A National Program of Research for

REMOTE SENSING

Prepared by

A JOINT TASK FORCE OF THE
U. S. DEPARTMENT OF AGRICULTURE
AND THE STATE UNIVERSITIES
AND LAND GRANT COLLEGES

FOREWORD

The United States Department of Agriculture and State Agricultural Experiment Stations are continuing comprehensive planning of research. This report is a part of this joint research planning and was prepared under recommendation 2 (page 204, paragraph 3) of the National Program of Research for Agriculture.

The task force which developed the report was requested to express their collective judgment as individual scientists and research administrators in regard to the research questions that need to be answered, the evaluation of present research efforts, and changes in research programs to meet present and future needs. The task force was asked to use the National Program of Research for Agriculture as a basis for their recommendation. However, in recognition of changing research needs it was anticipated that the task force recommendations might deviate from the specific plans of the National Program. These deviations are identified in the report along with appropriate reasons for change.

The report represents a valuable contribution to research plans for agriculture. It will be utilized by the Department and the State Agricultural Experiment Stations in developing their research programs. It should not be regarded as a request for the appropriation of funds or as a proposed rate at which funds will be requested to implement the research program.

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This report has been prepared in limited numbers. Persons having a special interest in the development of public research and related programs may request copies from the Research Program Development and Evaluation Staff, Room 318-E Administration Bldg., USDA, Washington, D.C. 20250.

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INTRODUCTION

The purpose of this study is to:

1. Examine the potential of remote sensing for the improvement of agricultural and forestry programs which depend upon the rapid accumulation, analysis, and application of information on crops, forests, soils, and water conditions. In this context, the allocation of resources to agricultural production is considered in its broadest sense.

2. Evaluate current research in this field and identify those applications which could be improved, augmented, or replaced by remote sensing technology, and to identify in particular those applications where the benefits achieved would have a major impact on the agricultural economy.

3. Recommend a level of public-supported agricultural and forestry remote sensing research that would be a fruitful investment through 1973.

BACKGROUND

A special USDA-States Task Force was convened on August 7-10, 1967, to examine a program of agricultural remote sensing and to make appropriate recommendations. The Remote Sensing Task Force membership was as follows:

A. B. Park, Cochairman
Agricultural Research Service
USDA

H. H. Kramer, Cochairman
Agricultural Experiment Station
Purdue University

J. W. Clifton
Agricultural Stabilization and Conservation Service
USDA

R. Keith Arnold
School of Natural Resources
The University of Michigan

M. L. Cotner
Economic Research Service
USDA

D. J. Belcher
Center for Aerial Photographic Studies, Cornell University

H. F. Huddleston
Statistical Reporting Service
USDA

D. S. Simonett
Center for Research in Engineering Science, The University of Kansas

C. W. Koechley
Soil Conservation Service
USDA

G. A. Thorley
School of Forestry
The University of California

A. J. Loustalot
Cooperative State Research Service
USDA

M. R. Holter, Advisor
Institute of Science and Technology
The University of Michigan

T. F. McLintock
Forest Service
USDA

John Fedkiw, Advisor
Planning, Evaluation and Programming Staff, USDA

Staff Secretary for the Task Force was Dr. David J. Ward, Research Program Development and Evaluation Staff, USDA.

In the conduct of its deliberations, the Task Force adopted several ground rules.

First, it was concerned with improving any agricultural and forestry activities amenable to application of remote sensing technology and systems. These activities include those dealing with crops, forests, range and wildlife management, soil survey, watershed management, and land use classification and management, to name only the more obvious.

Second, it accepted that the subject of interest was the agricultural and forestry functions amenable to remote sensing techniques rather than the particular technology of space, aircraft, or ground systems, per se. In this context spacecraft and aircraft, and the instruments they carry, and ground-collection devices are merely tools to carry out the functions and should be considered in whatever proportions are best suited to the needs of agriculture and forestry.

Third, it also accepted the view that insofar as feasible research should be conducted with hardware of "state-of-the-art" quality, even if this means that the research must, in some cases, be classified.

The Department of Defense has various restrictions on what hardware can be utilized in a completely unclassified mode. For some systems both the hardware and the data produced by the device are considered classified. In other cases, the hardware must remain classified, but the data generated may be declassified. Since all the scientists who are working on the present U. S. Department of Agriculture - National Aeronautics and Space Administration (USDA-NASA) remote sensing programs and who have a need to know have been granted security clearances, research to date has been abreast of state-of-the-art.

