts are not out of line if we could determine how much progress we are making in improving the developing world's agriculture and food production (note that the budget table shows less than $1 million now devoted to checking on foreigh economic assistance).

3.2.4. EXPENDITURE DATA FROM THE 1966 BUDGET OF U. S. In Sections 3.2.1 and 3.2.3, the 1966 Budget of the United States is referred to in connection with the discussion of potential benefits of agricultural applications. Selected agriculture and economic assistance related items from the Budget for Fiscal Year 1966 (Reference 5) are presented below. Figures given are expenditures rather than new obligation authority

Item Description	1964 Enacted (Million)	1965 Estimate (Million)	1966 Estimate (Million)
Department of Commerce			
The 1964 Census of Agriculture	$ 1,206	$ 15,473	$ 6,056
U.S. Department of Agriculture Agencies			
Agricultural Stabilization and Conservation Service (ASCS), USDA (Total)	717, 794	666,512	618,387
Cropland Conservation Program	7,097	14,162	8,430
Conservation Reserve Program (Rental Payments)	289.9	197.0	152.2
Agri. Conservation Program (High Priority practices)	213.563	225.6	222.8
Emergency Conservation Measures (Lands damaged by natural disasters)	3.393	6.384	3.278
Expenses, ASCS	116.845	111.560	136.701
Commodity Credit Corp. (CCC), USDA			
Price Support and related programs	3211.3	1551.4	1939.6
Public Law 480— sale of Commodities	1415.3	1246.7	1140.0
Total CCC Budget	5100.3	4105.0	3677.7
Famine Relief, CCC, Grants of Commodities	228.2	210.5	305.6
Agri. Marketing Service (AMS), USDA			
Special Milk Program (Removal of surplus)	97.5	103.0	100.0
School Lunch	180.7	190.9	202.0
Food Stamp	30.4	59.6	99.6
Perishable agri. commodities	0.8	0.9	0.94
Removal of surplus agri. commodities	239.6	241.8	311.7
Total, AMS	594.0	637.3	732.5
Statistical Reporting Service (SRS), USDA (Agricultural Statistics) Total	11.184	11.869	14.316
Economic Research Service (ERS), USDA (Related statistical activities) Total	10.016	10.705	11.306
Forest Service (FS), USDA Total	317.0	360.7	340.0
Soil Conservation Service (SCS), USDA			
Conservation Operations	96.0	103.6	84.0
Watershed Planning and Protection	62.8	65.0	70.5

Item Description (continued)	1964 Enacted (Million)	1965 Estimate (Million)	1966 Estimate (Million)
Flood Prevention	22.4	25.3	25.7
Great Plains Conservation Program	11.9	13.2	14.4
Resource Cons. and Development	0.3	1.8	3.7
Total, SCS	193.3	208.9	198.3
Federal Crop Insurance Corp. (FCIC), USDA Total	7.1	7.5	8.5
Farmers Home Adm. (FHA), USDA Total	259.4	247.8	150.6
Rural Community Development Service (RCDS), USDA Total	0.187	0.337	0.718
USDA, TOTAL (includes items given below)	7896.9	6858.9	6357.4
Foreign related programs			
Foreign Agri. Service (FAS), USDA	19.9	22.7	23.0
PL 480—Losses on long term sales contracts, USDA (additional to PL 480 given above)	60.5	204.3	215.5
PL 418—Sale of Commodities, USDA for foreign currencies (repeated from above)	1415.3	1246.7	1140.0
Famine Relief, USDA (repeated from above)	228.2	210.5	305.6
Office of the President, Economic Assistance			
Technical Cooperation and Development Grants	226.3	190.0	205.0
Int. Org. and Programs, e.g., UN, Indus Basin Development	178.9	125.0	105.0
Supporting Assistance	371.0	370.0	390.0
Contingencies	121.8	75.0	70.0
Alliance for Progress Tech. Coop. and Development Grants	94.4	90.0	89.5
Alliance for Progress Dev. Loans	112.6	195.0	228.0
Office of Inspector General, Foreign Assistance, State	0.024	0.020	0.015*
Total, Economic Assistance, Office of the President	1996.8	2050.0	2100.0

*Advances of $825,000 from other appropriations will finance continued review of foreign assistance activities

Item Description (continued)	1964 Enacted (Million)	1965 Estimate (Million)	1966 Estimate (Million)
Peace Corps, Office of the President	60.4	80.0	105.0
Food for Peach Program (included in PL 480 and Famine Relief items, USDA, given above)			
AID (Agency for International Development) (Included in several items under Economic Assistance, Office of the President, already listed above).			
Grand Total, Foreign Related Programs (in USDA, Economic Assistance and Peace Corps)	3781.1	3814.1	3889.1
Total Domestic Related Agricultural Budget (Dept. of Commerce and USDA less foreign related items)*	6174.2	5190.2	4679.4

3.3. CONCLUSIONS

The development of an observation spacecraft system carrying appropriate multispectral sensing devices would add to our stock of information about the world's agriculture and food production, increase the accuracy of this information and allow determination of the precision of this information. In order to obtain these benefits the sensing devices must provide accurate and reliable methods for identifying crops, estimating their health and state of maturity, measuring the areas and yields of these crops and measuring water availability for crop and grass growth. With such capability, the system would have many useful applications in agriculture. A ranking of these applications for the CONUS places the first five in the order named as:

1. Agricultural Census
2. Agricultural Statistics
3. Agricultural Programs
4. Damage Detection and Assessment
5. Crop Water Supply (surveys of snow, soil moisture, etc.)

For other developed countries the most important applications are considered to be 1, 2 and 4 from this list of five ranked in that order. In the developing regions, the first requirement is

*In relation to domestic agriculture alone, perhaps the Forest Service budget should also be subtracted from these figures which would reduce them about $350 million. Agriculturally related items which appear in the Department of Interior (Bureau of Reclamation for irrigation) and USA Corps of Engineers (flood control, etc.) budgets have not been listed in this table.

for the agricultural census application. Next come agricultural resource surveys and current agricultural statistics ranked in that order.

If observation spacecraft were applied to those applications for which they appear to be most adaptable, gross domestic benefits ranging from \$20 to \$50 million annually could be obtained to cover the cost of preliminary research and development, spacecraft construction and launch, and data transmission and processing. Applications in other developed countries would be similar to those in the United States, and could produce benefits to those countries at least comparable in magnitude to those for the United States. For the developing countries, which are faced with critical problems of food production, data obtained by remote sensing from spacecraft could provide much of the information needed for long-range planning of optimum land use and conservation, and could assist in the short-range tasks of predicting crop yields and forecasting maldistributions or shortages of foods. In terms of the direct interests of the United States, a minimum expenditure of \$10 to \$20 million per year would not be out of proportion to the \$1 to \$2 billion of U. S. funds devoted to foreign aid for agriculture. A much larger figure could be justified by considering the cost of obtaining the same types of data by conventional aircraft.

Finally, in terms of the extremely critical food situation faced by the world's population and the potential social and political consequences, the advantages of rapid and comprehensive data collection by observation spacecraft could outweigh any cost considerations. "How can the developing regions ever catch up?", has long been the question. It has seemed that medical progress plus public health measures and continued high birth rates in these regions have combined to keep pace with or even exceed their small gains in food production. Thus, it has been considered naive to believe, much less even to hope, that it would ever be possible to adequately feed the world's people. But recent progress in the technology of birth control and the current rapid increase in its social acceptance indicates that population limitation is now beyond the dream stage. Therefore, it no longer may be regarded as naive to expect to feed the world's people adequately.

What level of population, stabilized or even fluctuating within broad limits, the world may reach in the light of these new developments may not become clear until the next century. We do have considerable capacity yet for expanding the production of food. As the limit of this capacity is approached, the planning required to produce the desired variety and quantity of food must become more detailed and quantitatively exact. Such planning can only be successful with good information inputs. Spacecraft observation to assist in securing this information presents us with some of the "seven league boots" potential that must be investigated.

4
FOREST RESOURCES

4.1. BACKGROUND

The forest is a dynamic and varied resource that produces a variety of benefits and products. Timber products are the most obvious, but wildlife, recreation, water, and forage for livestock are also important benefits derived from forest areas, in addition to which the forest resource provides continued employment for millions of people. Wildlife resources are considered separately in Section 6, water resources in Section 5, and forage for livestock in Section 6.2.1.4. The values of forest areas for these other purposes may rival the value as a source of timber; for range and water values of a given land area often exceed the timber values by 300 or 400 percent. However, since this report includes specific sections related to these products of forested areas, the analysis in this section is directed almost exclusively toward the timber products visualized by many laymen as "the forest."

Forest products industries, including lumber and building materials, pulp and paper, and chemicals (largely cellulose to date) constitute one of the four largest industrial complexes in the United States, based on gross revenue. The forest resource may prove to be the largest, untapped chemical storehouse known to man. Intelligent management practices both in the United States and throughout the world are needed if it is to meet the increasing demands placed on it.

Expanding populations and the attendant needs for more food and more land for people to live on result in direct destruction of forests. The resulting pressures on these resources are as significant as those in agriculture. Population pressures are forcing forest production off more accessible sites to make room for urban growth and the attendant agricultural fields needed to feed the massed population. The land base from which all forest production stems will not increase in the years ahead.

Although forests are renewable, the soil or land base on which they must be produced is vulnerable. As this land base must meet increasing requirements, its total size and distribution become increasingly important.

As in agriculture, many problems stem from poor distribution of the resource rather than from shortages in the total world supply. Distribution of commercial tree species is almost as erratic as the distribution of mineral resources, and one region often has an oversupply of one kind of forest products but must import others.

The mistaken belief that large trees are always indicators of good agricultural soils has often led to destruction of highly productive forests on lands where forest population was the highest economic land-use. Resettlement attempts in Northern Minnesota during the 1930's, in the Atlantic coastal lowlands of northern Costa Rica, and in northeast Peru are illustrative. Such misguided agricultural exploitation frequently destroys the capacity of the soil to produce commercial forest crops.

Forests exert a major influence on climate, available water, and animal populations and often affect land areas considerably removed from the forest itself. Thus, changes in size or character of the forest in one area may exert profound pressures on other areas. Local problems become regional ones which can escalate rapidly into national, continental and world problems. Forest research is thus being forced into a world perspective.

To understand the influences of forests on other natural processes and to guide decisions on the proper use of forest lands, a comprehensive world inventory of the forest resource is needed. Existing inventory methods do not give an adequate picture of the total resource because of the time required to gather and analyze data. The first data collected may be obsolete and useless by the time a survey is finished. Rapid data collection from orbiting platforms could be a significant breakthrough for forest managers and resource planners.

Forest fires are a serious problem in many areas and the possible improvement in early fire detection capabilities that could result from passive microwave or infrared surveillance from an orbiting platform should not be overlooked. However, forest losses to disease and insects are even more serious threats than fire. Multi-sensor reconnaissance from an orbiting vehicle might provide data on insect or disease infestations on a world basis that would help understand the total forest productivity.

Forest inventory and cost data are most readily available for the United States and much of the following analysis of forestry applications is based on United States statistics. Since only 760 million of the approximately 10,885 million acres of the world's forest lands are in the United States (about 7%), benefits from spacecraft reconnaissance systems will be much greater on a world-wide than on a national basis.

4.2. DESCRIPTION OF APPLICATIONS

4.2.1. FOREST INVENTORY. No accurate inventory of the forest resources of the world has ever been completed. Attempts have been made but time elapsed between start and finish has made it impossible to compare or collate the data in a single time frame. The Food and

Agriculture Organization of the United States (FAO) is continuously attempting to evaluate the world forest resources. Periodic estimates have been published but high costs, poor records in many countries, and refusal of some governments to permit FAO survey teams to enter their borders leave several areas of uncertainty.

Effective management of any natural resource requires knowledge of yields that are possible or expected. Forest yields are often visualized as the flow of forest products harvested from a forest during a given period, or at a particular time. In this sense, yield means growth, for in the long run it is impossible to cut more than is grown.

As pointed out in the introduction to this section, forests provide a variety of benefits, a variety of yields. The tendency to visualize a forest as nothing but a collection of trees leads to grossly underestimated values for forest areas. But, since recreation and many other values are hard to quantify, financial advantages of spacecraft systems are here based on the timber resource alone.

Estimation of timber yields requires good inventory data. The intensity of inventory required varies with management objectives but the basic types of data required are the same at all levels. These are:

1. Forest Location and Distribution

It is impossible to manage anything unless you know where it is and how much of it you have. Total area of forest land, its location within a country or continent, and the distribution by species or species group within the total area are important. A reliable map of forest areas of the world can be prepared from spacecraft data and would fill much of this need.

2. Tree Size

Yields of lumber, wood particles, pulp, and chemicals come from trees, or parts of trees. Tree size controls the number of product units (board feet of lumber, tons of wood pulp, etc.) that can be cut from a forest, and influences the type of product produced. In conventional forest inventories, it is customary to measure:

a. Tree diameter (of bole or crown)
b. Tree density (number per acre or degree of crown closure)
c. Tree height (merchantable or total)

Experience with aerial photographs indicates that existing techniques will not permit tree height measurements of sufficient accuracy for forest inventory purposes to be made from orbit altitudes. On the other hand, crown diameter and crown density determinations should be possible from spacecraft imagery.

3. Tree Quality

Crooked, damaged, or diseased trees yield less usable material than trees without such defects. Even though highly desirable and usually determined during ground inventory, tree quality has proven nearly impossible to measure from air photography. It is extremely doubtful that tree quality can be determined from an orbiting spacecraft.

4. Growth Rate

Growth rate determination has created problems for foresters for decades. At the present time, remeasurement of permanent sample plots and computation of the change in volume over time seems to be most satisfactory. If tree size determinations can be made adequately, growth rate can be estimated from any series of measurements of volume at different points of time. Volume estimates based on whole stands rather than on individual trees, are most likely to be successful. Tree heights will be almost impossible to obtain from spacecraft imagery and stand volume tables based on crown diameter, crown closure, and/or other factors will be required. Preparation of volume tables for use with spacecraft imagery should be possible.

5. Site Quality

Productive capacity of forest land is the basic resource upon which a forest industry must be based. Tree size, volume per unit area in existing stands, soil type, and many other factors are suggestive of site quality but no consistently applicable index of site quality is available. Foresters generally use total height at a designated age as a "site index," but such indices are applicable only to a single species and for a limited geographic area. On the basis of current knowledge, direct determination of site quality from an orbiting platform appears unlikely (see also Section 4.2.3).

4.2.1.1. Forest Mapping. One of the most promising applications of orbiting spacecraft to forest inventory lies in determining forest location and distribution. Despite the intensity of forest use, even the United States has no detailed and reliable map of this distribution of its forest resources. Forests are a significant part of the vegetation on the surface of the earth. A map showing distribution of vegetation by broad species group, or type, is needed for the United States and for the world. At the Conference on the Use of Orbiting Satellites in Geographic Research held in Houston, Texas in January 1965, the panel on Plant Cover and Soils and the panel on Resource Utilization both listed world-wide mapping of vegetation as one of the highest priority needs (see Ref. 20). The report of the panel on Plant Cover and Soils states:

"It is not now possible, nor should it be, to anticipate all the scientific problems that may be attacked with the aid of these data once they become available. The benefits of the coverage would be of value, even though much were not put to immediate use, in that it would constitute a base datum as to the state of the world's plant coverage at a single point in time. From this base, studies of change, both that due to human activity such as clearing and cultivating and that due to succession could be carried on. For the first time it would be possible for any student of plants to learn what the vegetation of the area in which he was interested actually was at a known time in the past."

Aerial cameras mounted in an orbiting spacecraft could record the vegetational cover of the earth in a time-span sufficiently short to permit completion of the first map of world vegetation. Coverage will need to be complete but will not be required more than once in five years. Ground resolutions of 200 to 400 feet would be adequate in most cases and species determination will be facilitated if simultaneous panchromatic and photo-infrared imagery are obtained.

Large trees scattered through savannas represent a significant wood resource in some regions, but would not be detected unless ground resolutions of 75 feet or less were available. For applications discussed in following sections, substantially better ground resolutions are specified.

Forest mapping data should be made available to those organizations selected for map compilation within six months after data acquisition.

4.2.1.2. Determination of Tree Size. A second promising application of orbiting spacecraft in forest inventory arises from the need to determine tree size. If spacecraft sensors can provide imagery of sufficient resolution to permit determination of only average crown diameter of stands, it would be possible to recognize the size strata within the gross forest area and this ability to stratify the total area would greatly improve statistical sampling procedures and should permit significant reductions in the number of ground plots required to obtain a given confidence level in the final inventory figures. For this reason, visible and/or infrared photography having horizontal ground resolutions of five feet will be required. Coverage need not be complete and a one percent sample may prove sufficient. Repetition at five year intervals would be desirable and data should be available to the collating agency (probably U. S. Forest Service or FAO) within six months after acquisition.

4.2.1.3. Anticipated Benefits. Since a reliable map of the forest resources of the world has never been available, it is difficult to determine the actual value of this application of orbiting spacecraft in terms of alternative costs. However, the data that follows are suggestive.

Mexico is just completing a four year, $4.5 million survey under a grant from the United Nations Special Fund. Part of the costs arose from the need to determine the exact location of the forest resources, and this survey was concerned only with the coniferous forests. The broadleaved forests will require another survey.

In the United States, costs of forest inventories during the 1960's averaged 2.1 cents per acre, in the North Central and Central States Regions (including Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Ohio, North and South Dakota, and Wisconsin) (Ref. 21). Costs are higher in the mountainous areas of the eastern and western United States and the average cost for the entire U. S. was 3.0 cents per acre. If this figure is applied to the 508.8 million acres of commercial forest land in the 50 states, the cost of collecting data for a national forest inventory is at least $15.2 million. Possibly $2.0 million of this total represent data analysis and publication costs.

Forest resource surveys conducted by the U. S. Forest Service gather data by region, with gross figures by states, but do little to determine the exact location of the resources. Many states supply funds to pay increased costs of more intensive surveys within their borders. Michigan paid an additional $286.5 thousand to obtain enough data for a county summary of its forest resources.

When a reliable map of forest distribution is available for an area to be inventoried, improved statistical design is possible. This will permit reduction of the amount of ground sampling required to achieve a given degree of accuracy when inventorying large areas. In addition, location of new wood-using industries requires extensive surveys of available wood resources. In underdeveloped areas where such plant location is increasingly important, pre-investment and investment surveys are needed. A world map of the current forest resources will prove extremely valuable in such surveys.

An exact determination of cost savings resulting from a reliable map of vegetational resources is not possible; but since locating, classifying, and determining areas of forest stands accounts for the majority of the costs of a forest inventory, a significant cost savings should be possible when such a map is available. However, experience with aerial photography has shown a consistent need for at least partial field checking of data interpreted from imagery obtained from remote sensors. Taking all of these factors into consideration, it seems reasonable to expect a 20% reduction in cost for a forest inventory in the United States. Based on a total data collection of $17.5 million ($13.2 million in federal funds plus $4.3 million in state contributions), the savings would amount to $3.5 million per inventory. In Mexico, the savings would probably have amounted to more than 20% but even at that rate would total almost $1.0 million.

South America is 54% forested and contains one-quarter of the forest land of the world (Reference 22). Data for many parts of South America are unavailable and aerial photography needed for such surveys could be performed only at high cost; thus, cost savings could easily amount to 30 or 40 percent of the cost of conventional surveys.

Considering both the cost of obtaining such data by conventional means and its usefulness in the management of the world's forest resources, $50 to $75 million seems to be a reasonable estimate of the total value of a world map of forest vegetation, even though it might be limited to distribution by broad species classes. If in addition it proves to be possible to determine tree heights and/or crown diameter from orbit, the total value of the resulting forest inventory could easily double in the United States, and triple in less developed areas.

4.2.2. FOREST FIRE DETECTION. Wildfires have periodically burned out most of the temperate forest areas on earth and large areas of tropical forest have also been ravaged by fire. Even though fire has been a fact of life since carbohydrates first came into being, public recognition of the magnitude of forest fire damages remains negligible.

On October 8, 1871, the great Chicago fire began its historic rampage, and three days later 2,124 acres of the city had been destroyed and 16 persons killed by the fire. This disaster occurred at a time when long drought, hot weather, and strong winds combined to create severe burning conditions. The same weather conditions existed throughout Wisconsin and Michigan and contributed to the Peshtigo and Michigan fires that started on the same day. The Peshtigo and Michigan fires burned largely on forest lands, and covered 1,280,000 and 2,500,000 acres respectively, with a loss of at least 1,500 lives, yet most people have never heard of Peshtigo.

On October 21, 1947, a number of untended and uncontrolled fires were burning in Maine. The summer had been hot and dry, no rain had fallen since September 22, and strong winds on October 23rd created an uncontrollable "blow-up." By October 24, 205,678 acres had burned and 16 people had perished.

In 1963, over 145,900 wildfires burned over 7,120,000 acres in the United States, 3,317,000 acres of which were lands under federal, state, or private fire protection. These fires were not confined to the inaccessible areas of Alaska and the western mountains, for 200,172 acres burned in New Jersey, 20,670 acres in North Carolina, 195,585 acres in Arkansas and 7,155 acres in Kansas. Although most of these fires were small, 4,420 fires burned more than 100 acres each, 245 fires burned more than 1,000 acres each, and 30 devastiated more than 5,000 acres each. Total direct damages attributable to these fires is estimated at $71 million.

In this section, the possibility of using orbiting spacecraft to detect fires and aid fire suppression activities is discussed. Although subject so some limitations, this application is considered feasible. In the United States, it would achieve an estimated 2 or 3% reduction in total forest area burned, resulting in an annual savings of $1.4 to $2.1 million. For underdeveloped areas of the world, the usefulness of the method will depend on the development of adequate fire suppression forces to use the fire detection capability. If this is done, it is believed that by about 1980, a spacecraft fire detection system would permit a reduction of 8% of the total forest area burned (a reduction of 16 million acres per year) for a savings attributable to the system of $32 million per year.

4.2.2.1. Characteristics of Forest Fires. Forest fires occur with greatest frequency, and are most damaging, at certain seasons of the year. Timing of the "fire season" varies from one geographic region to another and two or more distinct fire seasons may occur annually in some areas. Fire danger rating has progressed to a point where the onset of dangerous fire conditions—a "fire season"—can be anticipated by at least a few days. Fire in the open is notably inefficient and most forest fires are of relatively low intensity; even hot fires seldom generate more than 1000 BTU's per second per foot of fire front (Reference 23). The flame temperature of forest fuels is 1600 to 1800°F but ignition may occur at 400°F. Temperatures of 400°F are common at the surface; above a hot fire, temperatures may exceed 1500°F. Soil temperatures may rise above 300°F at a depth of one inch under a hot surface fire (Reference 24). However, Heywood (Reference 25) working in the fine sandy soils in the southeast, did not record temperatures above 210°F with his thermocouples set at a depth of 1/8 to 1/4 inch, even under a fire burning in 15 years' accumulation of fuel. Soil temperatures at a depth of one inch may remain above 150°F for as much as 70 minutes after fire passage but often cool below that temperature in less than 20 minutes (Reference 26).

To reduce fire area, fires should be detected while still small enough to be suppressed by a small crew. Hirsch (Reference 27) suggested a fire "diameter" of 20 feet as the size that should be detected. Such fires do not actually provide a hot target 20 feet in diameter, for active fire is usually confined to the perimeter which may be only six inches wide.

The "sleeper" fire smoldering after a lightning strike will be quite small and may be confined to the inside of loose chunks of bark hanging on the struck tree, or to its roots. Bark is an excellent insulator and should reduce effective temperature differences between the "fire" and its background, possibly to 50°F.

Fires twenty feet and more in diameter can be detected from orbiting altitudes if burning in the open and large fires will probably be detected even if burning under a forest canopy. Small fires burning under a dense forest canopy are difficult to detect from aircraft (Refs. 27 and 28) and will probably be even more difficult to detect from orbit. "Sleeper" fires are the hardest kind to detect from any vantage point.

Reduction of fire size requires reduction of the time that fires are allowed to burn. Fire suppression organizations try to keep the time period between detection and arrival of a suppression crew at the fire to less than one hour. Detection within one hour of fire origin is just as important as fast action after detection, and a one hour delay in detection can give a fire a tremendous start.

Prompt detection of fires is essential but continues to be a major problem, particularly in more remote areas. In the western United States where lightning storms accompanied by little or no precipitation are common, lightning strikes may smolder for several days before breaking out as active fires. In other areas, poor visibility in the atmosphere limits visual detection capabilities to one or two miles for significant portions of the year. This makes it difficult to maintain adequate surveillance of some areas of highest fire incidence. Aircraft patrols, although expensive, are being increasingly used in such areas.

4.2.2.2. Operational Considerations. Use of orbiting spacecraft containing infrared scanners or passive microwave for forest fire detection was proposed by Singer in 1962 (Ref. 29). The primary advantages of orbiting sensing systems for forest fire detection stem from the large area, synoptic "view" available from orbit. Remote sensors, particularly infrared scanners, would achieve better resolution from aircraft altitudes than from orbit, but aircraft systems cannot provide coverage of the large areas sensed by spacecraft in any given time period.

On a world-wide basis, forest fire detection can be divided into three distinct types of problem:

1. Detection of large fires, or several active fires in close proximity which may coalesce and create a large fire, as in Maine in 1947.
2. Detection of small fires.
3. Detection of the "sleeper" (incipient) fire.

In each category it will be necessary to separate wild fires from heat sources. Permanent "smokes" are currently recorded from all fire towers, and a similar approach should work from orbit.

Detection of large fires, or several small fires which often spawn large fires, will require continuous monitoring of the earth's surface. The temptation to neglect coverage of specific areas because fire danger is low should be resisted. That attitude created the public apathy which contributed so heavily to the disastrous Maine fire of 1947.

Detection of large fires appears to be feasible with existing technology. Infrared sensors are ideally adapted to detection of the primary by-product of fire—heat, but are limited in their ability to penetrate clouds and haze. In a scanning system used to detect large fire conditions ground resolutions (spot size) of 200 feet are adequate, but must be combined with a temperature difference sensitivity sufficiently small to record background variations for the purpose of providing location information.

Passive microwave devices, due to their ability to "see through" clouds and weather, might appear to be more promising for forest fire detection than infrared sensors. However, even though forest fires generate relatively strong signals and may overcome the relatively low sensitivities of microwave devices, the microwave energy emitted by a fire is not sufficiently different from variations in background radiation to permit easy detection.

When large fires or large fire conditions are detected, the location and data characteristics of the trouble spot should be available to the appropriate fire suppression organization within one hour. Transmitting these data to a central dispatcher for retransmission to the appropriate regional office would be acceptable.

Reporting large fires will not present major problems because of the relatively small number of large fires. Occasional problems should be expected, however, because large fires often occur in clusters in those areas where dry weather has created optimum burning conditions.

Detection of small fires will require a continuous and complete coverage capability. If suitable command controls are available, sensing can be limited to complete, continuous coverage of those areas in which fire danger ratings are above a predetermined index. If infrared systems are used, they should be capable of ground resolutions (spot size) of 20 feet where the temperature difference will probably average $200^{o}K$ above the background within this resolution patch. If this does not prove practicable, a ground resolution of 100 feet with a temperature sensitivity capable of detecting an average temperature difference (integrated across the 100 foot spot) of only $10^{o}K$ will be needed. Fire location and data characteristics should be available to the appropriate fire suppression organization within one hour of detection. Transmission of data through a central dispatcher would be acceptable.

As mentioned previously, small fires may be difficult to detect. Also, reporting of small fires may prove to be as much of a problem as detecting them. As many as 50 small fires are often burning in a single county during certain periods, and there may be 500 burning in the southern fifteen counties of Illinois during the spring fire season. Thus detection, localization, and reporting functions may encounter overload conditions that could delay reporting beyond the acceptable one-hour limit. Despite this delay, spacecraft reports should help central dispatchers keep abreast of the overall fire situation in their area.

Detection of "sleeper" fires will require a complete coverage capability which can be activated on command to sense areas recently subjected to lightning storms. The infrared sensor should be capable of ground resolution (spot size) of 20 feet but must detect an average temperature difference between the resolution spot and the background of only 20°K. A ground resolution of 60 feet with a temperature sensitivity capable of detecting a temperature difference (integrated across the 60 foot spot) of only 2°K should also permit detection of "sleeper" fires. Use of the 4.5 to 5.5 micron wavelength band should reduce "thermal noise" resulting from natural variations in background temperatures and emissivity and permit detection of the relatively higher fire temperatures. Fire location and data characteristics should be available to the fire suppression organization within four hours after detection. Transmission of data through a central dispatcher would be acceptable.

If sleeper fires can be detected, the reporting function will be relatively simple. There are not as many "sleepers" as there are small fires and the four-hour time for data processing should eliminate overload problems.

4.2.2.3. Value of Fire Detection Capability. Damages done by forest fires vary widely and are influenced by many factors, among them forest type, soil type, season of the year, and severity of fire. On rate occasions, forest fires may be beneficial but more often damages are high. A Douglas fir forest in Oregon may contain 100,000 board feet per acre, worth $25 per thousand while it is still standing on the stump. A crown fire in such a stand would kill all of the trees and could result in a loss of one-half of the value of the stand (direct loss plus lower value of residual, charred trees) - a loss of $1,250 per acre. Forest fire losses, however, are seldom this severe.

The U. S. Forest Service has not included damage estimates in statistics reported since 1951. In that year, 105,868 fires on protected lands burned 3,526,373 acres and produced losses estimated at $27,877,171; or an average cost of $7.91 per acre. However, the U. S. Forest Service prefaces this report with the statement:

"The estimates on fire damage should be used with caution. They admittedly are low because they fail to include full and complete tangible and direct damage to timber and improvements as well as the vast amount of intangible and indirect losses resulting from forest fires, such as those caused by decay of fire damaged timbers, replacement of desirable tree species by less valuable ones, soil deterioration and erosion, uncertain stream flow, destruction of game, interruption of tourist use and travel, and the like."

Between 1951 and 1963 the purchasing power of the dollar changed so that damages of $7.91 in 1951 would be equivalent to at least $8.95 in damages in 1963. Since the Forest Service admits that their 1951 figures are low, $10 per acre may be a good average value for forest fire losses in 1963. If this value is applied to the total burn in 1963, the resulting one year forest fire loss to the United States was more than $71 million. Suppression costs and intangible losses increase the economic drain of forest fires and $100 million is a more reasonable estimate of total loss during 1963.

In Reference 29, Singer stated that: "Our annual expenditure for the detection and fighting of fires ranges from $150 to $200 million and the annual loss from these fires has been estimated at between $50 to $300 million."

To reduce forest fire losses, either the number of fires or their size must be reduced. In 1963, the U. S. Forest Service reported 11,565 fires caused by lightning and 134,355 fires caused by man. Of the latter, 41,429 were classed as incendiary fires. Complete elimination of forest fires is obviously impossible and would probably be undesirable, for fire is a natural ecological occurrence. In fact, most of the pine forests on the North American continent in 1600 A.D. owed their very existence to periodic fire. While controlled burning is an accepted management technique in many areas, uncontrolled fires should be reduced as much as possible.

It is hazardous to place a dollar value on the use of spacecraft for forest fire detection. Like any other warning system, it is worth more than its cost if it detects one fire soon enough to permit supperssion before the fire "blows up" and becomes a disaster.

Some idea of the potential savings can be gained by assuming that if spacecraft sensors can provide earlier detection of forest fires and/or reduce the number of large fires through prompt recognition of potentially dangerous conditions, the spacecraft system could make a major contribution to a 2 or 3 percent reduction in acreage burned. This contribution, as small as it may seem, would have amounted to a savings of between $1.4 and $2.1 million in 1963, in the United States alone.

Since many parts of the world have no forest fire detection system in operation, it seems reasonable to assume that a spacecraft system would improve world-wide forest fire detection by a factor of 2 or 3. However, estimated annual savings to the United States from a spacecraft forest fire detection system cannot be directly extrapolated to obtain corresponding savings for the world. The United States has one of the best forest fire detection systems in existence and forest fires undoubtedly burn over a larger proportion of the total forest areas of many countries—particularly in South America and Africa—than of the United States. However, the dollar value of forests is generally lower in these countries, and fires are frequently allowed to burn after detection.

Because forests in developing countries are remote from markets, because labor costs are significantly lower, and because species composition often results in lower values for total stands, forest fires in such countries do not produce as great a loss per acre as in the United States. If $10 per acre is reasonable for the United States, an average value of $2 per acre may provide a useful estimate of forest fire losses on a world-wide basis.

In 1963, slightly less than 1% of the total forest area of the United States was burned. For the remainder of the world, it is likely that larger percentages of total forest area are burned each year. If 2% of the world's 10 billion acres of forest area outside the United States burns each year, the burn would total about 200 million acres.

Approximately two-thirds of all forest fires are started by man, and these usually occur in areas near human habitation or human activity, where values are highest. If detected while small, many of these fires will be put out. But, unless there are major increases in forest fire suppression activities in many countries, relatively few of the larger or more remote fires will be the object of direct suppression efforts. With the present limited availability of fire suppression forces, a spacecraft fire detection system could probably do no better in reducing burned acreage than for the United States. At present, therefore, reduction in burned areas would amount to 3% of 200 million acres or 6 million acres.

If improved fire detection resulting from a spacecraft system is made available on a world-wide basis, many countires will increase their fire suppression efforts and achieve further gains. Since forest fire suppression in many countries is handicapped by an almost complete lack of any detection system, the proportional reduction in area burned would probably be considerably greater for the world than for the United States. A capability for obtaining 8% reduction in burned areas would probably be achieved in about 15 years. This total reduction of 16 million acres at the estimated value of $2 per acre would represent a savings of $32 million per year for areas outside the United States.

4.2.3. ENERGY BALANCE IN FORESTED AREAS

4.2.3.1. Objectives of Energy Balance Studies. Growth of any living organism depends on the flow of energy through its environment. As Gates (Ref. 30) puts it:

"Looking at the various environments ranging from tropical rain forests . . . to arctic tundras, one is struck by one predominant feature besides the characteristics of vegetation and animal life, and that feature is the energy exchange. The flow of energy into and out of these environments must in many ways be an extremely critical conditions for the existence and propagation of life itself . . . The world in which we live is indeed a complex one. Conditions on the planet earth happened to have been just right for life to have evolved. It may be a fairly delicate balance, a rather thin thread upon which we dangle . . ."

Energy exchange is a continuous phenomenon that proceeds at varying rates, influenced by, and influencing in return, many atmospheric conditions. Energy-balance relationships in vegetation directly influence photosynthesis and through it evaportranspiration; therefore, water yield and stream flow are dependent on them, as is plant growth.

Plant growth patterns existing under one set of environmental conditions often change when this environment changes as a result of natural or artificial stimuli. The time at which plants break dormancy in the spring, the time of flowering, the time of active height growth, and the time of growth cessation, all show a seasonal march across the continents related to the changing energy balance of the local environment. When energy-balance changes from one year or season to the next, these will be reflected, a few days, weeks or months later, by related changes in plant growth. If these changes are better understood they might prove to be predictable enough to permit optimization of land management practices with attendant cost savings.

Energy-balance data obtained from spacecraft would have scientific applications as important as those of direct economic impact. Data are needed to provide better understanding of plant growth and growth processes. Such data will become increasingly essential as more forest products have to be produced from a shrinking forest land base (see also Section 5.2.7).

4.2.3.1.1. Site Productivity. Since rates of photosynthesis and transpiration are related to energy-balance in the environment, it should be possible to use data on insolation, reradiation, and surface temperature to estimate metabolic rates for plan communities. Metabolic rates are, in turn, related to plant growth and production on a given site. A great many technical problems need to be solved before this application can become a reality. However if this can be done, it may be possible to derive productivity indices for different vegetative forms and an index of site productivity independent of the species of vegetation growing on a given site at a given time. Such data would provide an important tool for land managers, faced with the task of optimum production of food and fiber materials from lands under their control.

4.2.3.1.2. Forest Fires. Energy-balance will also affect the amount of moisture in forest fuels. High moisture contents result in proportionally lower fire dangers and lower rate of spread in most fuels, and these same high moisture contents change the energy-exchange characteristics of the fuel materials. Assessment of energy-balance phenomena could provide a valuable insight into dynamic changes in fuel moisture over large regions, an insight that cannot be obtained from ground-based measurements except at prohibitive cost.

4.2.3.1.3. Forest Influences. Forest vegetation exerts profound influences on local temperatures, winds, stream-flow, and water loss. Regional and continental climates may reflect these influences to some degree, and in turn influence the growth of plant forms in the vegetative cover, producing attendant variations in energy-exchange. At the present time there is no way to assess the cumulative effects of these changes on climate over large areas. Spacecraft may furnish the large-area viewing platform required. (This use is analogous to weather observations from spacecraft).

4.2.3.1.4. Growth Processes. Any data obtained regarding energy-balance, regardless of source, helps us to understand the dynamic factors at work and provides a basis for more intelligent management of our available resource. The seasonal march of growth initiation, flowering, fruiting, and the onset of dormancy provides a continually varying pattern of energy-exchange in forested areas. Localized differences resulting from fire, soil fertility, soil moisture deficiencies, and insect and disease attacks intensify these variations and probably result in energy-balance anomalies which might be detected and used in diagnosing problems.

When existing energy-balance relationships are disturbed by man, fire, or other factors, the changes resulting may be irreversible. For example, treeless areas in many parts of the world have often been attributed to past conditions, particularly fire.

The Panel on Plant Cover and Soils at the Conference on the Use of Orbiting Spacecraft in Geographic Research (Ref. 20) reported: "For a few weeks at least following a burn, the ground thus affected should give quite a characteristic signature so that its extent could be sensed without human operators. With this information on a world scale we should be able to make rapid progress in answering the question of what relation fires have to the distributions of forest, brush, grassland, and savannas that seem so anomalous from a climatic standpoint."

4.2.3.2. Data Requirements. Requirements for specific data for any of these applications are not known precisely, and some items that are now considered desirable may prove to be unnecessary. However, the following types of data seem to be most necessary:

1. A map showing distributions of vegetation types around the world as described for forest inventory (Sec. 4.2.1).
2. Relative, or absolute, surface and soil temperatures for different forms of vegetative cover at different points in the seasonal development of the species included in the cover-type.
3. Broad spectrum radiation from different vegetation types during different periods in their seasonal development. This should include measurements of long wavelength radiation for use in the calibration of items 2 and 4.
4. Relative, or absolute, measures of evapotranspiration from different vegetative forms under different weather conditions.
5. CO_2 content at the surface associated with different vegetative types, at different stages in their seasonal development.
6. Surface wind velocities associated with different vegetative types.

Items 1, 2, and 3 can probably be obtained now. The remaining items will require new instrumentation, and probably indirect determination through correlation with other factors, if they are ever to be determined from orbit. However, any one item shown above would be useful; two or more would be of tremendous importance and would have applications in agriculture, climatology, meteorology, and hydrology. Like so many other types of data, energy-balance information is pertinent to most scientific disciplines, for these disciplines are only man's arbitrary divisions of an infinitely variable ecosystem.

Repeated attempts to obtain these data terrestrially have shown that meaningful data for areas larger than an individual corn field or groups of fields are prohibitively expensive to collect. Detailed data can be obtained for very small areas but almost instantaneous coverage of country, state, and regional areas is needed to expand these data to entire ecosystems. Aircraft systems are able to collect energy-balance data for sub-continental areas but cannot obtain world-wide coverage in a time span that is short enough to provide data representative of any one point of time. Orbiting spacecraft should provide an excellent source of the large-area coverage required.

4.2.3.3. Sensor Requirements. Multispectral data in the ultra-violet, visible and infrared spectra will probably be required. Ground resolutions of 1,000 feet should be sufficient for the application to forest influences but ground resolutions of 200 to 400 feet may be necessary for sensing anomalies in the seasonal march of growth processes. Within the infrared region, it is expected that a relative temperature sensitivity of $1^{o}K$ or less will be necessary.

The basic data required seem to be total insolation and its spectral distribution; total, and spectral distribution of energy reradiation (emitted) from the earth and its vegetative cover; surface temperatures; and vegetative characteristics of the area scanned. Total insolation can be determined on the ground for test sites. The other data would have to be determined from airborne or orbiting vehicles.

Once a base map of vegetative types is available, a ten percent sample of the land masses showing both east-west and north-south distributions should be sufficient for the applications to site productivity, forest influences, and forest fire discussed in this section. (Forest fire detection is a separate problem and is considered in Section 4.2.2). A one percent sample should be sufficient for the growth processes applications if the sensors can be operated on command and data collected for specific areas of interest.

While the requirements above seem realistic now, successful determination of the general pattern of energy-balance relationships will probably create an increasing need for complete coverage at regular intervals. If possible, coverage of specific test areas should be repeated as shown below:

Site productivity: In each sampling period, all test areas should be scanned on four successive passes of the spacecraft. These four successive passes may be distributed over two or three days. Sampling periods should be scheduled at one month intervals and continue for one year.

Forest influences: In each sampling period, all test areas should be scanned on ten successive passes of the spacecraft or as nearly successive passes as will permit scanning the test area. Sampling periods should be scheduled at two month intervals and continue for two years.

Forest Fire: Information should be collected continuously over all areas where forest fire are possible. Areas with significant snow cover need not be scanned.

Growth processes: Data should be collected at intervals of one week or less, and continued for one year.

In each application, the data should be available to the analysis group within two weeks of acquisition. Although not essential, availability within one week would be desirable, for it would provide better opportunities for continuous evaluation and redirection of the sampling program and permit more adequate data collection.

Concrete proof of the feasibility of these applications is not available at this time. However, proven abilities to record insolation and energy emission indicate a high probability of success. Energy that is not reradiated must have been absorbed in some fashion and the amount of this absorption is related to temperature increases, chemical changes, food production, or metabolic activity in an area.

4.2.3.4. Anticipated Benefits. Although several specific applications have been described in this section, determinations of energy-balanced relationships should have many additional uses. The increased knowledge of the functioning of our planetary ecosystem is, in some respects, of academic interest. However, interest at this level is necessary if we are to gain the knowledge essential to maximum utilization of our renewable resources—on both a national and a world basis. Since the specific benefits which will be realized are hard to visualize in concrete terms and harder still to predict, no attempt is made here to place a dollar value on these benefits.

4.2.4. DETERMINATION OF TOTAL TERRESTRIAL PLANT BIOMASS. Biomass, the gross weight of living material, of both plant and animal origin, can be expressed as total dry weight or as quantity of fixed carbon. No technique has yet been developed for quantitative estimation of the total biomass, land or marine. Nor is there any available technique for estimating total biological productivity (essentially CO_2 turnover rate). Accurate estimates of these quantities would be highly useful for several purposes.

The amount of carbon dioxide released to the atmosphere is being increased by the burning of fossil fuels and by other human activities. A declining terrestrial plant biomass, due to cutting of forests and cultivation of virgin land, adds CO_2 to the atmosphere and at the same time reduces one of the mechanisms by which CO_2 is removed from the atmosphere. If this additional release should significantly increase the mean CO_2 content of the atmosphere, an appreciable warming of the earth is likely. This general warming would have many repercussions, mostly detrimental, on ocean levels, rainfall patterns, and other climatic elements to which the earth's present settlements are adjusted. The two major buffer systems which may stabilize atmospheric CO_2 are solution in the oceans and atmospheric fixation by plants. Competent preliminary estimates suggest that these two buffering systems are probably of the same order of magnitude (Ref. 31). If one wishes to control future increases of CO_2 more information is needed about the size of the terrestrial buffering system and its direction and rate of change.

If a method is devised to measure the plant biomass of the earth as a whole, the data from this method would certainly be usable to determine the spatial distribution of this biomass. Since total plant biomass at any point is the result of the interactions between soil, climate, insects, fungi, animals (including man) and other factors, mreasurements of biomass have distinct implications relative to agricultural and forest productivity and to site-quality in general. On a more local scale, knowledge of the distribution of biomass and productivity would be of great value in planning future food and fiber production for a growing population.

Biomass measurements have many applications outside of forestry. Yet, one-third of the total land area of the earth contains a forest cover, and South America and Russia are 54% and 51% forested, respectively. Therefore, attempts to determine total biomass would be closely allied to forestry.

An attempt to measure anything over the entire surface of the world is handicapped by the size of the task and the time required to complete it with conventional means. If biomass is a changing quantity, data need to be collected as nearly instantaneously as possible to arrive at a figure for total biomass at any specific point of time. Orbiting spacecraft permit rapid data collection over the entire earth. The orbiting vantage point also permits integration of irrelevant details into a more relevant whole.

Remote sensing techniques for quantitative determination of biomass do not exist, but must be developed. Forest and vegetation mapping will certainly provide pertinent data; also, it may be possible to determine CO_2 content at the vegetation/atmospheric interface directly, using multi-spectral sensing techniques. If not, it may be possible to correlate CO_2 uptake by vegetation with energy-balance data described in Section 4.2.3.

Measurements of physical quantities related to biological productivity are also needed. As pointed out in the report of the panel on Plant Cover and Soils to the Houston Conference on the Use of Orbiting Spacecraft in Geographic Research: "One observable characteristic of any major ecosystem that is related to primary productivity is the intensity of chlorophyll-green color, or a gray value or other measure derived from a sensing of this intensity.

A practical scale of such intensities, not dependent on discrimination by the human eye, could be easily established relative to the color resolution of the sensor used. The variability of this value within each ecosystem could be established by a fairly dense pattern of observations over a sufficient duration of time to get a full range of temporal, as well as areal, variation. By the time this is accomplished, the International Biological Program should have produced a significant density of productivity determinations for the ecosystems under study. These may, with appropriate correction for temperature and seasonal dormancy, then be used to relate productivity values to the ranges of variations in greenness determined for the ecosystems. For these both relative and absolute values can be established for each total ecosystem as well as for a unit area of each. It is realized that the reliabilities of these values will, at first, be very low; however, as more and better productivity determinations become available, and perhaps also more reliable color-intensity determinations, repeated calculations can be made of even higher reliability."

If techniques for measuring biomass can be developed, operational measurements of total terrestrial biomass should be made once during each of the four climatic seasons during a one year period. Following this, reestimates of total biomass would be made once or twice a year to measure annual changes and to keep the total biomass inventory up-to-date. Coverage would need to be world-wide but data availability is not critical. A delay of three or four months between initial acquisition and availability of processed data would be acceptable.

5
WATER RESOURCES

5.1. INTRODUCTION

An adequate supply of fresh water in lakes, streams, and subsurface aquifers is universally recognized as a major determinant of economic growth and development. Water is used for domestic consumption by men and animals, industrial processing of raw materials, production of food and fiber under irrigation, generation of hydroelectric power, inland navigation, dilution and transport of human and industrial waste, and for such recreational activities as fishing, boating, and aesthetic enjoyment. There is no shortage of fresh water on earth; the problem is one of distribution in space and time. As population pressures mount, increasing quantities of water will be required at times and places determined by man's needs rather than by nature's plan.

The principal tasks of worldwide water resources management are to find water of high quality at low cost, to forecast tomorrow's supply and to control the location, quantity, quality, and timing of that supply. Quantity refers to the total amount available—the water budget of the earth, of a region, or of a stream basin. Quality is affected by the content of dissolved and suspended organic and inorganic matter that degrades water for one or more uses. Timing refers to the seasonal pattern of water delivery, and to those gross maldistributions that we call floods and droughts.

Because water is a rapidly moving flow resource, its effective prediction and control depend upon extensive data from widely dispersed locations. The necessary data are of two principal sorts: inventories of land and water features that vary within reasonable time periods only from place to place; and records of dynamic processes that fluctuate in both space and time.

5.1.1. USES OF HYDROLOGIC DATA. Short-term forecasts of probable future conditions are among the most profitable uses of hydrologic data. Forecasts have substantial economic value to irrigation farmers who must plant their coming season's crops, to businessmen and bankers who must decide how much merchandise and credit their farmer customers will demand, to power companies whose schedules of water release from storage reservoirs become increasingly efficient with better foreknowledge, to municipal water supply and treatment plants, and to many other water users. Forecasts add to efficiency in management of water as a resource and in design of capital facilities for its control. For instance, an improvement of 25% in reliability of knowledge about expected future flows of a stream can lead to a 40% gain in the flow regulation effective by a large reservoir. Accurate forecast data can save lives and

and property when water becomes destructive. The value of forecasts increases as water becomes more costly and as flood plain occupancy becomes more intensive.

Data are needed to locate untapped water sources in remote regions, and to define areas such as snow accumulation zones that are potentially manageable for increased water yields. Data are needed on vegetation, geology, and climate, from which to classify areas similar in their water regimes, and hence in their capability for water management.