The future of the program hinges in great part on the unequivocal demonstration of the national need for these devices for peaceful purposes, therefore it is of vital importance to the scientific and educational community that the proposed expanded research continue at a pace commensurate with instrument development. For this reason, it is proposed that the equipment chosen for the USDA aircraft be "state-of-the-art" which will mean that proper security measures will have to be initiated and maintained during the research and perhaps during the operational phase for some period of time.

SUMMARY

In view of the state-of-the-art of remote sensing systems and of proposed NASA spacecraft schedules, the Task Force recommends immediate emergency funding of \$3 million for test site preparation and a research program to utilize the data derived from laboratory, field and aircraft instruments, all of which is preparatory to spacecraft overflights.

The Task Force sees the need for a continuing program of research and development and recommends the following:

1. A minimum annual funding of research and recurrent operations costs of \$5.7 million for each of fiscal years 1969 and 1970, and \$7.9 million for each of fiscal years 1971, 1972, and 1973.

2. In addition to the above funding, that \$2.5 million be allocated in fiscal year 1969 for development of a suitable multi-instrument remote sensing aircraft, and that a further \$2.5 million be allocated in fiscal year 1971 for a second aircraft.

3. A research and development program roughly balanced 50 percent in-house and 50 percent university.

4. Development of university research and training centers to provide needed interdisciplinary strength.

5. Top priority for research in the following areas:

   a. Laboratory Research. The theory of reflected and emitted radiant energy from plants, soil, and water is not well understood. Because of this, two approaches are necessary; one is directed to the theory itself and the other is an empirical approach where predictions of spectral response are derived from the evaluation of repetitive samples. Both lines of research are underway; however, additional emphasis and effort are necessary.

   b. Application and Information Systems Analysis. The entire field of airborne sensing can be considered as an information gathering system. Research in the field can be divided into two categories: (1) data acquisition and (2) data exploitation. In the acquisition phase, research is underway on the various agricultural applications such as insect and disease detection, nutrient deficiency detection, and species identification. This research looks to the technical questions that must be answered; i.e., can we develop spectral signatures

for crop and forest species; can we detect specific nutrient deficiencies? The exploitation phase starts with the data from the sensors and looks to the requirements of the user agency, such as:

(1) What format is required by the agency -- a photograph, a map, a computer printout, or a statistical table?

(2) Given the format required, how can sensor output be processed to produce the information?

(3) In the data processing field, how much of the information output of the sensors is required for an individual application; can this be machine analyzed; is a man-machine interface required; is a man required for part or all of the analysis?

(4) Can inflight onboard pre-processing of data be accomplished; for what applications?

(5) Can some or all the data be telemetered and what effect does this have on the quality of sensor output?

(6) Can data compaction or sampling be achieved?

(7) Are transmission bandwidths adequate?

When an end-to-end systems analysis is complete, the time factor is considered; i.e., (1) how often does the agency need the information--daily, weekly, monthly, seasonally, at infrequent intervals and (2) what is the input-output time factor for processing and analysis? These problems which are presently under investigation are the key to an operational system and require major emphasis.

c. Airplane Measurement Research. A substantial and early expansion in the airborne measurements part of the research is needed. Research in the laboratory and the field is absolutely necessary in learning those physical and biological parameters that affect the spectral response of vegetation and soil; i.e., anatomical structure, chemical properties, particle size, reflective surface configuration, and moisture content. Nevertheless, these data can only indicate those parts of the electromagnetic spectrum which appear promising. It is impossible to equate directly the laboratory and field data to that which is obtainable at conventional aircraft altitudes, to say nothing of high altitude (70,000 feet) or space (600,000 feet). It is possible, however, to acquire data at 30,000 feet and relate this on up to space since one is looking through 80 percent of the earth's atmosphere.