Perhaps most important, basic scientific data are needed to better understand the operation of the hydrologic cycle. Improved understanding is fundamental to fully effective prediction and control of water resources. As an example of a field in which more information is needed, there is now no satisfactory known method for estimating evaporation from extensive vegetated areas even though evaporation is often the largest single component of the water balance.

Scientists have until now been unable to look simultaneously at large areas of the earth's surface. They have not had effective methods of measuring fast changes in water and energy balance over large areas. Orbiting spacecraft, by removing this limitation, may permit environmental measurements that have never before been possible. The new knowledge gained may, in ways we cannot yet imagine, be the most valuable product of the program.

5.1.2. ADEQUACY OF PRESENT DATA ACQUISITION PROGRAMS. The existing capital investment in water resources facilities in the United States, based on an evaluation made by the U. S. Department of Commerce (Ref. 32), is about $235 billion. This investment is being added to at a rate of some $7.5 billion annually. These figures include public and private investments for municipal and industrial water supply, navigation, sewage disposal, irrigation, hydroelectric power, flood control, and all other water facilities.

To service this capital investment, it is estimated from Reference 33 that some $40 million is being spent for routine collection of basic hydrologic data useful for planning of new projects and management of old installations. This is about 1/2% of the current annual expenditure, for public and private works for the use and control of water. Because of the need to service specific development projects or other emergency situations, hydrologic data acquisition programs have not been well balanced. Many important areas have been almost wholly neglected. The definciency of data is substantially greater in most other parts of the world than in the highly developed United States.

In addition to routine collection of current data, an estimated $72.4 million is being spent by federal agencies in 1965 on all aspects of water research (Ref 34). Research expenditures by universities and other non-federal organizations probably add about 10% to this amount (Ref. 35).

The concept of diminishing returns is applicable to the need for hydrologic data. The earliest water developments in any region can profitably be undertaken with only a minimum of information on the quantities and variations likely to be encountered over a long period of time. More and more information is needed to develop each succeeding increment of water. For this reason the present relatively meager worldwide hydrologic data acquisition program will be increasingly inadequate as water development and utilization become more intensive. Because of the acknowledged inadequacy of present programs, it is recommended that hydrologic data acquisition from orbiting spacecraft be used to supplement, and not to replace, existing ground-based data collection programs. The only exception to this recommendation is in the field of snow surveys, where there is hope that remote reconnaissance can eventually be brought to the point of measuring snow cover more effectively than can be done on the ground.

5.1.3. ROLE OF ORBITING SPACECRAFT. Remote hydrologic measurements fall into two broad categories: inventory and description of worldwide or regional conditions which change relatively slowly, and evaluation of those rapidly fluctuating processes that govern the short term water balance of the earth or one of its major segments. These two categories pose somewhat different problems of feasibility analysis and economic evaluation.

Remote sensing is a useful inventory tool if data of sufficient accuracy for operational use can be obtained at lower cost than by more conventional means. Satellites are simply one of many possible data acquisition systems; their selection over competing systems must be based on the relative cost and the operational adequacy of their information output.

The synoptic view and the frequency of coverage from satellites make it possible, on the other hand, to gather data on rapidly changing terrestrial conditions and processes that cannot be obtained in any other way. Evaluation of satellite systems for these purposes depends, not on cost comparisons with other systems, but on study of the technical feasibility and the worth of the information that can be collected.

The continually changing features at the earth's surface can in turn be subdivided into those that vary on a time scale of days or weeks, and those dynamic processes that vary on a time scale of days or weeks, and those dynamic processes that vary on a time scale of hours or minutes. The first class is primarily useful for prediction of streamflow and other hydrologic features 5 to 90 days ahead. Among the principal elements in this class that are susceptible of remote measurement are the quantity and distribution of snow and ice in terrestrial snow packs, the extent and distribution of ice in lakes and streams, areas inundated during floods, and extent and depth of frozen soil and of unfrozen soil over permafrost.

Failing this, it would be useful to have data on the areal extent of snow cover regardless of its depth or water content. Data are needed on the spectral reflectance characteristics of snow over large areas, the total integrated reflection, and changes in these values with time. It would be useful to be able to distinguish the presence or absence of free water in the snow, or alternatively, the establishment of isothermal conditions at $0^{o}C$, signaling the start of melt.

These measurements might exploit the selective polarization of microwaves by water, and the differential depths of emission of microwave and infrared radiation. Areal coverage of snow could be established easily through its light color. Identification of the time that melting begins will be more difficult.

Effective use of the data would probably require a horizontal resolution of about 200 ft. Vertical resolution requirements are about 1.5 ft. snow depth, or 0.5 ft. water content. These values appear to be close to the limit of feasibility of satellite reconnaissance. The target to be examined is the entire land area poleward of 40^{o} N and S latitude, plus major mountain ranges. All of this area would need to be examined at intervals for scientific studies. For forecasting and other operational purposes, regions of progressively greater priority could be established to accommodate the feasible extent of coverage. Only the temperate region snow zone would need to be surveyed routinely for forecast data, at least until extensive arctic water diversion projects are constructed. Complete coverage of selected sample areas and basins would be preferable to continuous narrow strip samples.

Forecast data would need to be obtained at biweekly intervals from December 1 to May 15. Data would need to be returned within 4 days of acquisition. Flood predictions would require observations and data return as often and quickly as could be arranged during danger periods designated from the ground. For most scientific data, detailed coverage at 30 day intervals would be adequate.

Costs of present snow surveys are almost impossible to determine because most of the field measurements are made by employees of cooperating agencies, and no central compilation of actual expenditures is made. An estimated 1800 snow courses in the United States are measured each month during the winter, taking at least one-half man-day per measurement. On this basis, a conservative estimate of the cost of data collection, including charges for men and equipment, is $135,000 per year.

These forecasts far more than repay their costs in added revenues from power generation and irrigation farming and in prevention of flood damage. On a single medium-sized multiple-purpose project in western Canada, it is estimated that each 1% increase in accuracy of forecasting April to August flow is worth $1 million in power revenues that would otherwise be lost because of the need to waste water in order to provide room for unanticipated floods. On a single 31,000 acre irrigation project in Idaho, it is estimated that farmers realized $317,000 in savings or increased income in 1960 because forecasts of abnormally low flows permitted them to reduce their acreage and change their cropping pattern. In the same year, release of stored water in Arizona on the basis of streamflow forecasts prevented about $600,000 in flood damages to the city of Phoenix with no loss of water for agricultural use. These examples could be multiplied throughout the United States and Canada. The benefits of the forecasts will be increased as their reliability improves.

5.2.2. RIVER AND LAKE ICE, AND AREAS OF FLOODING. Measurement of river and lake ice, and of areas inundated during floods are considered together because of similarities in operational and sensor requirements. Sea ice reconnaissance, an important oceanographic application (discussed in Section 7) would be part of the mission of any satellite that measures river and lake ice.

Information on the extent of ice formation on navigable inland waterways is needed to plan icebreaking schedules and to decide on the feasibility of navigation during critical periods. Information about ice on rivers will help in estimating the likelihood of flooding due to temporary ice jams during the spring breakup. When floods do occur, planning of emergency action and relief programs, evaluation of damage, and planning for future flood control would be facilitated by accurate data on area flooded. This information is often hard to obtain when bad weather and breakdown of communications during the emergency period prevent both ground and low level aerial reconnaissance.

An operational system would have to distinguish water surfaces from other surfaces through a dense cloud cover. It should detect the presence of ice in excess of nine inches thickness, but should not respond to thinner ice. The sensor should distinguish ice blocks with a minimum diameter of 50 feet in rivers and of 200 feet in the Great Lakes. In flood regions, the system should be able to fix the water boundary to within 400 feet in relation to conspicuous landmarks along the stream.

The target complex is the Great Lakes and major river systems north of 40° N Latitude. The target areas are limited in extent but are widely distributed. Complete coverage of the selected targets is necessary. In flood emergencies, the target area would be selected from earth. Weekly coverage would be required for navigation purposes, particularly in spring and fall, with data return within 3 days of collection. For flood surveys, observations should be made at every pass of the spacecraft during the emergency period. Fast availability is necessary if the data are to be of maximum value. Real-time data return would be desirable; return within hours is essential.

An active microwave system is probably best for this application because of its all-weather capability. Although the attainable accuracy of estimate may not be all that is desired, the necessary measurements seem to be feasible with present equipment.

The value of such information relating to flood conditions can greatly exceed its cost. The U. S. Weather Bureau estimates that an annual expenditure of $1 million for flood forecasting and flood surveys reduces annual flood damage by $30 million.

A related application is the measurement of the seasonal variation in surface area of water in very large river systems of low gradient, particularly the Amazon and the Congo. Although there is little present likelihood of using spacecraft to make quantitative flow measurements in ordinary streams, much useful information about flow rates might be obtained from regular synoptic observations of these two enormous and little known rivers.

5.2.3. SURFACE TEMPERATURES OF LAKES AND STREAMS. Local temperature variations in lakes and streams, when combined with other data, may help in identifying zones that differ in biological productivity and other limnological characteristics. Information on lake currents is needed to plot the long-term general circulation of lakes, and as an aid in understanding lake dynamics and estimating the probable future distribution of pollutants added to lakes. Short-term variations in the normal current pattern may indicate how movement of pollutants will be affected by abnormal wind patterns and other meteorological phenomena. It would be desirable to be able to distinguish separate sources of inflow to streams. These sources might include groundwater accretions, surface streams, or large pollution outfalls which can be identified and followed by means of temperature differences. For small lakes, this information can perhaps best be obtained from low level aircraft, but a synoptic view from orbiting platforms would be helpful in such large bodies of water as the Great Lakes.

Successive maps of the surface temperature of lakes and streams, interpreted by skilled limnologists, may yield much information about currents. It is doubtful that the information can successfully be digitized for automatic analysis, at least for the first several years. Subjective and highly skilled interpretation will be needed.

A temperature resolution of $1^{\circ}C$ would probably be adequate. Excessive temperature detail would only be confusing. Horizontal resolution of 200 feet would be required on lakes, and 50 feet on streams. Observations should be made both by day and by night to allow for solar heating effects at the surface. Temperature maps of the area being analyzed should be obtained twice daily for 3 to 4 days. These concentrated observations should be repeated every 2 to 3 months throughout the year.

5.2.4. VEGETATION, LAND USE, AND SOURCES OF STREAM SEDIMENT. The distribution of natural vegetation is an important indicator of regional climate, and the character of its vegetation tells much about the quantity and quality of a region's outflow. Possibilities for improvement of water regimes through vegetation manipulation can only be defined if the vegetation is known. Information about vegetation is particularly valuable as a hydrologic guide in remote and underdeveloped areas with few meteorological or streamflow stations. Because vegetation surveys are also difficult in such regions, satellite reconnaissance may prove an effective means of obtaining the necessary data.

Man's use of the land—urbanization, drainage, irrigation, cultivation, deforestation and afforestation, grazing, highway construction, and others—often markedly affects water yields, water quality, stream regimes, ground water recharge, erosion, flooding, and attendant sediment deposition. Evaluation of these effects is essential to the intelligent development and utilization of water resources.

Orbiting spacecraft offer one means of obtaining worldwide data on vegetation and land use, which change only relatively slowly over most of the earth. Methods and feasibility of vegetation and land use analysis are discussed in detail in the geography, agriculture, and forestry sections of this report. It should be noted that these data will be of as much value to water resources development and management as to the other subject areas.

A high proportion of the sediment carried by most streams originates from a few relatively small regions or discrete sources. Research to improve methods for indentification of land use and vegetation condition from spacecraft reconnaissance may eventually permit delineation of local sediment sources within a major stream basin more cheaply than can now be done on the ground. This would enable corrective action to be taken quickly, leading to reduction in downstream damages from sediment deposition and stream turbidity. Effective identification of local sediment sources from spacecraft is probably not feasible at present; however, experiments with airborne sensors would establish the ultimate capabilities of this method.

5.2.5. BASIN GEOMORPHOLOGY. The shape, relief, and form of the drainage pattern of a stream basin result from interaction of underlying geology with climatically controlled erosion processes. Basin geomorphic characteristics thus tell much about a region's climate, past and present. In turn, the geometry and morphology of the drainage basin influence the quantity and time distribution of runoff from a given amount of rain.

There is evidence that streamflow characteristics can be correlated with quantitative measures of basin geomorphology. This is a particularly promising approach to water resources evaluation in underdeveloped areas where direct information on streamflow is lacking. The exact measures and relationships have not been adequately defined, partly because in developed areas such as the United States so many other sources of data are available that the geomorphic approach is not really necessary, whereas in more remote regions even the necessary geomorphic data are not to be had.

Orbiting platforms are well suited to obtain quantitative geomorphic data for the earth's entire land surface. The most promising techniques are side-looking radar, which responds well to variations in topographic roughness, and conventional aerial photography. Availability of good data on basin characteristics might break the vicious circle in which intensive effort has not been put into correlating streamflow with geomorphic characteristics because there were few basins for which sufficient geomorphic data were available that did not already have adequate hydrologic measuring stations.

Since the necessary relationships have not yet been developed, extensive research will be necessary before geomorphic data can be used to evaluate worldwide water resources. The first step will be to determine what physical characteristics of stream basins can effectively be measured from satellites, and to develop satisfactory methods for reducing the observations to digital form. Among those that should be tested for feasibility are basin shape, channel dimensions, several measures of slope and relief, and drainage density and texture. Remote sensing of these characteristics on a number of basins whose hydrologic behavior is well known would then provide a basis for relationships that can be applied to comparable basins in remote parts of the world.

5.2.6. DETECTION OF FROZEN OR UNFROZEN SOIL. Many floods from spring rain or sudden snowmelt are aggravated by frozen soil which impedes infiltration and forces water to flow quickly over the surface to streams instead of moving slowly through the soil. In mountain regions, the water yield from a given quantity of snow is normally greater if the ground is frozen beneath the snow than if it is unfrozen. Soil freezing usually occurs when severe cold precedes heavy snowfall. If permanent winter snow arrives before the soil freezes deeply, its insulating effect prevents further soil freezing. In the arctic, many aspects of plant growth and of vehicle trafficability are related to the depth and duration of soil thawing over permafrost.

The minimum sensing requirement is the ability to discriminate between deeply frozen soil and soil that is completely thawed or frozen to a depth of less than 2 inches. Minimum horizontal resolution is about 400 feet. Temperature techniques alone will not serve, because the system must be able to distinguish frozen soil from snow and ice at the same temperature, and because of solar heating heating and radiation cooling effects at the immediate surface, which may be a plant cover overlaying the soil. A practical system might eliminate snow areas on the basis of their high visual albedo. Microwave emission might then differentiate between frozen and unfrozen soil through differences in dielectric properties. Surveys are needed at biweekly intervals during the period of interest: fall and spring in temperate regions, summer in the arctic.

5.2.7. EVAPORATION, TRANSPIRATION, AND ENERGY BALANCE. Among the most important components of a region's water balance are daily, monthly, and seasonal rates of evaporation and transpiration from vegetated surfaces. Evaporation and transpiration are extraordinarily hard to measure on an area basis; no satisfactory field method now exists. Accurate estimates of the changing flux of water vapor from vegetated surfaces under the influence of rainfall, solar radiation, kind of vegetation, and management practices would be of great value for predicting, classifying, and managing regional water supplies.

It is doubtful that efficient direct methods can soon be developed for evaporation measurement from spacecraft. Evaporation can theoretically be determined from the difference between the water vapor that enters the column of air above an evaporating surface and the water vapor that leaves the column. It is possible that the water vapor content of the air column between a satellite and the ground can be estimated by exploiting the differential absorption by water vapor of infrared energy in closely adjacent wavelength bands. Most of the water vapor in such a column would be a consequence of the rapidly changing large scale circulation of the atmosphere, however, only a small proportion would originate from evaporation at the ground. The signal-to-noise ratio would probably be too small for reliable estimation of terrestrial evaporation. Furthermore, surface air velocities would also have to be known before actual rates of water loss could be determined. Direct measurement of evaporation from orbiting platforms will probably have to await development of reliable methods for measuring the vertical and horizontal gradients of water vapor in the lowest 100 feet of the atmosphere and the rates of turbulent air movement in the same zone.

Indirect estimation of evaporation through knowledge of the surface energy balance may be more promising. The ultimate source of energy for evaporation is the sun. If the input of energy at the earth's surface is known, and if all forms of energy dissipation except evaporation can be measured, the energy used for evaporation, and hence the amount of water evaporated, can be computed by subtraction. Several components of the surface energy balance besides evaporation probably cannot be measured from satellites, but the radiative and reflective components can.

Outgoing longwave radiation can be measured by remote sensing of the apparent surface temperature. Infrared sensors of sufficient resolution and sensitivity are now available. Problems of data interpretation remain, related principally to inadequate knowledge of the emissivities of various surfaces and to energy absorption and radiation by the atmosphere. It is likely that further research will show that areas similar in longwave radiation characteristics are similar in other ways, such as annual water budgets.

Surface temperature data are also potentially useful because evaporation and transpiration are effective cooling processes. Temperature differences between transpiring and non-transpiring vegetated surfaces are small, but may be detectable. Further research may show that temperature differences can be used to make quantitative estimates of transpiration differences. The estimation will not be straightforward, and there is little except theoretical studies and small scale laboratory experiments to go on. This is another example of a field whose real potential cannot be evaluated because there has been no way to get the necessary data prior to the spacecraft era.

Another major component of the energy balance that can be estimated by remote sensing is reflection of solar energy. Vegetated surfaces differ from non-vegetated surfaces, and various types of vegetation differ among themselves in reflection characteristics. Hence they retain different proportions of incoming radiation. This retained energy is used cheifly for evaporation and for heating of the surrounding air.

Changes in the energy absorption of snow through changes in its surface reflectivity are particularly important in snowmelt phenomena. Frequent observations of snow reflectivity are needed for better understanding of melt processes and for better prediction of probable melt rates. Currently available methods can measure reflection characteristics of snow and vegetation with the necessary precision.

5.2.8. DETERMINATION OF SOIL MOISTURE. The top 6 inches of the soil is the zone of the earth's primary hydrologic activity. Under the influence of rainfall and evaporation, this zone displays the most marked daily and seasonal changes in moisture content. Plant roots extract most of their water from this zone. Conditions at the immediate surface govern the rate of infiltration, or conversely, the quantity of water running over the surface. Much of the water that reaches streams after a rain moves through the surface soil layer. Frequent synoptic observations of the moisture status of this layer would therefore help in understanding many hydrologic processes and in predicting the runoff to be expected from rains of various amounts, intensities, and durations. Practically all the remaining water that enters into hydrologic exchanges is contained in the top 6 feet. Measurement of the water in this zone in addition to that in the surface layer would therefore also be highly useful.

It would be desirable to integrate the moisture content of the top 6 inches of the soil over an area of about one-fourth square mile. Separate measurements should be obtained of the water content in the top two meters. It would be desirable to separate the moisture status of any area into at least three classes: dry, moist, and wet. These three categories correspond to differences of about one inch of water in a six-inch soil layer. It would be useful, and perhaps more realistic, to be able to distinguish only two classes, wet and dry soil, although the value of this information would be substantially less than if three classes could be recognized.

Sensor systems would probably have to depend upon selective polarization of microwave emission by contained water, or perhaps upon differences in heat capacity and thermal diffusivity of wet and dry soil. Color differences, an obvious choice, have been shown not to work because non-uniform drying at the immediate surface distorts conclusions based on color, and because the surface of the soil is partially or completely obscured by vegetation in most regions of interest.

Observations of moisture content would need to be obtained at least weekly. More frequent observations would be needed for short periods during special studies. The target area would ordinarily be a sample stream basin 100 to 1000 square miles in area.

6
WILDLIFE AND FISHERIES RESOURCES

6.1. BACKGROUND

The wildlife and fisheries resources of the world provide food (particularly the fish resource) and other essentials (furs, leather, etc.) to sizable portions of the world's population. In addition, they offer man a source of recreation, a diversion from routine, that seems necessary for his mental well being. Knowledge and management of wildlife and fisheries for these purposes is essential if they are to assume their proper relationship in an ecosystem strongly affected by man's needs and activities. The ability of a spacecraft to provide broad synoptic coverage and to eliminate unnecessary detail is its prime advantage for aiding in the understanding and management of a resource that is found in different forms throughout the world and will soon be important in a world-wide scheme to improve local ecosystem efficiency.

6.1.1. WILDLIFE AND FISH PRODUCTS. Unless the function of protein synthesis now provided by animals can be replaced in the future by a more efficient system, the wildlife and fisheries of the world will remain valuable as a food resource. Production by the world's marine fisheries increased from 25 to 42 million metric tons between 1955 and 1962. The direct use of fish for food is increasing 5-1/2 to 8 percent per year (Ref. 36). The value of the U. S. catch of 2,717 million pounds in 1962 was $381 million dollars. When allowance is made for tripling of value between producer and consumer, this represents over a billion dollars of the gross national product. Besides being used as food directly, the fish resource is converted to fishmeal, oil used in industry, and other compounds. Fishmeal is nearly 80 percent protein and is the most likely source of protein available for meeting the increased demands of the expanding human population. As described in Section 7, spacecraft observation could be very useful in finding fish and describing their environment for management purposes.

Wildlife is also valuable as a source of food and other products. While we have reached a state of civilization in this country where man no longer hunts to live, this is not the case in many parts of the world. Indian tribes in the northern reaches of Canada survive or perish depending on their ability to intercept herds of caribou. People in parts of Africa and Australia depend on wild animals for food. In many cases, the wild animal makes more efficient use of an environment than domestic meat producers, and is particularly valuable in utilizing lands that are unsuitable for agriculture.

Wild animals also provide hides and products for clothing, tools, and ornamentation, necessary in some cultures, desired in others, such as ours. As the world's population and standard of living increases, people will no longer demand such animal products to the same extent. This will not be seen in many parts of the world for 10 to 50 years, however, simply because technology will not spread to those remote areas untill the living space they provide is in sufficient demand.

One of the least noted but most important functions of wild animal populations lies in their role as scavengers. As such, they return bound-up energy to the more active parts of the food energy system where it can be more readily utilized, and perform many other ecologically necessary functions.

At present our use of wild animals falls below an efficient level because most of the total wildlife population of the world is unmanaged. The surplus harvested from these unmanaged populations, on a long term basis, falls below the harvest possible with a managed population. If wild animals continue to be the most efficient link in one portion of the world-wide ecosystem, they will have to be harvested or protected to a degree that maintains them at an efficient level. Efficient utilization of parts of the natural environment will continue to be the function of a certain proportion of the animal population, and their products or recreational value will be necessary to certain economies.

The use of spacecraft for observation of migrating caribou, detection of fur seals instrumented with transponders or monitoring of the nocturnal location of herd animals in large aggregations would, if feasible, be of great value in the management of these animal groups. Assessment of their habitat as performed by systems also used for agricultural applications would be even more valuable and is discussed below.

6.1.2. RECREATIONAL USES. Our fisheries and wildlife resources are also of increasing importance as a source of recreation. Periodic diversion from routine activities raises the total level of human productivity in the long run. Also, the contribution of recreation to mental health has often been cited. Aside from the individual's needs for recreation, society's demand for it can only increase as our improved technology provides us with more leisure time.

One of the sources of recreation that sub-marginal lands can produce is wild animals. Technological advances in agriculture suggest the probability that increased demand for food will be met with improved techniques of utilization on lands favorable for agriculture rather than through cultivation of sub-marginal farm lands. The centralization of populations in urban areas seems to indicate that lands becoming sub-marginal for agriculture or mineral exploitation because of their remote location will not be used for residential areas.

Wild animals living on these sub-marginal lands can provide recreation for hunters, fishermen, sightseers, and camera enthusiasts. Maintenance of a population of selected species at a level such that the most efficient use of the land resources and the animal resource for recreation is attained will be a goal for the future. In most cases recreational uses of land are compatible with other uses, and hence constitute part of the most efficient total use. In cases where there is limited compatibility, the value of maintaining a wildlife or fish population for recreation must be judged against its cost in terms of the value of the other resource lost or reduced by the wildlife or fish.

Recurrent assessment from space of agricultural lands and waterfowl breeding and wintering areas, synoptic records of natural conditions on National Wildlife Refuges, and studies of oil pollution and biologic conditions of inland waters all will aid in maintaining wildlife at effective levels in our varied environments.

6.1.3. ECOLOGICAL STUDIES. More generally, the role of wildlife and fisheries resource management may be viewed in terms of the establishment of an ecological system in which most efficient use for man's purposes is made of all the energy impinging on the earth. This goal requires that the energy cost of animals to the system be assessed. Knowledge of animal ability to store and return energy and convert energy provided by various plants, when combined with knowledge of the optimum plant for a site in terms of energy utilization, leads to a decision on the optimum species and population levels of animals for a given area or portion of the ecosystem.

Better knowledge of the numbers and distribution of animals and fishes is required. Their availability for use as food and for recreation needs to be known on a world-wide scale over substantial time intervals. The demands and contribution of animals to the energy budget must be assessed by individual areas. The effect upon animals of weather, ecological succession and evolutional development, as well as man's activities must also be assessed. This information will lead to selection of the most efficient land use system for various environments of the earth.

Spacecraft data when added to present knowledge of physical conditions and demands would provide forecasts of the wildlife and fisheries role in relation to those conditions and demands. Such knowledge would permit us to judge the type of management to pursue with respect to type and intensity of land use, selection of species, and time scheduling.

While incapable of some of the details required, spacecraft observation because of its global capacity would provide clues to the proper direction of research. In many cases, the impact of animals on their environment could be measured directly simply by observations over a period of time. Depredation of crops and vegetation by animals and influence on successional changes could be monitored. The effect of meteorological conditions, land use practices, seasonal anomalies, and successional changes on animals could be established if we had an adequate time record of these phenomena to compare with ground data on numbers and conditions of wildlife and fishes.

A research tool providing global coverage of cause and effect phenomena at regular intervals would permit the necessary integration of data. A spacecraft performing continuing coverage of large areas, if capable of being directed for intensive surveying of a given area within a limited time span, would be valuable. If a spacecraft merely directed the activity of ground-based or aircraft reconnaissance, it would still be very useful.

6.2. SUMMARY OF APPLICATIONS

In the following discussion, the function of spacecraft observation for wildlife and fisheries is divided into three parts:

a) habitat assessment,
b) studies of animals as units or populations, and
c) assessment of man's activities in relation to animals.

For purposes of habitat assessment, spacecraft could be used to study water and vegetative conditions in waterfowl breeding and wintering areas, monitor water and vegetation conditions and state of vegetative maturity on national wildlife refuges, assess conditions on agricultural lands and livestock range, and study the temperature changes and eutrophication of inland waters. All of these applications could likely be accomplished by employing the agriculture and oceanography sensing systems and/or using the data collected for agricultural purposes.

Detection of migrating caribou against the snow of Northern Canada, location of fur seals in the Pacific Ocean by means of transponders, and nocturnal location of herd animals fall within the province of direct detection of animals or population dynamics.

In order to evaluate the interrelationships of animals with man's activities, we would hope to detect water pollution by oil and other contaminants, and agricultural damage.

6.3. DESCRIPTION OF APPLICATIONS

6.3.1. ASSESSMENT OF WILDLIFE AND FISHERIES HABITAT

6.3.1.1. Waterfowl Breeding and Wintering Grounds. Maintenance of recreation dependent on waterfowl represents a sizable investment by many countries, and harvest of waterfowl a portion of the food resources of many other countries.

The National Survey of Fishing and Hunting in 1960 found that 1,955,000 persons in the U. S. hunted waterfowl that year and spent an average of $46 for a total of $89.4 million (Ref. 37). Hunters seek to bag a portion of the estimated 70 million ducks and large numbers of other waterfowl available to them during the fall hunting season. The average bag per year is on the order of 20% or 14 million ducks. Aside from consumptive recreational uses of waterfowl, 10.4 million people visit national wildlife refuges each year, the majority to observe waterfowl (Ref. 38). The latter activity has shown the faster increase in popularity, other than boating and sailing at reservoirs, and has grown since World War II at a rate of 12 percent per year.

The waterfowl necessary to sustain these activities are produced in the prairie pothole region and other portions of the northern U. S. and Canada. The birds migrate to the south and winter in high concentrations along the southern and eastern coasts of the U. S., in California and Mexico. Unlike other wild animals, waterfowl are particularly subject to decimation due to their tendency to stay in a group. During the migration period they are hunted and suffer numerous losses from pollution, predators, etc. sufficient additional mortality occurs during migrations and in the wintering grounds that only an estimated 30 million ducks reach the breeding grounds in the spring.

The major influence on waterfowl abundance, however, is the amount and quality of suitable breeding and, in some cases, wintering areas. The latter requirement of waterfowl is continually shifting due to drought and agricultural activities. Drought produces drastic but normally short term or cyclic reductions in waterfowl numbers; the withdrawal of wetlands for agriculture is usually more permanent in its effect.

6.3.1.1.1. Breeding Ground Survey. Proper management requires knowledge of the numbers of waterfowl available in the fall and consequently information on the water and vegetation conditions in the waterfowl breeding grounds. Two evaluations are made each year, in the spring and in July, costing the U. S. about $115 thousand and Canada an additional sum. The results of these evaluations are used to better manage the resources, for example, by setting up hunting regulations (Ref. 39).

A spacecraft system would not be capable of counting broods of ducks but should be capable of habitat evaluation on a broader and perhaps more objective scale than is currently possible. Resolution on the order of one acre (200 × 200 foot), as proposed in Section 3 for obtaining agricultural census and statistics data would provide useful information on water area extent and relative amounts of water-land interface. Data might be obtained bi-weekly or weekly for large areas throughout Canada, the United States, and Mexico. Visible photography, providing better resolution (on the order of a few feet), might be obtained monthly from April to September depending on latitude (See Agricultural Programs, Section 3.2.1.2.). The development of multispectral analysis with resolutions on the order of 200 ft would be very useful in vegetation analysis in the breeding areas.

The use of systems designed for oceanographic assessment of water surface temperature and aquatic biomass could be used to indicate eutrophication and available aquatic food in the breeding grounds. Resolutions near one acre size and assessment two or three times a year between April and September are desirable. Data should be made available to the U. S. Fish and Wildlife Service, the states, Canadian Wildlife Service, and Mexican authorities, as required.

6.3.1.1.2. Wintering Ground Survey. In the wintering grounds, waterfowl gather in large concentrations on relatively large bodies of water. The breeding habits of some species are so scattered that this is the only time their numbers are estimated. At present the birds are censused by estimating from the air or direct counting on photographs. A spacecraft observation system, while unable to count individual waterfowl, might yield photographs from which measurements of the aggregate size and relative density of flocks would lead to estimates of numbers. The advantage is one of synoptic evaluation; flocks of birds could not move significant distances within the time span of the survey.

In these concentrations, the birds often do a considerable amount of agricultural damage. The problems of using present methods of observation to correlate the concentration of waterfowl with agricultural damage can be easily grasped. On the other hand, employment of the same types of orbiting sensors used for agriculture and oceanographic applications in observing the wintering grounds would provide useful information on the location and extent of agricultural damage in relation to waterfowl concentrations, aquatic food potentials of the waters where waterfowl concentrate, and influences of pollution and other results of man's activities upon the aquatic environment used by waterfowl.

6.3.1.2. Survey of National Wildlife Refuge. Wildlife refuges comprising approximately 28,560,000 acres are integral parts of management plans of continental, national, and local scope (Ref. 38). For waterfowl the refuges provide breeding grounds in the northern states, wintering grounds in the southern areas of the U. S. and feeding/resting stations in between.

As species management becomes increasingly intensive and the need for more accurately applied hunting regulations develops, one of the prime needs will be for accurate and last minute knowledge of water and vegetation conditions on wildlife refuges. There is some evidence to suggest that multispectral analysis will detect changes in vegetation before they become recognizable to refuge personnel. This objective type of detection coupled with the subjective and more complete reports of the men on the ground would be very useful. Multispectral analysis systems used for crop identifications and state of maturity estimates would be adequate for most refuges.

National wildlife refuges keep relatively accurate records of changes in vegetation and water conditions and phenologic changes on the refuge and surrounding area. Since many refuges are located in agricultural areas and still others are situated on the sea coasts, they would provide excellent test sites for sensors used for agricultural and oceanographic (coast geography) applications.

Other wildlife refuges are responsible for protecting big game animals and would profit from the measurements and coverage proposed for forestry (Section 4), agriculture (Section 3), or water resources (Section 5).

6.3.1.3. Wildlife Management in Agricultural Areas. According to Reference 37, approximately 72 percent of the hunting in the U. S. is for small game, which normally occurs in huntable numbers where agricultural lands provide an abundant food supply. These animals also require cover, which might be thought of as living and hiding space.

Proper management of farm game species, such as rabbits, pheasants, and quail, require up-to-date knowledge of vegetation and land use patterns in the farm land areas, particularly those near urban population centers. The history of agricultural development shows a trend toward increasingly intensive use of all land within the farm boundary. Fencerows are eliminated, swamps drained, and sub-marginal soils treated until they are capable of cultivated yields. This process eliminates cover and reduces the game population carrying capacity of the farm.

These changes coupled with shifts in hunting pressures and phenologic events are the factors upon which management practice decisions are made. A spacecraft system, as designed for agricultural purposes, and would provide a fund of information useful to state conservation departments in carrying out their management responsibility; hence, they should be a secondary recipient of agriculture data. Present meteorological satellites approach the capability of providing phenologic information such as the number of cloudy days for a given area and for specified months of the year. This type of assessment should improve the cooperative results of the local units of the Soil Conservation Service and the State Conservation Agencies.

6.3.1.4. Range Management. Meat and hides, wool, milk and milk products are integral parts of the nation's economy and health standards. Much of these products come from large areas of the western parts of the United States, which are in range land privately or publicly owned and grazed. Most of the grazing is by cattle and sheep, some by wild herbivores such as elk, antelope and deer. A unit of range land is capable of supporting only a certain number of livestock per year or season. If the number of livestock days calculated as the carrying capacity of a unit of land is exceeded, the grass is damaged in such a way that the carrying capacity is reduced or eliminated for long periods of time.

Spacecraft observation of range lands to provide rapid evaluation of range conditions in terms of species distribution, height, maturity and density of grass seems feasible with multispectral techniques. Moisture content and depth of moisture may well be detected with radars operating in the 1/4 to 2 gigacycle frequency range, having the ability to penetrate foliage and soil.

Such a system providing better estimates of carrying capacity before and during grazing, and possibly damage after grazing, would be valuable in making the most effective use of existing grazelands. A system capable of such surveys would require extensive testing and analysis in an escalation of platforms from ground to high flying aircraft.

The operational data would be distributed to regional units of the U. S. Department of Agriculture and thence to individual stock owners, their associations, and local units of the agencies responsible for management of public grazing lands, chiefly the U. S. Forest Service (see Section 4.1).

6.3.1.5. Temperature and Eutrophication of Inland Waters. Seasonal changes in the temperature and amounts of organic material in lakes, streams, and rivers are two of the most important factors regulating the amount and kind of fish and the possible recreational activities. Spacecraft systems would be capable of recording relative apparent temperatures for lakes on the order of five acres and possibly for streams and rivers as narrow as 100 ft due to their linear character (see Section 5.2.3). The amount of organic material in lakes and other inland waters should be detected by multispectral analysis utilizing chlorophyll absorption bands and other bands shown in the experimental phase of the program to yield significant enhancement of spectral contrast. The measurement would be relative; however, biologic data coupled with temperature data should indicate the probability and time occurrence of plankton blooms, and the conditions present in the lake limiting various species of fish.

The spacecraft report would tend to improve the reliability of inferences made from existing data and thus would be very valuable. Computer analysis of the recurring spacecraft data input should help to ease the acute problem of handling large volumes of data with the inadequate numbers of personnel and limited funds available for inland fisheries research.

6.3.2. STUDIES OF ANIMAL POPULATION

6.3.2.1. Northern Canada Caribou. Even today, in some parts of the world, man hunts to live. Noteworthy examples are the Eskimo and Indians of Northern Canada who depend heavily on migrating herds of caribou as a food supply. A 1948 study indicated that the 20,000 inhabitants of approximately 600,000 square miles in Northern Canada depended, in some cases, entirely on caribou for food and clothing. The annual harvest is on the order of 100,000 animals and proper management is required to prevent the permanent decreases in the total population of caribou which occurs each year primarily due to human wastage (Ref. 40).

The users of caribou depend upon anticipating the migration times and routes of the caribou. If for any reason they miss the migration, starvation is a certainty without outside assistance. Prevention of costly food supply programs by the Canadian government can be achieved by proper management; this requires accurate knowledge of the caribou movements.

Caribou migrate in large herds of several hundred to a hundred thousand or more individuals, across large areas of northern Canada. Caribou follow parallel trails, normally in single file, when travelling from summer to winter ranges. The trails (up to 12 parallel) are generally 6-12 in. wide and when used for several years become up to 4 in. deep and are observable from aircraft. During the spring migration (April and May), the routes lie along water bodies while in the summer and fall migration they follow the heights of land. Their speed of migration probably averages near 20 miles per day with major advances at dawn and dusk. During the summer months the animals weighing between 150 and 200 lbs. are quite dark but in the winter months take on a salt and pepper appearance.

Spacecraft observation should be capable, using visible photography or possibly infrared, of detecting "warm" lines of caribou against a snow background due to the linear nature of their migration habit. Visible photography would be feasible if restricted to the major migration routes as illustrated on the preceding pages. Multispectral analysis of vegetation in tundra and forest areas would also be of value in managing caribou herds. Manned spacecraft using visible photography could be very useful in recording the location of bands of people or inhabited dwellings that tend to move with the caribou. The spacecraft is particularly adapted to this remote area where operation of aircraft is expensive and hazardous. The proper recipient of data would be the Canadian Wildlife Service, Department of Resources and Development.

6.3.2.2. Alaska Fur Seals. There is an opportunity for discovering the home range of Alaska fur seals, Callorhinus alaskans, utilizing an intermediate telemetering buoy system or data relay to spacecraft directly. Fur seals have been brought back from the verge of extinction by intelligent and stringent management procedures. Since 1910, when a limited harvesting program was started, enough surplus male seals have been taken to make 200,000 coats with a yearly revenue on the raw hides as high as $3 million.

To this day, no one knows where these animals go when they leave the Pribilof Island Group for 10 months of the year. With the development of transmitting devices small enough to be attached to seals, and powerful enough to send signals from buoy and/or ocean locations to an orbiting spacecraft, we should be able to trace the movement of this valuable animal for the first time. The movements of equally valuable sea otters might be traced in the same manner. World-wide observation of the seals should help to further international cooperation for their proper management and conservation.

Fifty to a hundred seals might be released with transmitting devices and an orbiting spacecraft system triangulate on hourly signals to provide daily location. A polar orbiting spacecraft might fix the location once a week in accordance with its other data loads. Data would be distributed to the Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife.

6.3.2.3. African and Australian Herd Animals. It may be possible to detect large aggregations of game in Africa or Australia and perhaps herds of domestic animals in other areas. Wild game in some areas make more efficient use of their habitat than domestic animals. They require proper management if they are to remain on a sustained yield basis. There is little chance that these warm climate animals would be detected during the day. However, imagery acquired at night for other purposes could be searched for nocturnal locations of large herds. This information when coupled with daytime observation from the ground and light aircraft would provide very useful management information.

6.3.3. ASSESSMENT OF MAN'S ACTIVITIES IN RELATION TO WILD ANIMALS

6.3.3.1. Pollution. One of the chief pollution problems in respect to wildlife is that of oil and its effects on waterfowl. When waterfowl come in contact with petroleum products, they may drown because the resultant matting of their feathers reduces their buoyancy. Or they may die from exposure because oil permits water to reach their skin. In addition, upon ingesting oil either on vegetation they eat or through preening of feathers coated with oil, the birds become sick and may die. The value of this resource has been illustrated earlier. Annual loss of waterfowl due to oil pollution is substantial, and has been estimated as high as one million on a world scale. The annual loss of waterfowl in this country alone due to oil pollution could exceed 100,000 (Ref. 38). In March 1960 oil pollution on the Detroit River killed 12,000 waterfowl, mostly canvasback, a valuable game species. Alfred L. Hawkes, in the Transactions of the 26th North American Wildlife and Natural Resources Conference noted a number of losses, including the following major ones:

1) A loss of 250,000 ducks in 2 years due to oil pollution in Newfoundland.
2) Over 250,000 in the North Sea as a result of one oil spill.

Waterfowl are not the only resource lost to oil pollution; shell fisheries often are drastically affected. By 1964, 32 countries had signed a convention for the prevention of pollution of the sea by oil and the U. S. Congress passed Public Law 87-167 to carry out the purpose of the convention (Ref. 38).

Petroleum products emit radiant energy characteristically as a stretched bond hydrocarbon absorbing at wavelengths near 3.0 microns. A multispectral system would be capable of detecting oil spills on sea water if they are at least 1/4 mile in diameter. A recurrence of data collection of the order of 3 days would be required in order to detect all oil slicks (based on the rate of spread of oil slicks under calm conditions with heavy oils). Light oils in rougher seas would spread more rapidly and daily detection would be more useful. Daily detection would also be necessary for inland bodies of water.

A device that responds only when an oil slick is detected and indicates its position when redetected on a future orbit or by a second spacecraft could be used in conjunction with data from other systems detecting meteorological and sea state data. The results would provide data on direction and velocity of movement for the slick and allow preventive measures to be taken, where feasible. This simple detection would also help to enforce PL 87-167 cited earlier.

Rapid readout approaching real time transmission is required if the data are to be useful in preventing waterfowl and shellfish losses. The data would be distributed to the Fish and Wildlife Service, the Coast Guard, and the Public Health Service in the U. S., and to agencies responsible for control of oil pollution in foreign countries.

Pollution of many other kinds, chemical, physical, and biological, also affect wildlife and fisheries either by raising the biochemical oxygen demand (such as proteins and domestic sewage), by lowering the water's capacity for dissolved oxygen, or by adversely affecting aquatic organisms and their food. Detection systems as previously discussed for detection of water temperature, multispectral analysis, or color photography should help in assessing water conditions. The extent to which spacecraft observations can contribute to solving these problems will be clear only after an experimental program.

6.4. BENEFITS OF SPACECRAFT SURVEYS

The value of applied or basic research in the field of wildlife and fisheries conservation is in formulating management policies and procedures that will provide a usable resource for present and future generations. Spacecraft have the ability to contribute to that goal.

Aerial studies of waterfowl habitat are presently used on a limited basis. The U. S. Fish and Wildlife Service spends approximately $130,000 each year to assess these areas. The Canadian Government spends nearly half that amount; additional amounts are spent in the wintering area of Mexico, and much work is donated by interested individuals (Ref. 39). The funds allocated for this research do not indicate its true worth and even more effort devoted to habitat surveys would be very useful. Spacecraft observation could make the decisions based on these studies more up-to-date and hence more reliable.

The recreational role of the wildlife and fisheries resource has been discussed in Section 6.1.2. The benefit to the individual has been indicated in terms of the enjoyment of a relaxed atmosphere, the mental well-being wrought by a change from routine, the increased efficiency and productivity upon return to routine activities, and the chance to broaden one's horizons.

It is generally accepted that recreation cannot be reliably evaluated in monetary terms, since it is not strictly a consumptive item. Only if game and the recreational enjoyment it provides were sold on the open market would we be able to define its true monetary value. However, when game become quite scarce in relation to the number of hunters, fishermen or sightseers, its substantial value becomes more evident. This situation is approached in Europe where trophy fees on the order of $50-100 are often charged and willingly paid by sportsmen.

Similarly, increasing use of the limited fish and wildlife resource in this country will lead to greater evidence of its value to the individual and society.

The fees that people are willing to pay for licenses is another index of the recreational value of game. In 1960, $110,844,000 was spent on licenses, tags and permits and $4,575,000 on duck stamps. Additional information on the value of the fish and wildlife resource can be derived from studying the distribution of public spending. It can be argued that the recreational resources in a free enterprise alternative cost system are worth as a minimum the amount governments spend in furnishing recreational opportunities. In 1960 the total direct outlays for outdoor recreation by all public agencies were $1.15 billion of which $610 million was spent by fish and game agencies, federal and state (Ref. 41). The states added the greatest amount of acreage for fish and wildlife areas although they spent the most money for part areas (Ref. 42).

The expenditures for fishing and hunting indicate its importance in the economy; the total spent by the U. S. population in 1960 was $3,852,110,000 (Ref. 37). Lakes, streams, and rivers have tremendous recreational value; fresh water fishing alone accounted for $2,064,580,000 of the 1960 total expenditure. The condition of these inland bodies of water also has important effects on forest and agricultural growth and on man's activities; this matter is treated in other sections of the report, particularly in the discussion of Water Resources (Section 5).

An analysis leading to estimated benefits of spacecraft application may be based on the well-known "Greek Book" (Ref. 43) which states that Primary benefits from hunting, fishing, and other forms of outdoor recreation consist of the value of any increase in the amount of recreational use expected as a result of the project. Such an increase may be expressed in terms of recreational days or in terms of sport fish and game harvests. This increase is measured by comparing future recreational activity in the area with and without the project. Since market prices are not available to express the value of this increase in monetary terms, an estimated or derived value comparable to market value may be used for this purpose." Two particular approaches to the problem of selecting monetary values of recreational activity are cited below.

The Fish and Wildlife Service has used the "sportsman expenditure" method (Ref. 44) for evaluating the merits of particular projects. The concept assumes that the public benefits from fishing and hunting represent an amount equal to the expenditure of participating sportsmen for goods and services purchased in preparation for use of project facilities.

Another basis for estimating project benefits is the work of a panel on recreational values of the Interagency Committee on Water Resources (Ref. 45). This panel listed the proposed schedule of values (Table V), although it gave no indication of their origin. The schedules given in Table V, which give more conservative results than figures derived from the "sportsman expenditure" approach, are used later in this section for estimating anticipated benefits.

The following analysis attempts to arrive at a conservative indication of wildlife and fisheries benefits to be derived from the spacecraft program as proposed in this and associated sections of the report. The cited benefits should not be equated with market price evaluation, but should be used with judgment and appreciation of their derived nature.

Game management can be defined as the art of utilizing land resources to produce wild animals on a sustained yield basis for recreational purposes. To meet the goal, an attempt is made to balance the productive capacity of the land, the use of the game for recreation, and effects of the animals upon their habitat particularly where those effects influence man's activities. Spacecraft can contribute to reaching that goal by increasing knowledge of game, game habitat, and the relation of game to people.

Most game species, fish or wildlife, place specific demands on their environment and consequently the amount of suitable habitat is often quite limited and poorly distributed in terms of recreational use. Population expansion and continuing trends toward higher living standards tend to withdraw habitat for other uses or impair its suitability for wild game populations. Consequently, there is and will continue to be only a limited amount of game-producing habitat available. The extent to which habitat can be adapted for use is also limited and therefore the ultimate available quantity of game is fixed. These limits have not yet been reached and spacecraft observations of farm game habitat, waterfowl breeding and wintering grounds, wildlife refuges, forested areas, inland and coastal marine waters, and rangeland should help us to assess the dynamics of animal habitat and formulate the steps necessary to maximize the production of game animals. Increasing the usable game production of land where habitat manipulation has occurred can be approached in two ways, by distributing the game producing units of land, and by distributing recreational use. Spacecraft observation of environment can help to designate suitable habitat not presently under management and indicate areas where effort is presently being wasted on unsuitable habitat. Spacecraft reconnaissance of man's distribution and recreational activity, in relation to game habitat and observable concentrations of game, should point the way to proper regulation of when, where and how man uses game, and should help to equitably distribute that use.

Another method of producing more usable game is to limit mortality factors other than hunting. Game populations whose yearly surplus is harvested by man tend to be healthier and produce higher quality recreation than those where natural checks are inadequate because of

TABLE V. SCHEDULE OF VALUES FOR RECREATION

Item	Range of Values per Recreational Day of Fishing and Hunting
Fishing	
Reservoir	$0.50 to $1.50
Stream or Lake	
Warm Water	$0.50 to $1.50
Cold Water and Bass Fishing	$1.00 to $3.00
Hunting	
Small Game	
Mammals	$0.50 to $1.40
Birds	$1.00 to $3.00

man's influences. Left alone natural checks are very effective, but where man's influence disturbs the natural balance, they are often more drastic than necessary resulting in a reduction of available game for several years. Many game populations are known to be cyclic in their abundance, but the cause of cyclic population levels is uncertain. Early warning of changes in habitat that favor mortality factors other than man's harvest, continual observation that should help in understanding and accounting for cyclic populations, and detection of man's influences such as oil and other types of pollution are ways in which spacecraft can be used as a research and management tool to improve the resource and its use.

It is believed that spacecraft used for the functions described in Section 6.3 could be responsible for increasing by about 2 percent the amount of game usable for recreation; this game would otherwise be lost because of the pressures on land use, improper harvesting of game, and management practices based on inadequate knowledge.