CURRENT STATUS

The results of research to date lead to the following statement of projected new capabilities resulting from the application of remote sensing to agriculture/forestry:

1. Data gathered in the ultraviolet, visible, infrared, and microwave regions of the electromagnetic spectrum which measure the reflectance, emittance, dielectric constant, surface geometry, and equivalent blackbody temperature of plants, soils, and water will, when correlated with existing knowledge of agricultural and forestry practices and a minimum amount of ground sampling, permit:

    a. Identification and area measurements of the major agricultural crop types.

    b. Mapping of soil and water temperatures.

    c. Mapping of surface water, including snowpack.

    d. Identification and mapping of disease and insect invasion.

    e. Identification and mapping of gross categories of forest types.

    f. Identify salinity and moisture stress in plants.

2. Fire mapping is past the developmental stage and is now operational. Additional research is necessary in the area of fire detection; nonetheless, the feasibility and value of this effort has been amply documented.

3. Detection and mapping of insect infestations in forest stands also is operational. This system, however, is primarily useful when the trees appear discolored when viewed by the naked eye; hence additional research is necessary to develop a "previsual" system of detection.

4. Delineation of gross forest types (e.g., hardwood and conifer) has been operational for some time. More research is needed to identify and map forest species on which all forest inventories are based.

Although somewhat more speculative, the research results indicate the possibility that further development of the same methods may produce a capability to:

1. Determine and map soil moisture content.

2. Delineate and measure critical indicators of forest and rangeland productivity as a function of energy budget.

3. Assess crop vigor, and where the plant lacks vigor determine the cause.

4. Predict and map areas of high potential forest fire hazard.

5. Map silt producing and other water pollution sources.

6. Identify and map major soil boundaries.

7. Identify forest and range species and make detailed inventories of their composition and density.

8. Previsually detect and make determinations of the extent and severity of incipient forest and crop insect and disease epidemics.

APPLICATIONS AND POTENTIAL BENEFITS

The above-listed research findings have direct application in a number of activities of the U. S. Department of Agriculture in the following areas:

Applications and User Agency

- Government compliance checking - Agricultural Stabilization and Conservation Service
- Crop forecasts, crop conditions, and estimated harvests - Statistical Reporting Service
- Range surveys to aid in assessing carrying capacity - Forest Service
- Soil mapping - Soil Conservation Service
- Detection of crop diseases - Agricultural Research Service
- Detection of crop insects - Agricultural Research Service
- Snow surveys - Soil Conservation Service and Forest Service
- Irrigation programs - Agricultural Research Service and Soil Conservation Service
- Forest inventorying - Forest Service
- Forest insect pest and disease detection - Forest Service
- Detection and location of forest fires - Forest Service
- Detection of forest fire hazard levels - Forest Service

Each of these areas has an impact on agricultural and forestry programs and the national economy and each is dealt with separately with respect to benefits that may be expected.

Government Compliance Checking

Production controls and crop adjustment payments were started in the early 1930's to protect purchasing power of farmers. In order to assure that the acreage allotments were not being violated, a system of inspection was inaugurated.

The use of aerial photography began prior to 1935 on a limited basis and has progressed through a cycle of 100 percent coverage to a program of annual voluntary reporting and photographic coverage on an 8-year cycle.

Research on remote sensing to date has shown the promise of automatically identifying the species and measuring it. Additional research in this area should provide a completely automated system of compliance checking, eliminating the need for both reporting by the farmer and the ground inspection by USDA personnel. Research to date has demonstrated the feasibility of inflight recording of spectral signatures of several crops species; i.e., wheat, oats, corn, soybeans, alfalfa, red clover, and rye. These data have been digitized and computer processed into a map-type display from which both the species and acreage can be derived.

Crop Forecasts, Crop Conditions, and Estimated Harvests

The collection of periodic data on crop forecasts, crop conditions, and estimated harvests during the growing season is of vital importance to Federal and State governments as well as private industry. These data affect all phases of agricultural production, as well as the processing, storage, and disposal of agricultural products. Although in the United States forecasting and estimating yields of major crops has been carried on for a 100-year period, present methods yield results which are often at variance from the real-time (i.e., current) situation. The use of an airborne remote sensing system to provide real-time data on crops could reduce the lag between observation and data reduction by at least 50 percent and improve the accuracy of crop data. There does not exist the capability to respond quickly to any major natural disaster in a way which will permit an adjustment in the forecast with any degree of certainty. An airborne system will have this capability.

Range Surveys to Aid in Assessing Carrying Capacity

In the United States there are over a billion acres of range and pasture land suitable for livestock or wildlife grazing, but which are not primarily adapted for crop production or other intensive land use.