Assuming that an increase in available game would permit a corresponding increase in allowable recreational activity, an estimate of benefits is obtained by using the schedule of values cited in Table V. (This estimate is more conservative than one based on the "sportsman expenditure approach.") Estimates of demand are assumed to be those derived by the National Survey of Fishing and Hunting made in 1960 and those made in Ref. 46. From these figures, we foresee benefits of spacecraft activity as shown in Table VI.

Other benefits of spacecraft observation would be derived from the increased ability to protect the carrying capacity of rangeland from the effects of overgrazing. The original cost of an acre of grassland varies from a few dollars per acre to $500, but $10-25 per acre is a representative figure. A spacecraft observation program would be annually worth the savings accrued as a result of warnings of overgrazing and the preventive measures taken after that warning. Benefits of remote sensing would be realized from the better estimates of carrying capacity for a given year or season resulting in more efficient planning of herd size and probable market conditions. Although the amount of land completely lost each year due to overgrazing is no longer significant, seasonal variations in carrying capacity are not always accounted for and this leads to reductions in that capacity for a number of years.

TABLE VI. BENEFITS OF SPACECRAFT TO WILDLIFE AND FISHERIES RECREATION

	Total Days of Activity	Average Value Per Day	Spacecraft Benefits Due to 2% Increase in Recreational Activity
	Million Days	Dollars	Million dollars/year
National Survey of Fishing and Hunting (12 mo. evaluation)			
Fishing	465.7	$1.30**	$12.1
Hunting	192.5	$1.50	5.7
Total			$17.8
ORRRC Report (for 2 month peak period of activity)			
Fishing			
1960	260	$1.30	6.76
1976	350	$1.30	9.12
2000	521	$1.30	13.58
Hunting			
1960	95	$1.50	2.84
1976	123	$1.50	3.68
2000	174	$1.50	5.22
1976 Total			$12.80

**Average of values, Table V.

Sources: References 37 and 46.

7
OCEANOGRAPHY

7.1. INTRODUCTION

Oceanographic research in the United States, as described in the long range plan proposed by the Interagency Committee on Oceanography (Ref. 47) is directed toward a national goal: "To comprehend the world ocean, its boundaries, its properties and its processes, and to exploit this in the public interest, in enhancement of our security, our culture, our national posture, and our economic growth."

The long range plan proposed for oceanographic research calls for an expenditure in the 1963-1972 period of $1300 million for basic research and $750 million for applied research. An additional $280 million---"supports routine surveys and services of general utility to the entire oceanographic community." To meet the demands of increased research, the national fleet of oceanographic vessels would increase from 76 to 128 and major oceanographic laboratories would increase from 63 to 82.

Existing knowledge of the oceans can best be described as sporadic, with great variation in the numbers of observations from one area of the ocean to another. Present United States oceanographic research is carried out by groups of scientists studying relatively specific problems. It will be of great advantage to provide these scientists with ocean-wide surveys to aid in their research. To realize its full potential, the spacecraft research should conform to the demands of a science characterized by international cooperation. Thus USSR, Japan, the United Kingdom, and Canada are the other major oceanographic nations that cooperate with 39 smaller nations which are members of the Intergovernmental Oceanographic Commission. Presumably, since the U. S. has had access to most of their findings in the past, they will also utilize the spacecraft data.

7.1.1. SUMMARY OF SPACECRAFT'S ROLE IN OCEANOGRAPHIC RESEARCH. Proposals for a program of orbiting research laboratory experiments presented in this section are directed to the solution of problems relating to the discovery, utilization, and control of the world's vast ocean resources. Covering 71% of the globe's surface area, the oceans are used as a biological environment for a food supply, as the source of economically valuable minerals, and as a means of transportation. In addition, the simple existence of large masses of water provides recreational facilities, causes weather definition and modification, and produces shore-line processes which have many effects on man's activities.

Oceanographic applications of observation spacecraft were thoroughly explored during a NASA-sponsored Conference on the Feasibility of Conducting Oceanography Explorations from Aircraft, Manned Orbital and Lunar Laboratories, convened at Woods Hole Oceanographic Institution in August, 1964 (Ref. 48). A wide variety of potential uses for observation spacecraft were proposed by the oceanographers attending the meeting. The applications selected for detailed consideration in the present study have been based largely on the results of that conference. The study reported herein does not cover all suggested uses for spacecraft observations, but is restricted to the acquisition of certain types of data which are believed to have the highest potential for obtaining scientifically or economically significant results.

The significance of the selected spacecraft applications lies in their ability to contribute to the overall scientific knowledge gained by an integrated oceanographic research program, their impact on the industries that harvest the resources of the sea for human consumption, and the savings they may bring about through more efficient direction of man's activities in, over, and upon the ocean.

Spacecraft seem capable of generating relative apparent sea surface temperature maps, recording $1^{\circ}C$ differences in temperature for surface area resolution elements of less than 1 sq. mi. Delineation of ocean currents is feasible to the extent that they can be distinguished by thermal differences or spectral response. The detection of ocean waves in 10 foot classes appears feasible; better accuracy is possible with laser techniques, but these can only be used under good weather conditions. Sea ice of reasonable extent can be detected. The resolution will range from less than 100 ft to 5 miles, depending on extent and frequency of coverage and choice of instrumentation. Surveys of coastal geography will require color photography and are feasible if area coverage is restricted. The detection from a spacecraft of biomaterial, ocean fronts, fish or their indicators, atmospheric constituents, and fishing vessels is marginal and will depend on developments brought about by the experimental programs. The use of spacecraft to interrogate buoys and ships is presently feasible; its potential will depend on available transmission bandwidths and the facilities to assemble, correlate, distribute and analyze the data.

Overall scientific knowledge of the oceans as physical and biological environments could be enhanced by measurements of sea surface temperature, and by observation of ocean currents where they are thermally distinguishable, possess special physical characteristics, carry contaminants, or in some other manner produce a significantly different spectral response. Measurements of ocean waves, sea ice, atmospheric constituents at the air-sea interface and interrogation of buoys and ships could also add to the fund of oceanographic knowledge.

The world relies heavily on the oceans as a source of food. Fish and fish meal products have great potential for combating the world's protein deficiency. Forty-two million metric tons of fish were harvested in 1962; however, indications are that the world could be harvesting 200 million metric tons, which, if valued at the United States market value of approximately 7 cents per lb., would be worth $30.8 billion annually.

The spacecraft has a potential for aiding the harvesting and management of fish resources, by indicating the location and change in availability of fish. Aids to locating and exploiting additional fish for the world's protein-starved population can come about through detection of herring-like or tuna-like fishes directly or by their sea surface indications (e.g., location of upwellings, oceanographic fronts, or biomaterial such as phytoplankton). Tracking of fishing vessels would provide valuable information concerning world-wide fishing activities.

We will increasingly rely on the ocean for mineral resources, the present value of which is estimated at $190 million per annum for the United States alone (Ref. 49). The direct detection of the minerals by spacecraft is not likely but knowledge of the environment from which minerals can be extracted would result in a reduction of removal costs. Studies of coastal geography, surface temperature and sea state will help to locate minerals by providing indirect information on bottom condition, topography, and evolution.

Marine recreation is rapidly increasing in extent and value, with estimated expenditures on the order of $2 billion per year. Oceanographic data on the ocean-shore interface is required to assess the impact of man's recreational activities on the sea and secure his safety while enjoying the marine environment. Spacecraft observation of sea state, and interrelationship of shore and sea, as well as gathering of biological information would help in the management of shore recreation and sport fishing.

Improved long range weather forecasting may provide many economic benefits, for example, aiding agricultural planning and use of ship routing to reduce shipping costs. Wave forecasting at present saves the Navy approximately $2 million for its 1000 ocean crossings per year (Ref. 47). Savings in ship routing should accrue due to spacecraft measurements of sea ice, surface temperature, sea state, and atmospheric constituents, and correlation of these factors with meteorological measurements to produce long range weather and sea state forecasts.

More accurate location of stricken planes or ships which have lost their ability to communicate by radio might reduce search time and thus produce savings in lives and search expense. However, this application has not been given detailed study in this report.

Man has long used the ocean for sewage disposal and now is also disposing of radioactive materials. Oceanographic spacecraft research may provide some knowledge of the ability of the oceans to absorb wastes and may locate those areas which are most adaptable or least dangerous for disposal purposes.

The use of spacecraft for oceanographic research can also contribute significantly to our military effectiveness, but this aspect has not been considered in this report.

A spacecraft system is capable of collecting vast amounts of information, an important fact that must be reckoned with by oceanographic researchers. Dr. Woodrow Jacobs, Director of the National Oceanographic Data Center, strongly cautions that the availability of personnel capable of interpreting oceanographic information of worldwide scope should be assured before the spacecraft data acquisition begins. This is necessary to prevent scientifically and economically costly delays in analyzing large backlogs of data. The amount of data collected should be based on the ability of oceanographers to utilize the data rather than on its ease of collection (Ref. 50).

The realization of most of the previously mentioned benefits of oceanographic research with spacecraft depend on international cooperation. An international distribution of data may well be one means of fostering that cooperation.

7.2. DESCRIPTION OF APPLICATIONS

7.2.1. SEA SURFACE TEMPERATURE. Sea surface temperature is an indicator of many varied oceanographic phenomena. Some ocean currents can be delineated thermally; upwellings and sinkings, important in their effects on the biological community, could be located thermally. The location and time stream occurrence of fishes, such as tuna and possibly other species, have been inferred from thermal gradients. The sea can be thought of as a moisture and heat sink for the world and hence has a major influence on weather. For example, it is believed that hurricanes have their origin in sea surface temperature anomalies. Knowledge of temperature at the air-sea interface will be an integral part of world energy balance studies, long-range weather forecasting and such useful applications as ship routing.

It is expected that the need for an essentially synoptic, worldwide record of the sea surface temperature can be met with a thermal mapper detecting relative temperature differences of $0.5^{o}C$ to $2.0^{o}C$. The resulting thermal map would show apparent temperatures; conversion to absolute temperatures would require extensive calibration of the sensors, in areas where ship-based oceanographic research is being carried out so that simultaneous absolute temperatures can be obtained. The operational system would also require continual calibration checks with operating research vessels recording absolute sea surface temperatures.

Thermal maps are presently generated for the Pacific Ocean by ship measurements taken by and for the U. S. Weather Bureau. By obtaining continuous worldwide coverage, a spacecraft system is expected to provide more accurate thermal maps of the oceans.

Sensor technologists are well aware of the fact that oceanographers desire much greater accuracy, on the order of 0.1°C (Ref. 48) and also temperature gradients in the vertical plane. It is hoped that improved technology will enable spacecraft and spacecraft-buoy systems to come closer to the desired accuracy.

The operational spacecraft would utilize an infrared scanner or microwave radiometer system to map the apparent surface temperature of the world's oceans. The data should be telemetered to the National Oceanographic Data Center or cooperating stations . . . "which can accept numerical weather and oceanographic information by radio and teletype, construct synoptic charts of many parameters, combine these into derived products, and distribute the product by radio and telex in numerical or facsimile, all within a space of a few hours."

The advantage of a spacecraft system for mapping sea surface temperature is the essentially synoptic obervation possible and the 100% coverage of the oceans. The problem of cloud and weather effects on the sensors can be overcome in two ways: (a) by extending the time intervals of single complete coverage to 10-12 days, and (b) using passive microwave techniques (which would also increase the size of the resolution element). Either method would provide a more synoptic thermal map than is being obtained at present, with less reliance on interpolation between point measurements.

7.2.2. OCEAN CURRENTS. Currents are an important factor in the ocean environment and if we are to understand the mechanisms and processes of the sea, particularly as they affect sea-air and sea-land interactions, we need to know a great deal more about them. Information on ocean currents is important because of the influence of currents on weather, shipping, fishing, and the movement of ice. Weather affects almost all of man's endeavors, and ability to forecast weather for longer periods and with greater reliability is a present objective of much research. Since currents could be utilized or avoided to save shipping time, ship routing will depend on accurate knowledge of the location, extent, and velocity of currents. Currents influence the amount and distribution of biomaterial and correspondingly the amount and distribution of harvestable fish. The movement of sea ice is of interest for many reasons; in particular, it constitutes a major hazard to shipping.

Several phenomena may be used to detect ocean currents. Some currents are known to be associated with large thermal gradients. Thus, a relative thermal map will in some cases provide a synoptic picture of entire currents, and through rapid repetition indicate shifts of the current. It is also known that contaminants of any sort in fluid systems become aligned in the direction of flow (Ref. 48). The Gulf Stream can be seen from the air due to a color change visible to the human eye. Multispectral analysis and/or color photography will probably record many other current systems, most likely enhancing the edge gradient contrast of some known currents. Imagery of ice-covered regions might also reveal isolines that indicate current systems. Telemetering buoys in an integrated system, could provide current velocity data for the water at the surface or at predetermined depths. Time-lapse stereo methods, as reported by Cameron (Ref. 48) may permit velocity measurements through the use of false parallax, if sufficient resolution can be obtained.

The spacecraft system as defined in Section 7.2.1 would provide a relative thermal map from which some currents could be delineated. Multispectral, infrared, and microwave reconnaissance of the oceans and ice-covered regions would delineate still other currents. The coded information could be transmitted to earth and assembled by oceanographic data centers as described in the previous application.

It has also been suggested that from the vantage point of an orbiting spacecraft, a man trained in oceanography might be able to see current shears due to modifications of wave characteristics, wakes from islands, undersea topography, color due to contaminants or some other factors (Ref. 48).

7.2.3. MARINE BIOLOGY. Essentially all forms of life in the ocean occupy some part of a food chain that man ultimately draws on as a supply of food energy. Vast numbers of small planktonic organisms form the broad base of this food energy chain. Man normally harvests only the latter stages of the food chain, the larger fishes. It is estimated that 19 billion tons of carbon are synthesized in the oceans annually and that 18 to 140 million tons of that carbon reach the harvestable fish stage of the food chain (Ref. 48). In the United States alone the value of that harvestable food to the fisherman was $381 million in 1962. Allowing for value added through processing, this ultimately adds a billion dollars to the gross national product (Ref. 49). Extrapolation of that value to the world does not give the proper appreciation of the value of fish resources to countries where protein deficiency is a national health problem. An assessment of the benefits of spacecraft research is treated in Section 7.3.

The part that marine organisms play in the ebb and flow of the world energy system, carbon cycle, and CO_2-O_2 balance is much more basic and studies of marine ecology can provide large benefits.

Broadly speaking, studies of marine biology require information of four types; the physical parameters of the environment, the extent and distribution of plant and animal life in the ocean, the specific physiology of those life forms, and the activities of man in relation to the ocean's biomass.

Physical parameters of interest in studies of marine biology include sea surface temperatures, vertical temperature profiles, temperature fronts, extent, duration, and velocity of currents, salinity, transparency, dissolved O_2, nutrient levels and distribution, organic matter, and acoustic noise. These can best be assessed by an appropriate combination of ship-based research, spacecraft surveys and spacecraft interrogation of ships and buoys. Some of the possibilities of spacecraft sensing are discussed in other parts of Section 7.

The proposed spacecraft program would have the ability to detect certain biological conditions. Based on earlier investigation, known absorption bands of concentrations of phytoplankton and possibly zooplankton indicate that they have sufficient spectral contrast to be detected at least on a relative scale. Planktonic blooms, such as the famous "red tides" adversely affecting the recreation industry, would be detectable on simple visible photography and warning of their approach might be given. Bioluminescence, caused by excitation of planktonic organisms due to the movements of large numbers of fish, or by choppy seas, might also be detected with multispectral systems.

Certain fishes may be directly or indirectly detectable from spacecraft observation. It has been suggested that the clupeiod (herring-like) fishes may be directly detectable due to the shimmer of reflected light from their bodies. The limiting factors in this application will be the aggregate size of the fish grouping on a horizontal scale, its density, and proximity to the sea surface. Given sufficient spectral contrast, fish groupings at least 1/4 mile in diameter would normally be detectable.

Fishes might also be detected by locating large flocks of sea birds, riffled surfaces, slicks or shadows, again provided that spectral contrast can be enhanced sufficiently. Radar might also be used to detect schools of fish on the surface of the ocean.

The mapping of sea surface temperature should aid in the location and time scheduling of tuna fishing efforts. Knowledge of thermal gradients and time streams of sea surface temperature changes should also lead to predictions of the presence of other scombroid fishes such as mackerel, bluefish, sailfish, and swordfish and possibly many other species of the pelagic fish group. Sea surface temperature as it relates to oceanographic fronts, upwellings, and biological productivity will also indicate the probability of occurrence of fish resources in harvestable quantity, for any point of the ocean and in time. Studies of these physical parameters may also provide clues to possible fish farm locations for the future.

Although the fisheries of the world, producing 42 million metric tons of fish in 1962, could probably increase to a take of 200 million metric tons per year, the distribution of the harvest spatially and by species would be critical. A given portion of the ocean or particular species of fish will sustain only a certain level of harvest without irreversible reduction of the harvestable resource. Present fishing methods consist of exploitation, and because of the international nature of the resources' location, little progress has been made toward realistic management. Before a lack of management permits the destruction of valuable segments of the fisheries resources, it is hoped that some international agreements will be reached. International management agreements will call for mutually acceptable enforcement. Enforcement of this type would of necessity be worldwide and involve the detection of the world's fishing fleet at relatively frequent intervals (on the order of 1 to 7 days).

Detection of fishing vessels by spacecraft would meet the requirement of worldwide coverage. However, to obtain coverage of a given area at frequent intervals, a wide swath must be covered on each pass, resulting in resolution as coarse as 1 sq. mi. If vessels as small as 40 ft are to be detected, they must produce a high contrast with respect to the water. If experiments discover a means to enhance such a signature, the operational detection of the fishing fleet will be feasible. High resolution radar could be used but would place a tremendous load either on the spacecraft for data processing or on the data transmission system. Large vessels would be detected by other routine spacecraft activities.

Forecasting of fish migrations and annual time occurrence of fish abundance through analysis of fish location and physical parameters may not require real time effort or 100% coverage of the ocean in the operation system. Detection would perhaps be as frequent as weekly, but would likely be useful at monthly intervals.

Use of spacecraft for location of fish, indicators of fish (e.g., upwellings and oceanographic fronts), and fishing vessels would require very rapid transfer of data, if the reports are to be effectively utilized by the fishing industry. After a fund of experience had been gained, 100% coverage required for experimental purposes would be reduced to limited areas and selected times during the year.

In this country the appropriate initial recipients of these data are the various sections of the Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service, Department of the Interior. This agency, with the necessary expansion of staff, would distribute the information in usable form to the fishing industry of this country and possibly to other countries. Information on the location of fishing vessels or violation of national sovereignty (3 or 12 mile limit), to be internationally acceptable, might require the transmission of data to an international commission.

7.2.4. OCEAN WAVES. The amount of United States shipping is expected to increase from 277 million tons per year to 400 million tons in 1970, a 48 percent increase (Ref. 47). It has been estimated by the Naval Oceanographic Office that wave forecasts presently developed by the Naval Oceanographic Office save the ships of the Military Sea Transport Service over the year's 1000 crossings approximately $2 million (Ref. 47). Although available commercially, most United States shippers do not use this type of service; however, foreign shippers do use it extensively. When the total number of ocean crossings per year for world shipping is considered, an insight to the value of using an improved wave forecasting system can be gained.

The Bureau of Commercial Fisheries reports that in 1961, boating accidents caused $4 million in damage, the loss of 1100 lives and injury to over 1000 persons. Three hundred of these people died due to capsizings, many of which might have been avoided with better sea state and weather forecasting (Ref. 47).

In order to advance our knowledge of the ocean, oceanographers need information on sea level and the factors that influence it. They need a topographic map discriminating slopes of a few centimeters over tens of miles of the ocean's surface. They would like to know the height, speed, direction of propagation and shape of tsunamic wave fronts (Ref. 48). For wind generated waves, they wish to know rms wave height, the wave spectrum with or without directional information, and a pictorial presentation of wave structures with wave heights measured in 1 ft intervals or less.

It is believed that some of these quantities can be obtained by orbital sensors. A spacecraft system using laser altimeters should provide line transect samples of the ocean, measuring wave heights in 1 ft classes and possibly even smaller increments. Extrapolations from these transects could then be made providing maps of sea state on a worldwide basis. Developments of continuous wave FM laser techniques for altimeter measurements may improve the accuracy of sea state measurements. Passive microwave techniques may also be useful for gaining knowledge of other sea state factors, particularly sea state within storm centers. Likewise, utilization of presently classified radar systems is a future possibility. Operation of laser systems outside storm centers could be used to check calculations of sea state extrapolated from observation in the storm centers.

Spacecraft have an advantage over aircraft for sea state observations with altimeters because their flight path is not affected by weather. They also have an advantage over shore sites, in that they can cover the entire ocean.

7.2.5. SEA ICE. Studies of sea ice and its relationship to the ocean systems will have far-reaching scientific value, and will provide useful information of both a military and nonmilitary nature.

There are four major geographic areas of sea ice that require study, the two polar areas, the Grand Banks of Newfoundland, and the inland seas (see Ref. 48). Coverage of the inland seas is considered in Section 5. Information is required on both the north and south polar areas to determine their contributions of fresh water during melt periods for water regimen purposes. This particular portion of the study area is also covered in Section 5.

In the south polar area basic information on the winter formation of the Antarctic Deep, the Bottom Water, and the intermediate waters can be gained from detecting the geographic extent of the ice. Locally-formed sea ice in the south polar area normally is no older than a year; its depth, and thus volume, brine entrapment and fresh water discharge can be detected. Inferences of the surface circulation in the south polar area will be strengthened by the detection of large antarctic bergs detached from the ice shelf.

Detection of these same conditions in the north polar area will be more difficult because of the permanent ice field which varies both in extent and thickness. Greater effort would be needed for ground sampling and calibration of any spacecraft data. The location and movement of icebergs will have to be correlated with circulation information that will not likely be detected from spacecraft.

The area of the Grand Banks of Newfoundland needs to be assessed for fresh water content, and currents, the latter in order to define the movements of sea ice and icebergs, which might be detected by a spacecraft system.

For these observations, oceanographers desire all-weather capability, freedom from dependence on solar illumination, and resolutions in the polar areas of five miles. It has been stated that the orbiting frequency of 90-100 minutes will be adequate for sampling frequency and that complete polar coverage in 48 hours is required. However, Dr. Woodrow Jacobs, of the National Oceanographic Data Center believes that, in light of the amount of synoptic data now available, these requirements are overstated. Except for short periods of time when changes in the polar areas are fairly rapid, assessment over a two-week period, could still be considered synoptic and might reduce the need for all-weather capability (Ref. 50).

All-weather capability for obtaining resolutions less than two hundred feet, required for studies of polynyas, leads, or lakes, and locating floating ice, do not seem feasible from spacecraft without the use of high resolution radar, which involves problems due to the substantial bulk of data transmission and the need for a sizable antenna. However, large icebergs, on the order of 400 feet, can be sensed in all weather with passive microwaves, and smaller icebergs can be detected in good weather. Problems would be encountered in detecting icebergs with melt water on the surface.

The sensor program proposed in this report calls for data-acquisition in the areas from 60° S. Lat. and 70° N. Lat. to the poles, and in the Grand Banks of Newfoundland. Data on the physical extent of the ice in polar regions would be collected with 5-mile resolution. Large icebergs (as well as circulation patterns, if shown during the experimental phase to be identifiable) would be detected in the Grand Banks area and elsewhere. The data would be transmitted to oceanographic data centers, compiled, and distributed to those oceanographers, hydrologists, fishing and shipping fleets that require the information. Appropriate data transmission and sampling size depend on the number of receiving stations available and development of data-transmission capabilities.

The advantage of the spacecraft for sea ice reconnaissance lies in its ability for economically surveying areas of the globe where the use of aircraft is very expensive and hazardous. The spacecraft can provide much more synoptic data than any other means of data collection presently employed by oceanographers although the precision of the data would in some cases be substantially less than ship measurements.

7.2.6. COASTAL GEOGRAPHY. Recreational uses are presently placing increased demands on the available coastal areas of the United States. A total of 21,724 linear miles of these coasts are classified as having recreational potential (Ref. 51). The pleasure boat fleet in 1962 consisted of 7-1/2 million boats, an increase of 500 percent from 1958. The public invested $2.5 billion in 1962 on these pleasure craft (Ref. 47). The use of coastal beaches for swimming and bathing is expected to increase 76% by 1976 (Ref. 51). Near-shore real estate continues to increase in value. All of these factors increase the need for management of coastal areas and that management requires knowledge of the coastal environment.

Oceanographers at the NASA Conference indicated a need for measurements of beach width; measurements to the nearest 5 ft are desired but 25 ft precision is acceptable. Beach elevations measured to 1 ft are desired with 5 ft as the acceptable limit. Depths to the nearest foot for near-shore hydrography (mean sea level to 100 ft) are desired, particularly for mean sea level to the 12 ft contour. Contours of 3 ft in the 40 ft contour region would be sufficient, but measurements with one-third of these accuracies would be acceptable. Measurements of offshore topography through detection of water circulation patterns, fresh water inflows through detection of thermal gradients, and wave spectrums in the beach zone are desired. Detection of long-shore currents, tidal and fresh water currents, sediment transfer, shore ice, beach and offshore bottom composition, coastal vegetation, and characteristics of near-shore water, such as temperatures, salinity and pollution are all required (Ref. 48).

Although remote sensing systems are presently incapable of collecting data from orbit meeting all the requirements stated, experiments are recommended which use color and black-and-white high-resolution photography to assess some of these varied parameters. The spacecraft could measure beach widths with 5 to 25 ft accuracy, and permit analysis to draw inferences of near-shore bottom topography and composition. Profilers using laser principles for measuring sea state might also provide beach elevation measurements in 1 ft contours. The spacecraft would be able to sense near-shore currents or water characteristics that reflect visible light with detectable contrast. Multi-spectral analysis techniques might enhance contrast for detecting currents and its capabilities for terrestrial vegetation analysis could be used to study vegetation at the land-sea interface.

The data acquired by spacecraft would thus help to assess damage caused by waste and sewage disposal and by wind and wave action and to indicate necessary damage prevention measures. The data should be distributed, for specific purposes, to local units of government or federal agencies such as the Department of Interior and Coast and Geodetic Survey teams. This data load should not be placed on the National Oceanographic Data Center but they should receive the results of analysis for distribution to oceanographers around the world.

In many cases, aircraft reconnaissance of coastal geography may be the more economical method of data acquisition. However, when synoptic and recurrent observation is desired, the spacecraft appears to have a distinct advantage. This is particularly true for studies of coastlines in geographically remote areas.

7.2.7. DISTRIBUTION OF ATMOSPHERIC CONSTITUENTS. The oceans play a vital role in the worldwide exchange of energy which critically affects the character of life. Clouds over the ocean influence both incoming solar radiation and reradiation from the ocean surface. The higher moisture levels over the ocean increase water vapor emission, adding to the amount of downward-directed infrared radiation. Net radiation at the earth's surface resulting in gains or losses in energy must either evaporate or condense moisture or generate air density differences resulting in thermal winds (Ref. 52).

For these reasons the physical makeup of the atmosphere greatly affects the earth's weather, vegetation growth rates, level of biomass and many other factors. Knowledge of the physical makeup of the atmosphere, particularly over the weather-generating oceans, is vital to better understanding and forecasting of weather and weather patterns. Controversy exists over the role of atmospheric CO_2 in the world energy budget. Callendar and Plass theorize that broad climatic changes can result from shifts in CO_2 content as it influences heat flux. Kaplan, Kondratiev and Nilisk, however, feel that effects of water absorption neutralize the CO_2 effects.

The factors noted are important for determination of heat and energy budgets, evaporation rates and moisture distributions, changes in the atmosphere due to losses of elements to space, the atmosphere's "greenhouse effect" on vegetation, and biomass calculations.

If experimental programs indicate feasibility, detection techniques utilizing the absorption bands characteristic of the chemical molecules of water, CO_2, and perhaps other constituents would be performed and used operationally. Accurate measurements of atmospheric constituents are not likely to be possible with spacecraft reconnaissance; however, maps showing relative distribution of atmospheric constituents might be produced for the ocean basins.

The data would be collected on tape, coded and transmitted to National Oceanographic Data Center stations. After assembly and analysis, the information would be distributed to oceanographers concerned with air-sea interaction and marine meteorology. Correlation with data from meteorological spacecraft, such as NIMBUS and TIROS, is necessary and availability of real-time reports would be of value to the U. S. Weather Bureau and corresponding agencies of other governments.

Data processing is not a critical factor, unless real-time uses such as weather forecasting are involved. Large changes in quantity level and distribution of atmospheric constituents are relatively slow and assessment sufficient to detect seasonal changes, important because of their impact on vegetation, would be adequate.

It is unlikely that any type of sensing platform other than a spacecraft could perform a task of this nature, requiring broad synoptic coverage on a continuing basis, without large numbers of measuring platforms. Even with spacecraft sensing, the need for precise atmospheric measurements still exists and requires an added increment of ship or buoy research to calibrate the spacecraft results.

7.2.8. BUOY AND SHIP INTERROGATION AND DATA RELAY. A great deal of specific information is collected from ships, and buoys could be increasingly used for this purpose. The numbers and effectiveness of ships and particularly buoys will increase rapidly as their capabilities are expanded and data transmission methods improved. Because they are in direct contact with the ocean environment, these two data acquisition platforms have the ability to measure physical quantities with essentially any needed precision. They can also measure in the vertical plane, beyond the reach of remote sensors, to obtain data on many of the important physical characteristics and systems of the ocean environment, and the resources of the sea, such as fish and minerals, which are most prevalent beneath the surface. A spacecraft limited to surface research can however supplement other data systems in making surveys, and helping to direct the placement and scheduling of ship and buoy research for the subsequent collection of more accurate and intensive measurements. We have suggested that the greatest value of spacecraft research is its synoptic and extensive coverage of the earth. But a much greater increase in value can be derived from combining broad synoptic coverage with the order-of-magnitude increase in precision possible with buoy and ship instrumentation.

Two specific and interrelated problems that might be solved by buoy systems are. . ."world-wide measurements of internal waves of tidal and larger periods. . ." and determination of the . . ."generation and distribution of eddies with scales of geostrophic motion. . ." As reported by Tasashi Ichiye (Ref. 53), the first of these problems could be solved by measuring vertical temperature profiles. Five hundred master buoys distributed at 10^{o} intervals of longitude and latitude would be used, each master buoy receiving data from two slave buoys and transmitting to the spacecraft. Knowledge of geostrophic eddies could be gained with 4000 buoys, or fewer buoys strategically placed and some floating buoys released at given time intervals.

The extensive use of spacecraft for interrogation of buoys and ships would require multiple spacecraft or synchronous orbits. Values for almost any measurable parameter could be coded and transmitted to the NODC or affiliated stations.

The advantage of the new ability to collect vast amounts of data is very attractive but the less obvious advantage of being able to redirect research effort, as to sampling design, or schedules, based on real-time preliminary data analysis, should also be appreciated.

7.3. BENEFITS OF OCEANOGRAPHIC RESEARCH

7.3.1. INCREASED SCIENTIFIC KNOWLEDGE. Most of man's advancement can be credited to increased scientific knowledge. This is particularly true of oceanographic research because of the complexity of oceanic processes and their widespread effects on many other types of terrestrial phenomena.

The discussion in Section 7.2 indicates a number of scientific problems which require more complete information of interest not only to oceanographers, but to meteorologists, biologists, and members of other scientific disciplines. To mention only a few, scientists would like to know more about dynamic ocean processes, their relation to the atmosphere, their influence on weather, and the characteristics and habits of ocean life of all forms.

The vast extent and dynamic nature of oceanic processes makes the problem of data collection by surface-based instrumentation a difficult one. Observation from space platforms promises to fill some of the gaps of present collection methods by providing a means of obtaining worldwide synoptic surveys. Space reconnaissance techniques will provide much directly usable data; of equal importance will be their ability to increase the effectiveness of present research methods. For the first time, oceanographers will have a physical record of at least some parameters for the entire world ocean and it is likely that the research planning advantage afforded by that record will be extremely valuable. Understanding the ocean will be enhanced by maintaining long-term data records so that secular changes and local anomalies can be investigated.

7.3.2. ASSISTANCE TO THE FISHING INDUSTRY. Orbital sensing provides both a method of learning more about the habits of fish and an operational means of data acquisition in direct support of fishing operations.

Direct or indirect detection of commercially-useful concentrations of certain types of fish might be exploited to direct fishing fleets to good fishing locations, and perhaps to locate presently unknown resources. The result would show up in terms of both reduced cost of fish and increased total catch. By observing the physical environment as to temperature, sea state, upwellings, ocean fronts, and planktonic blooms, we can gain valuable insight as to the location of fisheries and the time stream of their occurrence. By detecting the fish themselves or some indirect indicator of their presence, we can gain the same insight with greater certainty. An improved ability for ship routing through observation of sea state and correlation with meteorological observations would further reduce harvesting costs.

Better resource management through international cooperation is also an important objective. Overexploitation of specific fishing areas can produce an irreversible reduction of harvestable resource. The ability to detect the location and concentration of fish and to detect the magnitude and location of fishing activity by observation of fishing fleets may form the basis for conservation measures necessary to protect the resource.

No attempt is made in this section to estimate specific values for an increase in the fisheries production due to spacecraft research. It is hoped that the following discussion indicates the potential of fish resources and the framework within which benefits will occur.

7.3.2.1. Contribution to the Domestic Fishing Industry. The presence and migration patterns of tuna are known to be correlated with sea surface temperature sufficiently for usable prediction (Ref. 54). Albacore and yellow fin tuna are probably at the optimum harvestable point but blue fin and skip jack tuna could be much more heavily exploited. The value of these two species in the United States markets is approximately $215 per ton. If cost of harvest is sufficiently reduced, there exists an annual market for American fisherman due to recapture of import trade for 800,000 tons of edible fish (Ref. 49) valued at an average price per pound of $0.077 (Ref. 55) or $123 million. Tuna now represent 20 percent of our catch. Assuming a switch to blue fin and skip jack tuna, 20 percent of a new 800,000 ton market (160,000 tons) would be valued at $34.5 million even before the value multiplication of processing activities. This benefit to the U. S. fishing industry could be achieved if the techniques of finding tuna and routing fishing vessels could increase the competitive advantage of U. S. fishing operations in comparison to foreign operations.

Tuna caught by this country are fished with bait boats or purse seiners. Bait boats in the 200 to 300 ton class spend an average of 70 days at sea per trip, 37 of which are spent scouting and fishing, 12 in securing bait fish, and 21 running. Purse seiners in the 100 to 200 ton class average 38 days out per trip, including 22 fishing and scouting, and 16 running (Ref. 56). Reduction in the time spent scouting and fishing will reduce associated variable expenses. Operational records of vessels have shown that experienced and more knowledgeable fishermen achieve time savings on the order of 15 percent per trip enabling them to make more trips per year (Ref. 56). The information acquired with spacecraft reconnaissance as described in the previous section would help to increase the fisherman's knowledge of fish location and behavior and hence reduce the unit cost of harvest.

The catch of many other types of fish may be increased with better knowledge of fish and their environment. The most likely fisheries to use spacecraft reconnaissance research are those harvesting pelagic or surface-dwelling groups, particularly the clupeiod and scombroid fish that are found near the surface. Table VII indicates some of these species and their relative importance to this country.

7.3.2.2. World Food Requirements. A protein deficiency is suffered by a major portion of the world's population. This deficiency is responsible for Kwashiorkor and other debilitating diseases. The population explosion adds to the problem and heightens the need for means to prevent the protein gap from widening. The resources and technology to feed the hungry are available on a world-wide scale, but social and economic restraints do not permit adequate distribution of the food wealth. Underfed people are not capable of the rapid strides in economic development that are required to purchase or harvest added food resources.

The Food and Agriculture Organization of the United Nations in its third World Food Survey (Ref. 57) has proposed protein standards for the low calorie intake countries of 69 grams of total protein per capita per day, including 15 grams of animal protein, and for the world average 75 grams total and 23 grams animal protein per capita per day. The U. S. Department of Agriculture proposes a standard for all countries---"60 grams total protein per capita per day, and 20 grams of combined animal and pulse protein of which 10 grams should be animal protein" (Ref. 58). The latter agency places most emphasis on the total protein standard and suggests that reference standards are most useful for indicating the low protein availability and other deficiencies in amino acids, minerals and vitamins that occur in some countries.

One source of animal protein is fish. In countries where all available land must be used solely to produce high calorie material, exploitation of the sea's resources seems a promising method of reducing the protein gap.

In 1962, 42 million metric tons of fish were harvested around the world. It has been estimated that from 100 to 300 million metric tons could be harvested per year on a sustained yield basis without resorting to intensive fish culture (Ref. 59). If one assumes that 200 million metric tons is a relatively safe level of harvest, we see a theoretical additional source of 160 million metric tons of fish to feed the world's protein-starved. But in most protein-starved areas, refrigeration is rare and the capital required for fishing fleets capable of offshore harvesting is entirely out of reach at present. The long run solution lies in the economic development of the countries involved. In the short run, reduction in the cost of fish harvest seems a logical goal. The research necessary to bring about lower costs is broad in scope, and a large part of the total oceanographic research efforts in the 1963-72 period will add to our knowledge

TABLE VII. SOME FISH SPECIES HAVING POTENTIAL FOR INCREASED HARVEST DUE TO SPACECRAFT RECONNAISSANCE

Fish Group	U. S. Catch in 1963 (Thousands of pounds	Value per Ton (Dollars)	Total Value (Thousands of Dollars)
Clupeiod			
Herring	193,603	25	2,360
Menhaden	1,815,798	25	22,386
Anchovies	4,653	34	80
Shad	7,445	315	1,141
Scombroid			
Bluefin tuna	41,313	216	4,479
Skip-jack tuna	108,997	216	1,778
Mackerel	43,158	55	1,175
Bluefish	5,583	222	620

Source of Data on Quantity and Volume: USDI Bureau of Commercial Fisheries, U. S. Fisheries 1963 Annual Summary (Ref. 55).

of the fish resource. The Bureau of Commercial Fisheries alone will spend $276 million for research in the 1963-72 period (Ref. 47).

The urgency of cost reduction might be indicated by comparing the per capita income of diet-adequate countries with the diet-deficit countries expected in 1970. Diet-adequate countries are expected to have a per capita income of $1,302 while diet-deficit countries will have only 8.8 percent of that, $115.

It has been established that the world's fish resources can contribute toward closing the protein gap. Table VIII indicates the theoretical possible magnitude of that contribution with the following assumptions:

1. That fish resources nutritionally yield an average of 20% protein.
2. Necessary development of underfed countries occurs to ensure purchasing power, storage or reduction facilities and adequate distribution.
3. Research leads to a sufficient reduction in harvesting costs such that the required tonnage of fish can be harvested economically.

As indicated in Table VIII, the fish resource is well within the capability of providing all the additional animal protein required. The cost of providing 63 million metric tons of edible fish to meet the FAO standard at a cost of $0.07 per pound is $9.7 billion; the cost of providing 11.5 million metric tons to meet the USDA standard is $1.7 billion. The USDA estimates a cost of $1.0 billion using fish protein concentrate at 1963 export prices (est. $330/metric ton) (Ref. 58).

The chief problem as indicated previously is that the countries needing the fish as protein food cannot afford to harvest, or import and distribute sufficient quantities of fish. Spacecraft reconnaissance indicating fish availability near countries with protein deficiencies and aiding in direction of the harvest of these fish could substantially alleviate the food problem. Table IX indicates those countries where protein deficiencies occur and the magnitude of the problem, as well as the distribution of protein consumption on a world-wide basis. Table X summarizes the magnitude of the problem.

7.3.3. ASSISTANCE TO SHIPPING. It has been estimated that the total freight cost for United States ocean trade will be $5 billion a year by 1975 (Ref. 49). The magnitude of this operation indicates that there might be sizable benefits to be derived from improved operational efficiency.

TABLE VIII. POTENTIAL OF FISH RESOURCES TO CLOSE THE PROTEIN GAP IN DEFICIENT AREAS

(Millions of Metric Tons)

		Based on Average World-wide Standard Proposed by FAO		Based on Average World-wide Standard Proposed by USDA	
		Total	Animal	Total	Animal
A.	Projected protein gap in 1970 (assuming projected 1970 catch listed in C)	15.5	12.6	3.2	2.3
B.	Additional quantity of fish required to meet A		63.0		11.5
C.	Projected 1970 catch		74.0		74.0
D.	Total quantity of fish to eliminate protein gap		137.0		85.5
E.	Estimated harvestable fish		200.0		200.0

TABLE IX. COMPARISON OF POPULATION LEVELS AND PROTEIN CONSUMPTION 1959-61 AVERAGE AND PROJECTED FOR 1970

	POPULATION 1/	Percent of World Total		PROTEIN CONSUMPTION/CAPITA/DAY Total		Animal & Pulse		Animal	
	1959-61	1959-61	1970	1959-61	1970	1959-61	1970	1959-61	1970
Subregion	Thousands	Pct.	Thousands	Grams	Grams	Grams	Grams	Grams	Grams
Oceania	12,700	0.4	15,538	101	102	70	72	68.6	70.4
River Plate	22,753	0.7	27,031	101	102	56	58	54.3	56.5
Canada	17,900	0.6	22,914	96	95	67	69	64.3	66.4
United States	179,900	6.0	208,000	95	96	69	70	63.8	64.9
Northern Europe	211,283	7.0	226,377	88	90	54	60	52.0	57.7
USSR	214,217	7.1	244,600	87	90	32	39	29.5	36.2
Southern Africa	17,619	0.6	21,997	84	90	38	42	35.3	38.4
Southern Europe	96,967	3.2	104,370	79	85	32	41	26.5	35.4
Eastern Europe	116,771	3.9	127,400	77	77	30	32	28.0	29.4
Japan	93,200	3.1	102,216	70	80	30	40	18.0	26.3
West Asia	79,391	2.7	101,012	69	72*	18	20	13.1	14.9*
North Africa	84,813	2.8	105,421	68	71*	24	26	17.0	18.2*
Mexico	34,934	1.2	47,406	68	69*	30	32	17.2	18.1*
East Africa	48,563	1.6	61,056	65	69*	20	23	11.5	12.9*
Brazil	70,551	2.3	95,739	65	67*	34	38	20.4	21.5*
Other South America	51,549	1.7	67,798	57	62*	26	30	20.6	23.7
India	431,700	14.3	536,646	56	59*	22	23	7.2	7.8*
Other South Asia	126,397	4.2	165,755	55	60*	17	17	11.0	10.4*
Central America and Caribbean	32,328	1.1	42,041	54	55*	24	25	17.0	17.4*
West Central Africa	108,808	3.6	134,346	52	54*	14	16	5.7	6.4*
Communist Asia	712,907	23.7	846,768	48	56*	10	16	3.2	5.4*
Other East Asia	246,238	8.2	315,044	45	48*	14	15	7.3	8.0*
World	3,011,489	100.0	3,616,259	64	67	26	29	18.6	20.5

*Deficient by FAO World average Standard of 75 gram total, 23 gram animal.

1/ 1959-1961 represent midpoint and are taken from USDA Food Balance Sheets. 1970 estimates checked against those from U.S. Census Bureau and the United States.

Source: USDA, The World Food Budget 1970, Economic Report No. 19, 1964 (pp. 14-20)

TABLE X. PROTEIN DEFICIENT PERCENTAGE OF WORLD POPULATION

Criteria	1959-61 Average		1970 Projected	
	Total	Animal	Total	Animal
FAO low calorie country standard	64.7	58.3	59.1	58.3
FAO world average standard	70.5	70.5	64.4	65.7
USDA world average standard	56.8	49.8	50.8	49.8

NOTE: For any country falling below the given standard by any amount its complete population is included in arriving at the percentage figures.

It is primarily the ship operating costs incurred at sea which advancements in oceanography might reduce. Recent estimates show that 43% of ship operating costs are incurred at sea. But expected changes in ship operations could result in reducing port time by 50%. On the other hand, it does not seem likely that ship speeds would be increased so as to reduce sea time by more than 30%. The net effect could thus be to increase sea time to 51%, thereby increasing the relative importance of at-sea savings.

Benefits of the form of reduced shipping costs might be obtained in two ways:

1. Decrease ship construction costs by improving the original design of the ships. This could be done by designing the structure nearer to the limits of actual conditions, thus reducing materials costs, and by selecting the best hull shape.

2. Develop operating economies through optimum routing techniques and reducing losses by utilizing improved weather information together with improved position determining techniques.

7.3.3.1. Benefits of Improved Design. It has been suggest in Reference 49 that a 10% savings in shipbuilding costs might be achieved, of which 30% or 3.3% of yearly construction costs could be obtained by utilizing better wave statistics. This estimate seems quite optimistic since structural steel amounts to only 8% of total costs and a 10% savings in material would save only 0.8% of the total cost (Ref. 60). Further it appears evident that the design of ships is strongly influenced by experience and conservative practice, neither of which will be influenced by data on a phenomenon not well understood by the naval architect. Thus it remains to be proven that sea conditions vary in global behavior in such a way that optimum ship designs can be developed. On the contrary, it is more likely that an increased complexity in ship designs will tend to keep the design cost of ships high.

7.3.3.2. Operating Economics Through Improved Ship Routing. The most interesting development in the method of operating a ship at sea is through the use of optimum ship routing techniques. Ships have traditionally followed routes which experience has shown to provide the best combination of time and safety. It is shown in Reference 61, however, that a route can be developed that is optimum for the sea surface conditions to be encountered on a particular ocean crossing.

An analysis in Reference 62 indicates that the potential annual savings to operations of the world fleet (estimated to total 7,300 ships) is about $33 million using present weather routing capabilities, and about $84 million with "ideal" weather routing, that is, weather routing based on complete knowledge of weather and sea state. This is a theoretical potential improvement of $51 million. Because of the increasing total ocean traffic, this potential improvement would increase to a figure of $68 million by 1975. The use of spacecraft for oceanographic research and collection of operational data may be expected to contribute both to the accuracy of long range weather prediction and the preparation of better forecasts of sea state. As a reference figure, the projected annual difference of $ 68 million indicates the upper bound between present capabilities and "ideal" capabilities for weather routing in 1975. No basis is available at this time for quantitative estimates of either the extent to which this ideal theoretical improvement could be achieved or the fraction of this improvement which might be credited to the use of space sensing techniques for oceanographic purposes. It is believed that these figures will be appreciable, but since space sensing of oceanographic data is only one of a number of factors contributing to improved ship routing, its total contribution would be only a small fraction of $68 million, perhaps 5 or 10 percent.

7.3.4. PROPER MANAGEMENT OF SEA AND SHORE RECREATION. Ocean shore areas have long been used for fishing, swimming, boating, and other recreational purposes. Because of our rapidly increasing population with more and more leisure time available, the demand for shore-based recreational facilities has accelerated rapidly in recent years and will continue to increase. Gross annual expenditures for recreational use of the sea are believed to be at least $2 billion per year.

The extent of the available shore line suitable for recreational purposes is limited; furthermore, it is subject to undesirable effects from water pollution and wind and wave action on the shore line. These effects can in some cases be so serious as to completely spoil the shore area for recreational purposes. A total of 21,724 miles of the total detailed shoreline of 59,157 miles were classed as recreational shoreline by the Outdoor Recreation Resources Review Commission. Of that mileage, only 1,209 miles were currently open to the public. The coastal areas with high population densities place particular pressure on beach resources. Thus increased demands of an expanding population will make better knowledge of the sea-shore interface imperative if we wish to conserve our coastal recreation areas. Since the total extent of shore line suitable for recreational purposes is definitely limited, there is no direct substitute for such regions; hence, the economic loss is reflected in terms of sizable economic damage inflicted.

In order to take steps to protect against deteriorating influences, the nature and extent of the processes of pollution and wave action must be observed. Information gained in this way can be used to guide the design of sewage disposal plants, the control of industrial wastes, and the reduction of wind and wave effects in producing erosion, accretion, and shoaling. The continuing observation of coastal areas for these purposes has been proposed as one application of observation spacecraft.

7.3.5. ASSISTANCE TO LONG-RANGE WEATHER FORECASTING. Through its interaction with the atmosphere, the ocean has an extremely important influence on the long term weather patterns of the world. By increasing our knowledge of ocean temperatures and currents, sea ice distribution and the transfer of heat and moisture to the atmosphere, we can contribute a great deal to the ability of meteorologists and oceanographers to make accurate long range weather forecasts. This capability can have very important economic consequences. It would aid the farmer in planting and harvesting crops. Better planning would be possible for transporting and storing seasonal fuels, for timing building and road construction, and for protecting against flood and drought.