Present productivity on much of these rangelands, measured either in herbage production or pounds of livestock and wildlife, is below potential as a result of deficient water, rough topography, remoteness, soil adversities, severe temperatures or past land abuse. In spite of these limitations, productivity on rangeland often may be increased two- or threefold by more intensive management. In order to effectively plan the development and management of rangeland for increased carrying capacity, accurate and up-to-date inventories of the plant communities and continuing appraisals of range condition and trend must be made.

Soil Mapping

Increasing knowledge about soils emphasizes the need that they be mapped, analyzed, classified, and interpreted as a base for optimum utilization of resources for farm production and other land use. In watershed and river basin planning and in planning any projects involving land use, there is a critical need for information on soils. Even in the United States there are many examples of failures in land use due to improper use or management of soil not suitable for the purpose. In other areas of the world, in exploratory soil mapping the new technology will, with collateral information, immediately provide more reliable, accurate, and timely data and will improve these soil surveys substantially.

Large-scale soil mapping takes a longer time than small-scale mapping and requires many trained scientists working in the field making and recording soil boundaries in detail on the airphotos and in classifying and interpreting them. There is a need for some means of obtaining soil information more quickly and efficiently. Although soil scientists have used remote sensing data (airphotos) for 35 years or more in obtaining and recording soil information, remote sensors utilizing more recent technology provide not only improved airphoto coverage, but additional information about the soil-landscape which should permit fewer soil samples to be taken and thus give an expanded soil mapping program with little or no increase in manpower requirements.

Enlarged reproductions from small-scale, high resolution aerial photographs will, if made available for general use, provide a photographic base map for preparing soil surveys for publication. This would eliminate the need for mosaicking and immediately save $4,000 for each publication and help substantially to reduce the backlog of unpublished soil surveys by making it possible to publish more of them with the same amount of money.

Detection of Selected Crop Diseases and Insect Outbreaks

Detection and control of crop diseases and insect infestation are important phases of agricultural management. Plant diseases and insects are among the principal obstacles in the way of efforts to feed, clothe, and shelter the world's expanding population. They not only have devastating effects on crop yield, but also reduce the quality and market value of products. Currently the Agricultural Research Service is spending about $3 million annually in surveying work to detect plant diseases and insect outbreaks. It is estimated that an operational remote sensing system could not only do the same work at a savings of over $1 million annually, but provide for earlier detection of the presence of diseases and insects than possible with current methods. Experimental studies indicate that the presence of plant diseases and insects can be detected using remote sensors before they can be detected through visible means. The use of an airborne sensing system affords the following advantages:

1. The total area of the outbreak can be quickly and accurately defined.

2. The deployment of control and eradication personnel and equipment can be planned and carried out more quickly and efficiently.

The effect of these two actions results in reduced cost for the control effort and savings in the reduction of crop loss. The estimated loss in the United States caused by plant diseases and insects is sufficiently large that a one percent reduction in crop loss alone could amount to as much as $75 million annually.

Watershed Inventory and Planning

There has been a surge in the public interest in multipurpose water development projects. Present data collection efforts of soil and water parameters are inadequate for current watershed planning, watershed protection and conservation operations. With the synoptic and sequential coverage via a remote sensing system, multipurpose watershed planning could be accelerated significantly. In addition to replacing or supplementing the current photographic coverage with improved synoptic coverage, an airborne sensing system would provide much needed collateral data.

Recent studies have been conducted by USDA in the development of linear computer programs for river basin models. The inputs for these programs have taken a minimum of many months to a maximum of several years to acquire. Many of these parameters, such as land use, thermal energy budget, rainfall pattern, water yield, geologic structure, can be acquired in essentially real-time by an airborne sensing system. There have already been proposals to change these static computer programs to dynamic ones with the input capability of airborne sensors.

Furthermore, high resolution photography and infrared sensing can become effective tools for the forest watershed manager, enabling him to locate and appraise critical indicators of hydrologic condition and to plan appropriate management measures. The effects of logging, grazing, fire, road building, and watershed management practices on stream flow, erosion, and snowpack could be measured.