In addition to weather predictions, oceanographic data might contribute to the longer range objective of finding ways to control the weather. However, this technology is in a very early stage of development, and it is not yet clear what methods might be employed and how successful they might be.

Experiments are proposed in this report for measuring ocean surface temperatures over large areas and for mapping ocean currents. Although information on these characteristics of the ocean represent only a part of the total amount of meteorological and oceanographic information needed to perfect and use methods of long-range weather forecasting, such information is essential if this objective is to be fully achieved.

Studies conducted by various investigators indicate that the impact of the weather on the national economy is in the range of billions of dollars per year and that lives lost as a result of severe storms amount to several thousand per year. Reference 49 suggests that the economic benefits of improved long-range weather forecasting could reach $2 billion per year in 15 years, and that the extent of these benefits attributable to oceanographic research of all kinds may be of the order of 20% of the total, or $400 million per year.

The rough nature of these estimates is recognized, but even if a considerably more pessimistic view were taken of the possibilities, it is apparent that contributions to improved weather forecasting represent the most significant type of economic benefit to be anticipated from space sensing for oceanographic purposes.

8
GEOLOGY

8.1. INTRODUCTION

Many valuable uses of observation spacecraft in geologic investigation for both scientific study and economic application have been suggested. The present study has emphasized the type of application which appears to have the greatest economic potential, namely, reconnaissance for new mineral and petroleum reserves. Other uses are mentioned briefly in Section 8.5.

Remote sensors are a very important aid in rapidly exploring the earth's crust and will no doubt be instrumental in further exploring presently productive regions for minerals and petroleum and locating new wealth in unmapped portions of the world. Photographic techniques have been used to date with considerable success, but the visible spectrum is only a small segment of the spectral range that may be exploited for economic use. Remote sensing techniques can be used to locate areas favorable to mineral and petroleum accumulations by the identification of geologic features peculiar to such areas. This preliminary reconnaissance makes it possible to concentrate field investigation in relatively limited areas. Spacecraft sensors could readily detect many types of geologic features; once located, any anomalies could be examined in greater detail by remote sensing from aircraft and even more limited areas would be investigated by field parties.

8.2. GEOLOGIC INDICATORS

Geologic structures are important as aids in concentrating minerals and hydrocarbons. Structural controls are summarized by Leuder (Ref. 63, p. 822) as follows:

> "These may be features of mass warping, such as evidence of folding, uplifting, and subsidence, that indicate igneous activity. Or they may be faults, fissures, joints, and cracks that bring different rock types into contact or provide channels for hydrothermal fluid movement."

Faults, whether small or large features, are important because geologists recognize their role in localizing economic deposits and the genetic relationships to igneous or tectonic activity. Faults control mineralization because they serve as channels for moving ore fluids to sites of deposition. Major faults may tap a deep magma source, but due to presence of gouge it is often complementary and smaller faults that are mineralized.

Lithology (rock type) is as important as structure in localizing economic deposits. Minerals are formed in the final stages of a cooling igneous mass which can therefore be considered a prime localizer. Igneous rock may intrude chemically receptive sedimentary layers to form large mineral deposits.

Petroleum accumulations are also related to favorable lithology. A petroleum accumulation must have a reservoir rock such as porous sandstone, dolomite or limestone in addition to favorable structure and it also must have petroleum source beds akin to the igneous magma, such as a marine shale basin rich in organic debris.

Certain rocks which are chemically receptive and favor concentration of metals over other varieties are called "host rocks." These rocks have physical and chemical characteristics which affect mineral precipitation. For example, impervious rocks such as certain shales and schists do not favor mineralization, while porous and permeable rocks such as breccia, limestone, sandstone, and basalt favor mineralization.

Goodman (Ref. 64, p. 101) specifically relates certain rock types (host rocks) to mineral deposits as follows:

"Ores are commonly associated with certain rock types. It would be pointless to list all ore-rock relationships here, for so many of the rock types cannot be recognized in air photos. However, some rock types can be identified or inferred. Among these are serpentine and unaltered ultrabasic rocks, limestone and marble, greenstone, and norite. Serpentine bodies are always worthy of investigation because of the possible occurrence of chromite and various nonmetallic minerals such as asbestos, talc, and magnesite. Limestone and marble may be included with these identifiable rocks, and because they are so chemically reactive to the mineralizing solutions, they may especially invite search for sulfide ores and deposits of iron oxides. Greenstone, an altered volcanic rock, is an especially favorable host for many mineral deposits, and, although this rock type cannot be positively identified as such in air photos, volcanic rocks are recognizable and should be checked for the possible presence of greenstone. Nickel-copper ore is commonly associated with norite and chromite with ultrabasic igneous rocks. The identity of neither rock can be established in air photos, but as both are dark colored and massive, any dark colored massive rock with the granite type of fracture pattern should be investigated in the field."

Mineral deposits may occur as large-volume low-grade metasomatic replacements which could be identified under certain conditions due to the presence of "high contrast" hydrothermal alteration zones enveloping a deposit. This type of alteration zone may be a bleached zone lighter in color tone than the country rock, or it may be a very bright alteration halo surrounding a large replacement deposit.

Veins, pegmatites, and dikes are commonly small-scale features in an area favoring ore deposits. These are generally in marked contrast in color and relief to the surrounding rocks and will be readily visible when using multispectral sensing devices.

Predictions can be made of the types of metals in an area from the nature of the igneous rocks— acid, intermediate, or basic in composition. For example, we expect to find lead, zinc, copper, gold, silver, or uranium deposits associated with acid rocks; nickel, cobalt, iron deposits associated with intermediate rocks; and chrome-titanium-iron deposits associated with basic rocks.

Vein deposits were studied from photos in the Corbin-Wickes district. Levings and Herness (Ref. 65, p. 455, 457) described the relationship of veins to host rocks, alteration, and topography with the following statement:

"The almost invariable associations of ore with areas of high relief can be traced to the alteration effects of hydrothermal solutions on the country rock they traverse. End products which are chemically stable and hence resistant to weathering and erosion have been thus produced."

Dikes and their relation to mineral deposits were discussed by Goodman (Ref. 64). Presence of dikes suggests crustal instability and may be favorable to ore fluids. The association of gold deposits with quartz porphyry dikes and cobalt deposits with diabase dikes are well known in Canada. Though dikes are readily identified in aerial photographs, not all dike swarms have associated mineral deposits. However, they should never be ignored.

Gossans are bright colored surface weathering effects overlying primary ore deposits and may be detected by aerial photography. Leuder (Ref. 63, p. 822) stresses the importance of gossans:

"Although not a 'localizer,' color may be an 'indicator' of mineral deposits. The color may be associated with an actual outcrop, an oxidation stain indicative of underlying minerals, or an alteration halo. In any case, the blacks, reds, greens, browns, and yellows associated with mineralization always bear investigation." Goodman refers to these gossans as oxidized croppings and specifically describes a gossan zone in relation to iron and copper deposits with the following paragraph:

"The oxidized zone of ore deposits, such as iron gossans and copper caps, may be detectable in air photos, both color and black and white. This is the exception to the statement that one does not pick out lode deposits directly on air photos. An oxidized cropping is direct reflection of mineralization and may appear on the photo as a bleached spot or other tonal oddity."

It is noteworthy that, in addition to geologic indicators, plant association may be an indicator of mineral deposits. Leuder (Ref. 63, p. 823) described use of plant association and its significance to mineral deposits as follows: "Plant association may be an indicator. Practically no scientific information was available on plant-mineral associations until Goldschmidt published the results of some tests in 1934, describing what has since been called the Goldschmidt Enrichment Principle. According to this principle, minerals are dissolved in soil water and absorbed by plant root systems. In the plant they ultimately migrate to the foliage. When the foliage withers and falls, and eventually decays on the ground, some of the minerals remain, enriching the soil. Concentrations of minerals result. Since about 1940, the Finns, Swedes, Norweigans and Russians together with some Canadians, have found that mineral concentrations may effect plants in several ways:

1. They may change the appearance of foliage.
2. They may cause certain tolerant (or indicator) plants to thrive while stunting or killing all others.
3. The minerals may be concentrated selectively in the foliage of certain plants.

Many plant-mineral associations have been found. For example, zinc may be indicated by luxuriant ragweed in the presence of other stunted growth; the so called zinc pansy is often a luxuriant grower in the vicinity of zinc dumps; the two-foot brilliant red campion has been found to thrive in a soil having a copper concentration of 14 lb/ton while other plants die. Douglas fir, larch, and the lodgepole pine may concentrate copper and zinc selectively in their foliage." Petroleum accumulations require favorable structures and lithology of host rocks. Favorable lithology includes the depositional setting, degree of porosity, and fluid content and levels. A hydrocarbon accumulation associated with structure and facies may be detected with present methods but newly developed sensors may delineate those hidden areas of hydrocarbons due to escaping trace elements and gases thay may affect the soil zone or vegetation. The general criteria used successfully in mineral findings also apply to oil finding.

8.3. CAPABILITIES AND PRACTICAL LIMITS OF SENSORS

It is believed that sensors carried by an orbiting spacecraft can detect known and unknown regional features; once located, any anomalies could be examined in greater detail with a multisensor equipped aircraft. Visible photography, infrared and radar imaging all seem to show promise in mineral and petroleum finding.

The success of black and white aerial photography applied to mining is described by Levings and Herness (Ref. 65, p. 454) as due to a number of guides which fall into categories of:

". . . (1) physiographic guides, including the topographic expression of ore bodies; (2) mineralogical guides, such as alteration effects; (3) stratigraphic and lithologic guides, for example, favorable host rocks; and (4) structural guides among which may be included contacts, fracture patterns and flow structures."

Recent developments in color photography further enhance possibilities of photographic techniques applied to geology. Minard (Ref. 66, pp. 112, 113) successfully used color photography to map formational contacts which were difficult to detect on black and white photos or in the field and showed up as subtle color differences on photographs. In addition Kent (Ref. 67, p. 866) evaluated color photographs of mountainous and upland terrains and found the images sharp, color balance good, and the aerial photos matched well when compared with actual ground cover.

The potential of infrared imaging is still being studied and it appears that this technique will have many applications in economic geology. However, parameters need to be established to relate geologic structure, mineralogy, and lithology to selected bands in the infrared spectral range. Kinsman (Ref. 68) also recognized the potential of infrared imaging and pointed out a lack of established parameters such as quantitative emissivity values of terrain materials.

An attempt to apply infrared techniques to an area of known sulphides is reported by Strangway and Holmer (Ref. 69, p. 9): "No conclusive results could be obtained in areas of known sulphides. This was partly due to the lack of suitable targets which have not been affected by mining operations. If effects exist, however, they must be small. Nevertheless, variations which appear to be related to geology were detected."

Microwave imagery to date has been used with great success to fill in where visible and infrared sensors leave off. Because of its great military significance in the past, this end of the spectral range has been virtually unexploited for civilian use. To date, geologic application of microwaves has been confined to mapping lineaments. Cameron (Ref. 70, p. 21) summarized the advantages as follows: "To summarize the possible advantages of using radar-scope photography for geological mapping:

(1) Single photo coverage is very large, thus giving an opportunity to compare different rock terrains, and to see very large structural features.

(2) Relative all weather capability. This is of great importance to areas such as the Canadian Arctic and some tropical areas where fog, haze, and cloud prevent successful air photography.

(3) Radar presents a possible unique method of viewing the surface of the earth. Though it is not proven the radar reflection across section of rocks may vary sufficiently to enable a definite correlation to be made between scope pattern and rock type."

Kinsman (Ref. 68) from independent work pointed out the potential of microwave techniques, using mapping radiometers and radar, for spatial distribution between terrain features and high resolution mapping aids in identification of features. He states that some detection problems awaiting the use of microwave imaging are depth of penetration of selected wavelengths, reflection, and attenuation of soils, minerals, vegetation, and development of prediction techniques.

Success of radar mapping in the Gaspe Peninsula in Canada attests to the merits of this technique. Cameron (Ref. 70, p. 6) concludes that:

"The radar linears and patterns of Gaspe suggest a number of new geological features, including two hitherto unmapped thrusts cutting across the fold trends, and a possible collapse basin of pre-Pennsylvania age."

Occurrences of large base metal deposits in the Gaspe Peninsula left a number of unanswered questions. Perhaps additional geologic information in the area will better explain the occurrence of these ore deposits. An aggressive research program in the microwave spectral range with increased emphasis on civilian applications, specifically exploration of metal and hydrocarbon deposits, is definitely in order.

8.4. APPLICATIONS OF REMOTE SENSORS TO ECONOMIC GEOLOGY

Thus far geologic features and capabilities of sensors have been discussed. Now specific application of sensors to economic geology will be described briefly. Without a doubt, remote sensors can be used to define regional crustal features. Further evaluation of these features in terms of geologic setting will then determine whether an area warrants additional petroleum or mineral exploration.

Sensors used in petroleum exploration may delineate faults, lineaments, folds, domes, basins, haloes, diagnostic minerals or elements and presence of hydrocarbons in an area. Remote sensing devices showing real promise are photographic, microwave, and infrared.

Sensors may prove valuable in mineral exploration as they may locate faults, lineaments, fold systems, and gossans. Depending on their geologic size, large metasomatic replacement deposits, supergene enrichment areas, and large veins may be detected from space. Photographic, infrared, and microwave techniques have already proved successful and show promise for further development. Perhaps some of the more sophisticated sensors (i.e., geochemical, ultraviolet, fluorescence) will also prove to be valuable after current research is completed, but their worth would best be determined from tests with airborne sensors.

Limestone deposits in more advanced countries have been mapped and evaluated in detail. Parts of the world that have poor photographic coverage would benefit most from space and follow-up aircraft surveys. Carbonates exhibit distinct topographic and tonal signatures in black and white photography and are readily recognized at the current state of art. Photographic, infrared and microwave would probably all be useful. "Tonal signatures" for various types of carbonates exhibiting facies changes may be detected due to the nature of the weathered suface, and differences in color and porosity which would show up as subtle color contrast. Geochemical sensors may detect sulphur dioxide, iodine, and hydrogen sulphide associated with certain carbonated areas.

Active hydrothermal zones detected from space will depend on the size and geometric configuration of the area. These zones would usually be found along or near lineaments, faults, and fold systems. Photographic, microwave, and infrared techniques may prove less successful in locating hydrothermal activity than in detecting faults and folds because of much less contrast in relief and color. However, some areas of ancient hydrothermal activity are in very sharp color contrast to adjacent rocks (e.g., red altered zones within dark grey to black meta-argillites in the Beaverlodge area, Saskatchewan).

Gossans are zones of bright colors due to surface weathering. A distinction should be made between gossans which are zones of surface weathering (oxidation-reduction) and hydrothermal alteration zones which result from deep seated hydrothermal metasomatism. Geochemical sensing of SO_2, trace elements, and radioactivity may be possible from aircraft. Presently "hot" areas, for example, the Hawaiian volcanoes (Ref. 71) would readily be detected from orbit if sufficiently large and from aircraft if less than one mile in size, as opposed to thermally cooled areas with hydrothermal haloes that would be detected only if high contrast in color or relief are present.

8.5. APPLICATIONS OF REMOTE SENSORS TO TECTONIC AND GEOLOGIC RESEARCH

Imagery acquired with electromagnetic sensing equipment could be used in compiling maps showing the world-wide distribution of geomorphological features and in particular tectonic landforms such as folds, faults, and eroded or exhumed igneous masses. Some of the big problems in basic research in the geological sciences include determining the mechanisms responsible for localized deformation of the earth's crust and those responsible for triggering global orogenies, and understanding the extent to which these diastrophic forces displace the land masses relative to one another (continental drift).

Much of the present knowledge surrounding the cause and effect of crustal deformation has been derived from localized studies in certain classic areas. With the advent of aerial photographic mapping techniques it became possible to expand outward from these areas and gather aerial data relative to the surface expressions of tectonic activity in the more remote regions of the earth.

Through the use of aerial photography, it has been possible to project more accurately the trends of some of the major fault systems of the earth. Since these fault systems present some of the basic clues to the direction and magnitude of past and present forces and the extent of their influence on the structure of a region, a complete world-wide picture of all primary, secondary, and tertiary fault systems apparent at the earth's surface would be an invaluable aid in unravelling some of the basic geological problems. Present-day, high resolution, side-looking radars can highlight lineations in the earth's surface representing alignment of structures, fault scarps, parallelism of drainage, etc., and can do this without the detailed "noise" of photography and the requirement of cloud-free atmosphere. This makes radar particularly suited to the task of world-wide tectonic mapping. The capability of radar to delineate physiographic features and offer something quantitative in the way of surface material classification has been adequately demonstrated on a local scale by existing systems in aircraft.

A spacecraft in polar orbit would be the ideal platform for performing the task of acquiring data to be used in the compilation of a global tectonic map because the entire land masses of the earth would be surveyed on successive orbits aboard this vehicle. It would also be possible, on a demand basis, to change the antenna train angle so as to change the aspect angle of data acquired over a given point. This would compensate for data drop-outs, caused by shadow areas on the backside of landforms when viewed from only one direction, and thus increase the probability of detecting important lineations. Furthermore, it would make it possible to operate the equipment only when the vehicle was passing over the land masses and thus reduce the amount of data storage space required.

Visible and thermal sensing devices could be used to augment the structural mapping capability of the radar system. The infrared scanning system would be operated over areas of active faulting, volcanism, and hydrothermal activity on a demand basis and over any other areas where knowledge of the thermal environment might provide a more clear picture of the state of tectonic activity. Likewise, photographic coverage could be acquired any time it was deemed necessary.

The benefits that would accrue from this proposed use of orbiting sensors are manifold. First of all is the acquisition of new knowledge relating to tectonic processes. The ability to preserve continuity of surface tectonic features over entire continental masses and an anticipated ability to more accurately project these manifestations from one continent to another will provide geologists with data leading toward a better understanding of the nature of terrestrial deformation mechanisms. Aside from the purely basic scientific merit of this data acquisition program, there is an attendant capability that has economic and social aspects that are of immediate interest to persons occupying the geologically unstable areas of the world. Through a combination of thermal, radar, and photographic data acquired over areas of active faulting and volcanism, it may be possible to derive criteria for predicting crustal movements or volcanic eruptions. If such criteria can be established, human life and property could be saved through adequate warning.

9
AIR POLLUTION

9.1. BACKGROUND

9.1.1. THE PROBLEM. Most life existing in the earth's biosphere is at least indirectly dependent on the blanket of air which surrounds the earth. Organisms with lungs are particularly sensitive to small variations in the chemical composition of this gaseous environment. The proportions of the different gases in the earth's atmosphere have not remained constant throughout the course of biological evolution; gradual alterations in air composition generally occurred over thousands or perhaps hundreds of thousands of years, and man and other mammals, through processes of natural selection, could keep pace with these slow changes in gas concentrations.

The almost explosive growth in our cultural development and ever increasing industrialization is introducing very rapid and severe alterations in our biosphere. The products of combustion, of chemical processes, and of respiration are all atmospheric pollutants. Often reactive chemicals are introduced in the gaseous and particulate form which locally are in concentrations severe enough to cause both irritation and in some cases permanent damage to living tissue. Studies in certain heavily populated urban areas have shown that deaths from respiratory diseases rise in proportion to the degree of air pollution (Ref. 72). Facts brought out at the National Conference on Air Pollution held in 1962 show that there is a direct statistical relationship between the incidence of lung cancer and the population size of various cities in which the studies were made. In the case of cigarette smokers, the same relationship was shown except the curve was shifted to higher numbers of lung cancers. It therefore appears that there is high correlation between air pollution and lung cancer. It is readily apparent that air pollution is a serious problem in terms of public health, particularly to those living in highly populated areas.

9.1.2. THE COST. In terms of pure economics, it has been estimated (Ref. 72) that air pollution is costing this country alone billions of dollars a year. Air pollution contaminates plants as well as animals, and in some cases, industries have been wiped out because of smog problems as, for example, an orchid growing industry near Los Angeles. Polluted air may contain strongly reducing and oxidizing compounds and because of their high chemical activity, both may act as severe irritants and may actually attack organic material, causing chemical and physical changes.

There is clear indication that pollution is an extremely expensive luxury that is paid for in terms of billions of dollars annually, unnumbered productive jobs, and even in uncounted lamentable human deaths each year. Pollution affects communities, productivity, population migration, and public health programs. It results from and further encourages slums. It is a distasteful, expensive industrial by-product.

9.1.3. PRESENT POLLUTION DETECTION. Measurements and detection procedures so far have been on a very localized basis. Certain factories have pollutant monitors in smoke-stacks or nearby buildings. Some cities employ mobile units for investigating the purity of the air in various regions. There have been proposals for remote monitoring by use of spectrometers with gas collection cells downwind and other such devices. In many areas where pollution and smog present a problem of very disturbing proportions, continous monitoring of air contaminants is carried out by governmental agencies. There is presently no large-scale coverage of air pollution throughout the world or even over sizable urbanized regions of the United States. Little or no information seems to be available concerning the influence of weather patterns, diurnal cycles, and seasonal cycles on large-scale patterns of pollutants and particularly on local saturation and subsequent atmospheric dispersion of the contaminants. Only the synthesis of specific measurements provide an estimate of the average pollution of a city or area. Such statistical estimators are of course only estimators.

9.1.4. THE ROLE OF SPACECRAFT IN POLLUTION DETECTION. If a means can be devised to measure the degree of pollution from orbital altitudes, the use of spacecraft as a platform for pollution detection devices could monitor large areas on a repetitive basis for both research and operational purposes. Daily and seasonal information at almost any prescribed rate could be obtained economically concerning the following factors:

a) the average pollutant levels of cities and industrial complexes
b) the rates of change of these levels
c) the influence of weather
d) the influence of season
e) the change with the diurnal cycle
f) the efficacy of preventive measures in reducing the rates of increase
g) identification of areas for detailed investigations

9.2. DETECTION OF POLLUTANTS

9.2.1. THE FEASIBILITY OF SENSING VARIOUS POLLUTANTS. The various molecular species present in polluted air show absorption characteristics in the near infrared region. Many of the absorption bands of these contaminants occur in the same places or very near the absorption bands due to water vapor and carbon dioxide. An example of the absorption characteristics of most of the primary air pollutants is given in Fig. 1, which also shows the solar spectrum representing the transmission of one complete air mass. Sulfur dioxide, present as a contaminant in the atmosphere, does not have absorption bands outside the CO_2 and water attenuation regions. Most of the gases shown in Fig. 1 are also produced from natural processes in our environment. For example, CO_2 exchange in plants is intimately involved in photosynthesis and the N_2O balance is controlled to a large extent by nitrogen fixation in the soil. Ozone appears to be the only gas showing some promise as a tool for monitoring air pollution because it is associated with pollution and because its spectrum is not completely masked by the normal atmospheric constituents.

Water vapor and ozone are the only gases of these discussed that are not uniformly mixed, that is, the mixing ratio is not linearly related to altitude. The variations in water vapor are as previously mentioned due to the pronounced localized variations in environment controlling factors such as solar heating and evaporation. Ozone on the other hand appears to be controlled by photochemical processes. At low altitude, that is from the earth's surface to about 3 kilometers, ozone results from the photochemical reduction of organic material in the atmosphere. Much of this organic material arises from air pollution sources, such as hydrocarbons released from exhaust fumes. An ozone layer existing in the upper atmosphere between 20 and 50 kilometers is produced from the photochemical dissociation of diatomic oxygen by ultraviolet radiation. There is no apparent exchange of the high altitude ozone with the ground layer. The high altitude concentration of ozones varies with season of the year and with latitude and longitude; however, the lateral variations are gradual and small and the equilibrium at high altitudes is slow to change. Some idea of the variation in the high altitude concentration of ozone is shown in the curves in Fig. 2 taken from Oppel (Ref. 73). Although there are ozone variations in the various geographical regions over the earth, the three curves of the figure are essentially similar in shape, and looking down on these regions from a spacecraft one might expect only gradual changes in the absorption characteristics as the spacecraft passed over these various regions.