Forest Inventory

The intelligent management of a wildland area is dependent upon the acquisition of accurate inventories of its principal resources. Data collection through the use of conventional aerial photographs has already been shown to be an extremely useful tool for the inventory of resources commonly found in these lands. Further research should allow the distinction of forest species and other attributes about the forest stand heretofore not possible to attain on conventional panchromatic photography.

Forest Insect Pest and Disease Detection

Insects and disease account for timber losses equal to annual growth and exceeding by seven times the loss due to fire. To determine the location and extent of major outbreaks the Forest Service spends more than $5 million annually on forest insect and disease surveys. Only recently has the use of aerial photography for delineating and evaluating extensive damage areas been incorporated into survey procedures on a small scale. Further research is needed to improve and expand both the photographic techniques and the ability to understand and interpet what is recorded in terms of the probable future course of the epidemic. But, in addition to more effective use of photography, there is need for research and development to exploit the potential for detection of previsual symptoms of insect or disease attack. This possibility, already established experimentally, could permit early detection and control action resulting in great reduction in operational costs and timber losses.

Detection and Mapping of Forest Fires

It costs about $150 million a year to control forest fires in the United States. Such fires cause many deaths and injuries, and result in tangible property damage exceeding $450 million. This does not include destruction of soil, water, and other intangible values. On large fires, which cause 90 percent of the damage, a major difficulty in control is determining where the fire perimeter actually is, and in which direction and how fast it is heading.

USDA research has recently developed an airborne thermal infrared scanning system, now in use, which permits instantaneous and precise mapping of firelines, day or night and through dense smoke. When fully operational, this capability will save millions of dollars annually in control costs and resource values and should cut the toll of human injury and death. A refinement of this technique now being studied would permit automatic detection and location of very small fires. This could result in substantial reductions in the $30 million annual fire detection cost, and would vastly improve mobility, flexibility, and utility of detection forces. Quicker and more accurate pinpointing of fires would result in earlier initial attack, which would in turn lower overall control costs and acreage burned.

Detection of Forest Fire Hazard Levels

For effective control and suppression of wildfire, forest protection agencies need techniques for the rapid appraisal of fuels in and adjacent to the forests or rangelands where such fires occur. Ground reconnaissance is too slow and often unfeasible for such evaluations. If airborne sensing techniques can be developed for appraising such elements of forest and range fuels as size, structure, density, and moisture content, forest managers will have tools which can greatly assist them in reducing destructive impact of wildfires on the timber and range resources.

This knowledge will permit close surveillance of these areas, including the closing of such areas to campers, hunters, and fishermen. Immediate monitoring of these hazardous areas after a lightning storm should reduce the possibility of a naturally caused fire spreading because the search aircraft can fly these priority areas first.

RESEARCH TO MEET FUTURE NEEDS

General

Airborne sensing, based on a combination of recent scientific developments, opens up almost unlimited horizons for the collection of resource data from the air and from space. Thermal infrared scanners, image-forming radar devices, and multispectral sensors have suddenly presented us with a new array of techniques for learning more about the earth's resources, and for doing it far more quickly than has been possible heretofore. Infrared and microwave radiations can penetrate haze and smoke and can be used both day and night. Furthermore, the equipment used to sense such radiations can be carried in highflying aircraft or earth-orbiting spacecraft.

One of the most urgent research needs is to develop ways to use these very sophisticated photographic and electronic techniques for more efficient inventory, protection and management of agricultural and forestry resources. At present, the mechanical capability is far ahead of the biological capability. Limited research has shown that certain insect and disease attacks can be detected by remote sensing before symptoms are visible. Ability to do this operationally could permit planning and organization of control operations 6 to 12 months earlier than is now possible. This would not only reduce control costs, but would save large crop and timber acreage which would otherwise have been lost. For certain physiogenic diseases and possibly some types of air pollution damage, this may prove to be the only feasible way to identify critical areas of damage.

There is very good evidence that remote sensing from spacecraft can be useful in appraising agricultural and forestry resources and identifying management problem areas.

Forestry

Research on the application of sensing to forestry should be vigorously continued in each of the following areas of great promise:

1. The use of thermal infrared scanning techniques for the detection and mapping of forest fires.

   Research should continue to improve the ability to find very small fire targets and reduce the false alarm rate. In addition, it appears feasible to telemeter imagery to fire control ground stations. This capability needs to be studied and developed.

2. The use of multispectral imagery for tree species identification, stand composition determination and precise type mapping in forest inventories.

In this regard, a great deal more information should be compiled relative to the spectral signatures of major timber, browse, and range forage species. This research must be conducted from aircraft as noted in 5(c), pages 5 and 6, of this report.

3. The use of airborne sensing techniques for detecting and evaluating insect and disease attacks, tracing buildup and decline of outbreaks, and appraising the effectiveness of control measures.

   As an adjunct to this research, investigations should be conducted on the possible <u>previsual</u> detection of vigor loss in trees and other wildland vegetation resulting not only from insects and disease, but also from air pollution, drought, or other causes.

4. The use of airborne sensing to appraise the condition and trend of range vegetation in response to grazing use, weather cycles, fire, and other impacts.

   Most promising of the airborne sensors for these studies is the thermal infrared scanner. Soil and foliage temperatures appear to be related to transpiration rates, soil moisture, relative humidity, and thermal capacity of the soil and vegetation. When coupled with the loss of reflected infrared in the vegetation, certain predictive capabilities appear feasible.

5. The evaluation of certain factors that are indicative of forest watershed condition, including incipient or active erosion; stream siltation; water temperature; stream depth; extent, depth, and duration of snowpack; moisture stress in vegetation; and rate of evapo-transpiration.

   These studies will involve the use of a complex instrument package encompassing multispectral photographic and scanning techniques as well as radar imagery.

6. The determination, by multispectral airborne sensing, of site quality in various parts of forested area, particularly in intensively managed man-made timber stands.

   It is probable that unique spectral signatures will be found for various mineral nutrition and soil moisture conditions that are indicative of site quality.

7. The use of repetitive overflights for obtaining accurate records of tree plantation survival and growth.

8. The use of both conventional aerial photographs and thermal infrared imagery for the census of big game animals and livestock in wildland areas.

9. The value of airborne sensing techniques, in areas of extensive fuel accumulation, to determine the character, amount, and moisture content of flammable material.

   These studies will involve the use of multispectral photographic and scanner flights on a repetitive basis. The research will define the frequency of overflights and the critical indicators to be measured.

10. The feasibility of incorporating airborne sensing methods into management and protection systems on highly productive timber lands for the continuous and comprehensive surveillance needed.

11. The use of airborne sensing for such atmospheric studies as analyzing the distribution of aerially applied insecticides, determining the amount and dispersion of smoke from prescribed fires, and evaluating the lightning capabilities of thunderstorms.

Agriculture

Research on the application of remote sensing to agriculture should be continued in each of the following areas:

1. The use of multispectral photographic and other imaging devices converted to computer format for the automatic identification and measurement of major agricultural crop types.

   This will be a continuation of research presently underway. Because of the geographic change of crop species and varieties within species, and because of the variability in soil types and climatology, it is vital that work done on present test sites be expanded to other locations.

2. The use of thermal infrared scanners and computer derived geophysical boundaries for the automatic mapping of soil and water temperatures and the automatic mapping of soil moisture content.

   It has already been noted that flights at several different times of the 24-hour day yield data that appear to be related to soil moisture. Because of the impact on planting and irrigation practices, an extension of these studies is extremely important.

3. The use of multispectral techniques and repetitive overflights for the assessment of crop vigor and yield prediction.

   Losses in crop vigor and the impact on crop yield are significantly important inputs on agricultural statistics. It appears feasible to equate an aerial assessment of crop vigor to yield predictions. If further research confirms this, it will permit real-time adjustments in crop forecasting.

4. The use of multispectral visible and infrared techniques for the mapping of silt-producing and other water pollution sources.

   Agriculture has been indicted as a major contributor to water pollution. Techniques now under development involving the use of water penetration film/filter combinations and sensitive ($\pm$ .5°C) thermal mapping should permit not only the assessment of the pollution but the location of its source.

5. The use of the visible, infrared, and radar frequencies for the mapping of major soil boundaries.

   In addition to obtaining the surface expression of soil boundaries on photography, it has been shown that the thermal capacities of various soils are measurably different both wet and dry. Certain radar frequencies have been shown to penetrate dry soils to an agriculturally significant depth. Considerable additional research is required in this area before these tools can be used to aid in soils mapping.