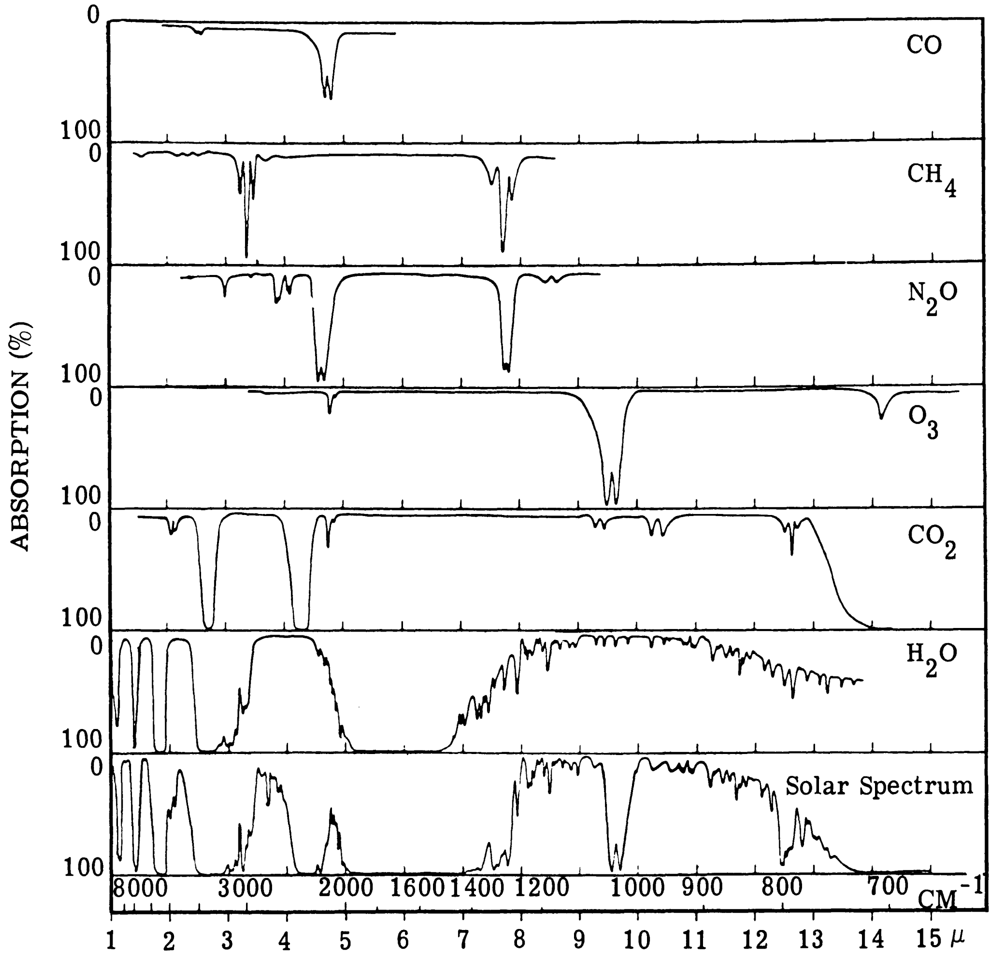


FIGURE 1. NEAR-INFRARED SPECTRA OF SOLAR IRRADIATION AND ATMOSPHERIC GASES

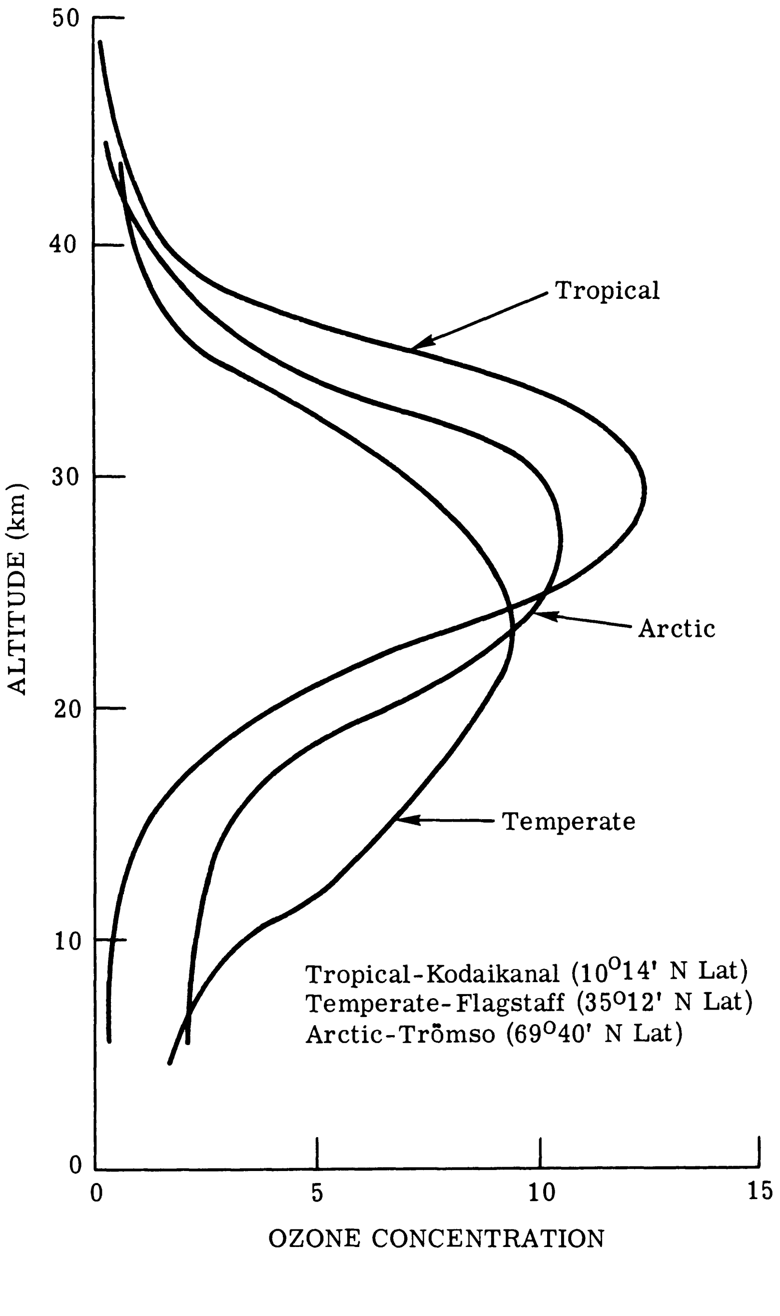


FIGURE 2. REGIONAL OZONE DISTRIBUTION (REF. 73)

9.2.2. DETAILED EVALUATION OF OZONE DETECTION. It has been established that near the earth's surface, that is, from 0 to 3 kilometers, the concentration of ozone is approximately one-tenth the value at the 20 to 30 kilometer region. At first sight, one would assume that the greater concentration of ozone at the higher altitudes would mask the radiation from lower altitudes. However, the lower concentration is at a higher temperature. Its variations are more rapid and fluctuate over a greater range. Thus the changes might be detectable. Large sections of the earth's surface radiate very much like a blackbody. Part of the radiation is absorbed by atmospheric gases and the remainder is transmitted through the atmosphere. In addition, the atmosphere itself radiates energy. For a given wave number interval, for instance in the region of ozone absorption from 1000-1100 cm^{-1} (9.1 - 10 μ), the outgoing radiation at the top of the atmosphere from the radiating earth's surface may be expressed by the general form

$$R = B' + \int_{B'}^{B} \tau \, dB \tag{1}$$

where τ is the transmission between a given level and the top of the atmosphere, B' is the blackbody radiation from the top of the atmosphere or from a level above which absorption is neglibible and B is the blackbody radiation at the radiating surface. (B is tabulated in many places and can be calculated readily by computers.)

The transmission depends on the amount of absorbing gas between a level at pressure p and the top of the atmosphere and a mean pressure P defined by the equation

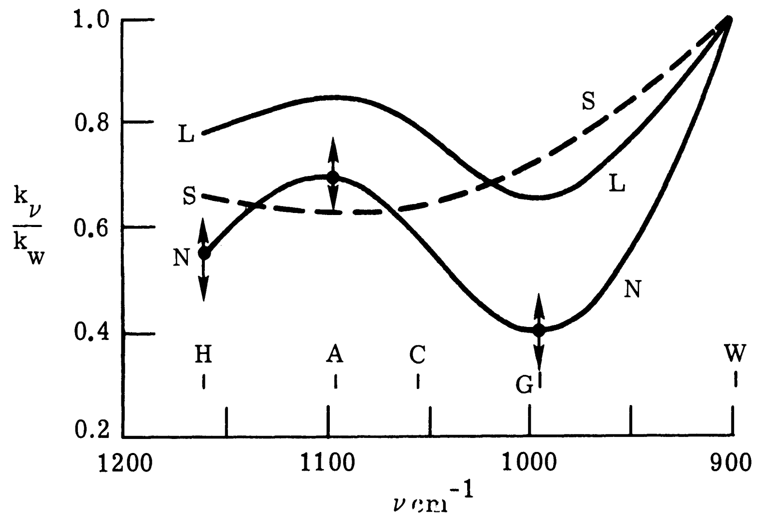
$$mP = \int_{0}^{m} p \, dm \tag{2}$$

where m is the amount of absorbing gas in centimeters of mercury at standard temperature and pressure. For ozone, integration must be made according to the vertical distribution of m; the transmission using the strong-line assumption can be found from

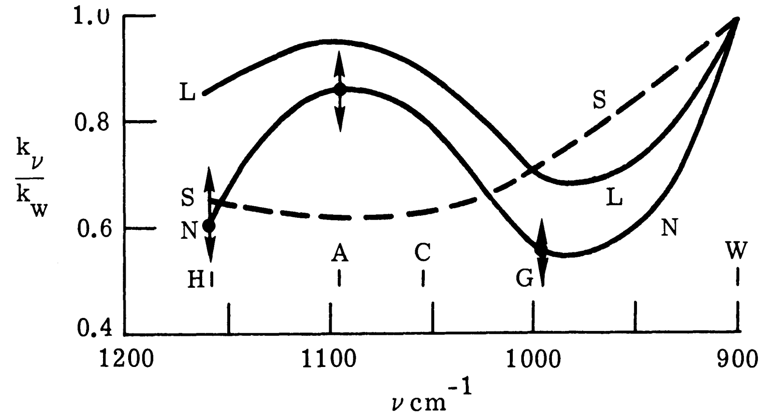
$$\tau = e^{-k(mP)^{1/2}} \tag{3}$$

A computer program was used to calculate the radiation from a polluted area through the higher altitude ozone distribution, and in fact through the entire atmosphere. The results of this calculation are as follows. The average spectral radiance is about 10^{-3} w $ster^{-1}$ $cm^{-2}\mu$. The ratio of the change in radiance to the average radiance for most of the 0.1 μ wide bands is about 5×10^{-5}; one band shows twice this amount (9.5 μ); all bands change in the same direction. For a 1 mr. field of view, corresponding to a 1000 ft. ground spot for a 200 mile orbit, the irradiance at the spacecraft is 10^{-9} w cm^{-2} μ^{-1}. The irradiance change on the average is 5×10^{-14} w cm^{-2} μ^{-1} and for the best narrow band it is 10^{-14} w cm^{-2}. If one uses the entire band, say 8 - 13 μ, the result is probably 2.5×10^{-13} w cm^{-2}. These results are neither forbidding nor extremely encouraging. It means that collecting optics of about 1 ft. in diameter can be used with thermistor detectors to get the required sensitivity for ozone concentration of twice normal amount. In an investigation (Ref. 74) of the vertical distribution of atmospheric ozone in a region around London, spectral measurements and analyses were made of the sky emission using a grating spectrograph in the 9.6 μ ozone band and comparing five standard frequencies in the 900-1200 cm^{-1} region (2.5 cm^{-1} spectral slit width). The purpose of using these various wavelength regions was to obtain information about the continuum, the radiation measured in spectral regions between absorption bands, due to band wings and atmospheric scattering. The frequencies used and the notations employed are shown in Table XI. A large number of sky emission measurements were made at these standard frequencies at sea level. The final analysis of this large amount of data was programmed on a computer. The authors compared the ratio of the absorption coefficient at the various frequencies in Table XI with the continuum frequency noted as W. These data are summarized for two seasons of the year in Fig. 3; the curve labeled S was obtained by Saiedey (Ref. 75) from absorption measurements of solar radiation. He concluded also that atmospheric aerosol has very little effect on the shape of the continuum and that the temperature dependence of k is very small. The curves N and L in Fig. 3, however, indicate small seasonal changes in the characteristics of aerosol in various concentrations of haze. The authors point out that the increase in the value of k_v/k_w at the H, A, and G frequencies from late winter to spring indicates a change in the aerosol content or a change in the aerosol emission temperatures from winter to spring.

There is other useful evidence which supports the thesis that pollution can be detected and monitored by spacecraft using techniques like those outlined above. These are data obtained from the TIROS II meteorological spacecraft (Ref. 76). This spacecraft contained instrumentation for measuring infrared solar radiation from the earth and its atmosphere. Using a medium resolution scanning radiometer, the spatial resolution was about 40 miles square when viewing the earth directly beneath the spacecraft. One of the bands examined was in the 8 - 12 μ region which would include the ozone emission and more, of course. A summary map was presented showing several orbits of this spacecraft over the United States area and the temperatures plotted along the path of the spacecraft. It is interesting to note that "hottest" areas (greatest radiation from 8 - 12 μ) were in regions where one would expect the presence of pollution. The black areas on the map in Fig. 4 show pollution areas over the United States. The hottest recorded "temperature" was near San Francisco and other regions were around Chicago and Youngstown, Ohio. The temperature over San Francisco was 10°K higher than a region over



(a) January-March 1961, late winter



(b) May-June 1960, late spring

Variation of $\frac{k_\nu}{k_w}$ with frequency in the range 1200-900 cm^{-1}

N: mean under conditions of average haziness
L: mean for the condition of very strong low level haze
S: Saiedy's absorption measurements of solar radiation
Arrows represent the extreme range for the curve N

FIGURE 3. RATIOS OF ABSORPTION COEFFICIENTS IN OZONE REGION SHOWING SEASONAL VARIATIONS NEAR LONDON (REF. 74)

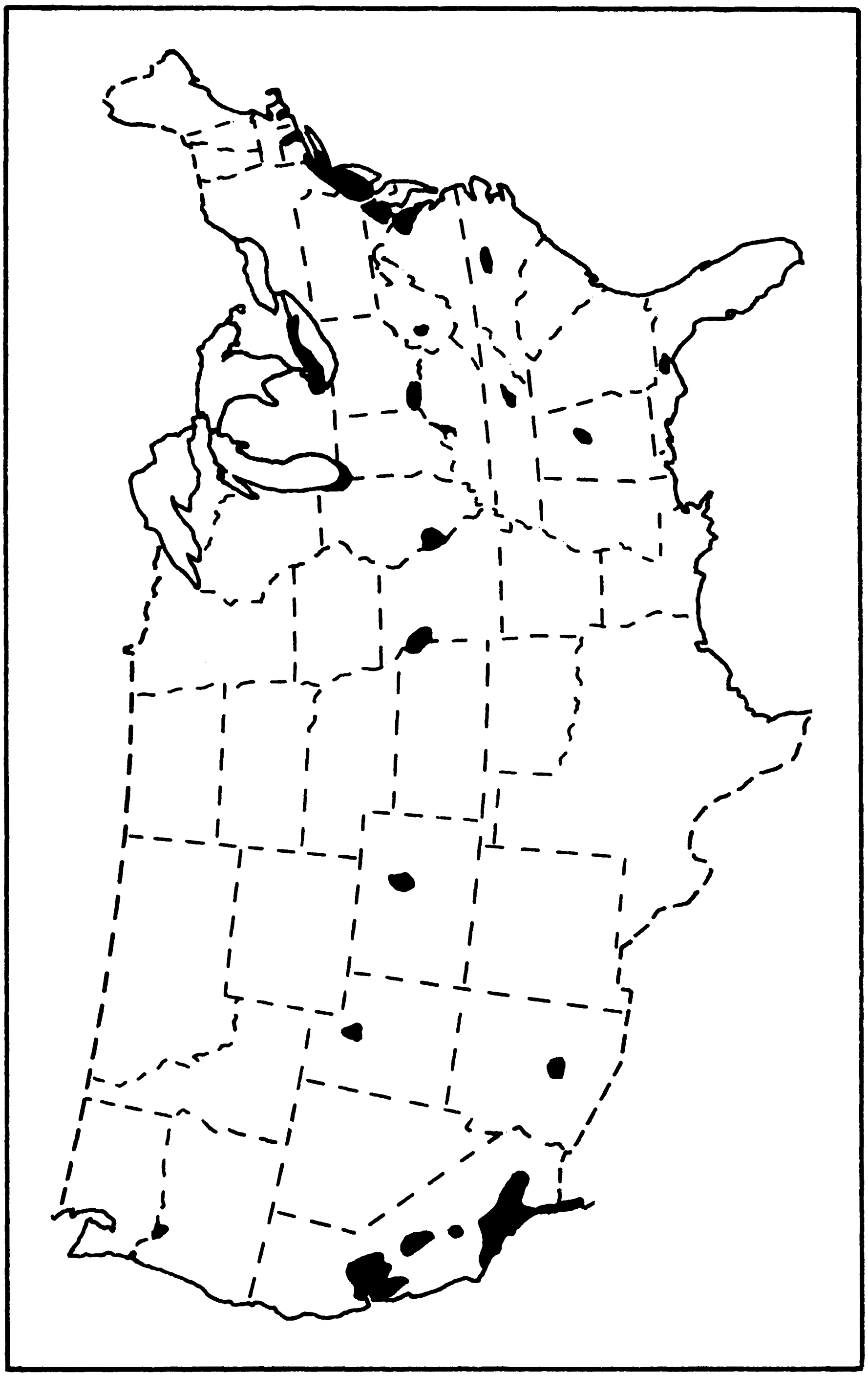


FIGURE 4. POLLUTION REGIONS INDICATED IN BLACK (REF. 72)

TABLE XI. STANDARD FREQUENCIES USED FOR MEASUREMENTS (Ref. 74)

Notation	Wave Number (cm^{-1})	Remarks
W	897.9	Continuum + very weak H_2O line 897.77
G	996.5	Continuum + moderate O_3 emission
C	1053.2	Continuum + strong O_3 emission
A	1095.4	Continuum + weak O_3 emission
H	1159.0	Continuum + weak N_2O emission

the ocean to the west. This orbit was made on November 23, 1960 and the surface weather chart showed these as clear areas in terms of cloud cover. Although this one isolated example certainly does not establish that these high temperatures were due to localized regions of ozone or pollution, it does point out that even in this very medium resolution region it might be fruitful to closely examine some of the TIROS data in terms of establishing localized "hot spots" related to air pollution regions.

The possibility of detecting these zones of enhanced radiation due to ozone emission was discussed in a telephone conversation with Professor Fujita at the University of Chicago. Professor Fujita is known to have interpreted much of the data from TIROS meteorological spacecraft. Although his work is concerned with studying the details of cloud regions, he mentioned that the technique of examining the 9.6 μ band might expose temperature variations over air pollution regions, and that the concept of making comparisons with a nearby reference site appeared to him to be valid. He pointed out that in terms of the present TIROS data a 2^{O}K temperature variation could not be considered significant; a 2^{O} difference is not above the noise level of the detector. In the example previously cited, a 10^{O}K temperature differential was observed over the San Francisco area and variations of this nature could be significant.

10
ARCHAEOLOGY

10.1. CURRENT STATUS OF ARCHAEOLOGICAL INVESTIGATIONS

Archaeology is the discipline which studies man's history through the examination and interpretation of the remains of ancient cultures. Its conclusions are useful in history and the related social sciences (primarily anthropology and sociology). It also provides methods of dating geological, climatic and ecological changes in the far past; these applications are based on the association of certain types of structures with specific environmental factors (as villages with lake- and sea-shores, bridges with rivers, wineries with fertile land and climates suitable for grape-growing).

Many of the remains to be studied have been buried during the time since their use, and careful digging is necessary to allow for proper examination. A large number of sites are known but have not yet been dug out; there are also many areas of the earth where there has been no satisfactory survey of possible sites. It is even true that there are many large sites such as cities which are known to exist (from written records or similar evidence) but have not yet been located. The location of sites at present involves the interpretation of ground signs of such divers nature as mounds, potsherds, earth stains and vegetation differences.

A recent development has been the extensive use of aerial photography in the detection of archaeological sites and in their subsequent studies. In addition to the large-size ground marks (mounds, earth stains, etc.) which indicate the presence of sites, medium- and small-size relief and vegetation effects detectable with aerial photography have been found to give some information as to the structure of the remains at the site. Infrared and color photography has proven particularly useful in the identification and interpretation of archaeological sites, and it is to be expected, therefore, that application of multi-spectral sensing techniques will yield further benefits.

10.2. USE OF OBSERVATION SPACECRAFT

Orbitally-based sensors, then, would have two possible applications to archaeological studies: the detection of large-size ground effects of archaeological remains and the detection of small-ground effects due to various types of structure within a known archaeological site. The first would aid in determining the location of a "dig," the second, in the detailed direction of the excavation. The technical requirements anticipated for the use of such sensors in the detection of sites are clearly within the abilities of orbital sensors, but the requirements for the use of such sensors in the detection of small features remains very near and possibly beyond the capabilities of orbital sensor equipment as presently envisioned. It is probable, therefore, that this application, if it is used at all, will be used only where vertical-angle observation is clearly superior to ground observation and aerial photography is difficult or impossible to obtain (for political or other reasons).

In locating archaeological sites, orbital observations would be used to detect buried structures such as cities, villages, canals, roads, walls and fortifications and also to detect the remains of agriculture, industry or habitation that did not involve construction. Some of these sites can be detected by large features, such as mounding, soil coloration, or differential vegetation growth; these characteristics are in turn capable of detection by ordinary photographic means. (Mounding is detected either by the use of stereographic photography or through the interpretation of shadows.) In addition, it is likely that infrared and microwave emittance spectra will have distinguishable characteristics over buried construction due to the effects of shallowly buried subsurface structures. Research will be necessary to establish the effects which buried archaeological sites actually have on emittance spectra. It is possible that multi-spectral scanner displays could be automatically processed to locate possible sites.

10.3. EVALUATION OF SPACECRAFT OBSERVATION

The principal advantage of orbital sensing over aerial sensing in this field is in the location and mapping of remains over a large area. Aerial methods require the piecing together of many photographs to form a mosaic of the region, while the orbital map, whether photographic or scanner-produced, would have none of the uncertainty involved in the matching of pieces of the mosaic. Archaeologists consulted have stated that the use of mosaics has posed definite problems. Orbital sensing would also allow investigation of areas where aerial photography is difficult for various reasons.

The photography needed for the location of sites is well within technical capabilities, the site sizes being on the order of hundreds of feet in diameter. Multi-spectral scanning techniques have not been used for this application and would have to be tested; resolution is of the appropriate magnitude for large sites at least, and possibly for narrow linear sites (roads, canals, walls, etc.). (narrow linear markings are known to be detected by scanner displays even though the width may be well under the display resolution.) In either of these cases, it is anticipated that archaeological interpretations could be made from data taken by the satellite, even when taken for another purpose.

The feasibility of orbital examination of individual sites for details of structure is questionable, however. The resolution required may approach the theoretical limit of resolution due to atmospheric interference (approximately one foot). In addition, the most useful applications of aerial photography for detailed site interpretation have been based on transient effects of lighting, and weather; it is unlikely that an orbital vehicle would be in place to photograph these, or that atmospheric conditions would be good enough to allow the necessary resolution.

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13. ABSTRACT

Earth-observation spacecraft have many potential applications in the fields of geography, agriculture, forestry, hydrology, wildlife management, oceanography, geology, air pollution, and archaeology. Substantial scientific and economic benefits could result from the use of sensors carried aboard earth-orbiting spacecraft for earth mapping, collection of agricultural census data, forest inventory, wildlife habitat assessment, detection of sea ice, measurement of sea surface temperatures, and many other uses.

Types of sensors to be considered for these purposes include photographic cameras with focal lengths ranging from 0.5 to 20 ft, infrared scanners, multispectral sensing systems, noncoherent and synthetic-aperture radar, microwave radiometers, and laser altimeters. The development of operational systems of observation spacecraft would require a research and development program which included preliminary ground-based and airborne experiments followed by a series of manned earth-orbiting experiments. The preliminary experiments would provide information on sensor characteristics and capabilities for observing natural and cultural phenomena on the earth's surface which would be necessary for design of experimental orbiting sensors and planning of orbital experiments. The objective of the manned earth-orbiting experiments would be to ascertain the optimum conditions for sensor operation and to demonstrate the feasibility of future operational systems. In the manned earth-orbiting experiments, predicted characteristics of the atmosphere would be checked, individual sensors calibrated, sensor performance measured, and imagery and other data collected over both land and water, which would be analyzed to determine the feasibility of detection and identification of earth-based objects and the best methods for employing future operational earth-observation spacecraft.

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