6. The use of non-visible reflected and emitted infrared spectral data for the previsual detection of insect and disease epidemics.

   Although the feasibility of this application was demonstrated years ago, very little operational use has been made of the technique in agriculture. The major problem was in quality control of the exposure and processing of the film. Our quality control has reached the point where a major increase in research on this application is feasible.

   The ability to say with confidence that this vegetation appears healthy and this does not on a photographic image is tremendously important to plant pest control officials who have to conduct survey and control programs. Even though we may never say what the disease or insect condition actually is, the more easily attained and much simpler goal of saying that something appears abnormal is sufficiently important economically to justify the research.

7. The use of color and multispectral black-and-white photography for the detection of essential nutritional deficiencies.

   There have been limited, but promising, results in this application. It is, however, an extremely important goal and it appears that with sampling on the ground and a knowledge of the agricultural practices in the area it is feasible to evaluate nutrient deficiencies from the air.

8. The use of high altitude, multispectral photographic and other imaging techniques for the evaluation of energy budget of broad areas.

   It is difficult, if not impossible, to instrument any large land area for an evaluation of the thermal energy budget. Thermal mapping from the air gives one an instantaneous thermal profile of a large area. Additional research is necessary to evaluate all of the mechanisms involved in the obvious (on the image) changes in the profile.

9. The use of photographic, infrared, and radar data for the assessment of hydrological phenomena on watersheds, including the prediction of potential water supply and erosion prone areas.

   The hydrologic cycle on watersheds is vital information for water management. Airborne sensing will provide many of the inputs required and when coupled with ground based sensors, such as stream gauges, can provide timely data for management decisions. Research is necessary using both types of sensors to evaluate the data from each as it applies to the management information requirement.

BENEFIT-COST COMPARISON

Estimates of potential benefits to be derived from use of remote sensing technology expected from the proposed research were made by the respective USDA agencies represented on the Task Force. Estimated benefits were restricted to savings in operations of ongoing programs. No attempt was made to estimate benefits from new programs that might be made possible by the new technology nor benefits that might accrue from improvements in currently operational programs; for example, more accurate and timely data. In the case of two potential applications, snow surveys and forest fire hazard surveys, estimated benefits quantified although it was felt that there would be significant savings. Thus consideration of benefits has been restricted to those for which estimates could be quantified with some degree of confidence.

Table 1 summarizes expected benefits from operational cost-savings by year. After fiscal year 1975, benefits are expected to remain constant. Costs for a research program from 1969 to 1973 also are shown. Benefits from the program are estimated to continue for 20 years. On the basis of the table, a ratio was computed of the present value of estimated future benefits related to projected research and development costs:

Present value of benefits (20 years at 5 percent)	$178,397,000
Present value of research costs (5 years at 5 percent)	$ 39,653,000

Benefit-cost ratio 5:1

TABLE 1--ESTIMATED OPERATIONAL COST SAVINGS FROM REMOTE SENSING RESEARCH[1/]
(Thousand Dollars)

Application	FY 69	FY 70	FY 71	FY 72	FY 73	FY 74	FY 75	FY 76[2/]
Govt. Compliance Checking	0	50	100	150	200	250	400	450
Crop Forecasts, Crop Conditions, etc.	0	700	900	925	1,254	1,287	1,320	1,320
Range Surveys (FS-SRS)	0	10	110	240	416	466	616	616
Soil Mapping	0	1,300	1,500	1,660	1,680	1,720	1,720	1,720
Detection of Crop Diseases & Insects	0	100	200	500	1,088	1,588	2,036	2,036
Snow Surveys	0	3/	3/	3/	3/	3/	3/	3/
Watershed Inventory and Planning	0	1,003	1,063	1,068	1,077	1,082	1,082	1,082
Forest Inventory	0	50	50	100	150	200	300	425
Forest Pest and Disease Detection	0	100	300	750	1,100	1,200	1,350	1,500
Detection and Location of Forest Fires	200	800	3,000	6,000	9,000	9,000	9,000	9,000
Detection of Forest Fire Hazards	0	3/	3/	3/	3/	3/	3/	3/
Total Cost Savings	200	4,113	7,223	11,393	15,965	16,793	17,824	18,149
Research Costs	8,200[4/]	5,700	10,400[4/]	7,900	7,900	5/	5/	5/

1/ Assumed to be net. That is, estimates account for costs of planes and equipment necessary to employ new technology.

2/ FY 1976 and subsequent years.

3/ No estimates made of cost savings.

4/ Useful life of an aircraft is 10 years. In this table, the residual value of the two aircraft at the end of the fifth year based on straight line depreciation is 2.5 million dollars.

5/ This phase of research projected as being completed in FY 1973. Equipment and facilities would be used for new phases of research.

RELATION TO SPACECRAFT PROGRAMS

The following instruments have been approved for space flight. The list is by no means complete but represents those of interest to earth resource survey scientists. Not all these will fly on any one satellite, but are documented to show the scope of the data that can and will be generated from space.

Visible and Near Infrared Sensitive

120mm focal length 70mm format (multiband) camera
6" focal length 9"x9" format camera
6" focal length 9"x9" format (multiband) camera
12" focal length 9"x14" format (mapping) camera
2" return beam vidicon high resolution (100') TV camera
1" image orthicon low light sensitivity TV camera
Dielectric tape TV camera

Visible, Reflected and Emitted Infrared Sensitive

Infrared (thermal) scanner
Optical mechanical scanner (ultraviolet through thermal infrared)

Active and Passive Microwave Sensitive

Radar scatterometer/altimeter
Microwave radiometer

Agriculture and forestry have been unable to mount a research and development effort of the necessary size and scope to evaluate the output of these sensor systems. Moreover, research on spectral, temporal, and spatial discrimination; ground truth reconnaissance of test sites; and manual and automated interpretive systems are not ready to do more than review a very small portion of the massive quantities of completely new kinds of earth resources data.

The Department of Agriculture has planned systematic and aggressive research which is aimed at the full utilization of satellite remote sensing data, and of greater importance the timely application of such instrument systems to the solution of major agriculture and forestry problems.

It is obvious, however, that the support presently available for ground and aircraft measurements for the purposes of establishing crop and soil signatures and calibrating test sites is not sufficient to permit more than minimal use of the orbital data to be generated by presently planned satellite experiments. In order to effectively use the data from orbiting experiments, an immediate and sizable increase is required in the support available for the ground and aircraft support measurements, research and calibration.

RELATION TO GLOBAL SITUATION

This report has addressed itself largely to the program activities of USDA, but the Task Force wishes to highlight the potential of this technology to the world food situation. It is in this area where space becomes the obvious environment for any future system to operate.

The implementation of worldwide coverage, input, analysis, and output would offer developing countries a chance to leap years in the technological cycle. For the first time, they would be able to truly evaluate their agricultural and forestry potential. It seems obvious that increasing the productivity of their available land would be the first order of effort. Nonetheless, the evaluation of all the potentially arable land in these countries seems assured. If the population distribution warranted resettlement, they would for the first time know the area options open to them, the economically feasible transportation routes that could be developed, and thus be able to commit scarce currencies with complete knowledge of the alternatives available.

It is difficult to overstate the importance of this technology in its sociological impact. Political decisions may delay implementation of such a concept. Nevertheless, the Task Force recommends that USDA be prepared to accept this responsibility at the proper time. The impact of such a program could assume proportions which would far outstrip the importance of the research for energy sources conducted in the 1940's.

COSTS OF PROGRAM

Non-recurring Acquisition Costs	(Thousands of Dollars)
Modification - Air frame	250
Cameras - 6" mapping	
12" mapping	
6" multiband	
70 mm - radar tracking oblique	160
Scanner - multichannel .32-14 microns	500
- ground processing equipment	500
Side looking radar	700
Platform (instruments)	100
Power	20
Aerial photo laboratory (processing equipment)	250
TOTAL	2,480

One aircraft acquired during fiscal year 1969, a second during fiscal year 1971, and a fleet decision made in fiscal year 1971 to be acquired over the next 3 years.

Recurring Costs	(Thousands of Dollars) FY 69-70	FY 71, 72, 73
Flight crew and aircraft operations	550	1,100
Engineer staff	160	320
Maintenance (cameras, scanner, radar)	240	480
Photo laboratory	750	1,500
USDA - Agriculture	750	1,000
Forestry	750	1,000
Universities	2,500	2,500
TOTAL	5,700	7,900