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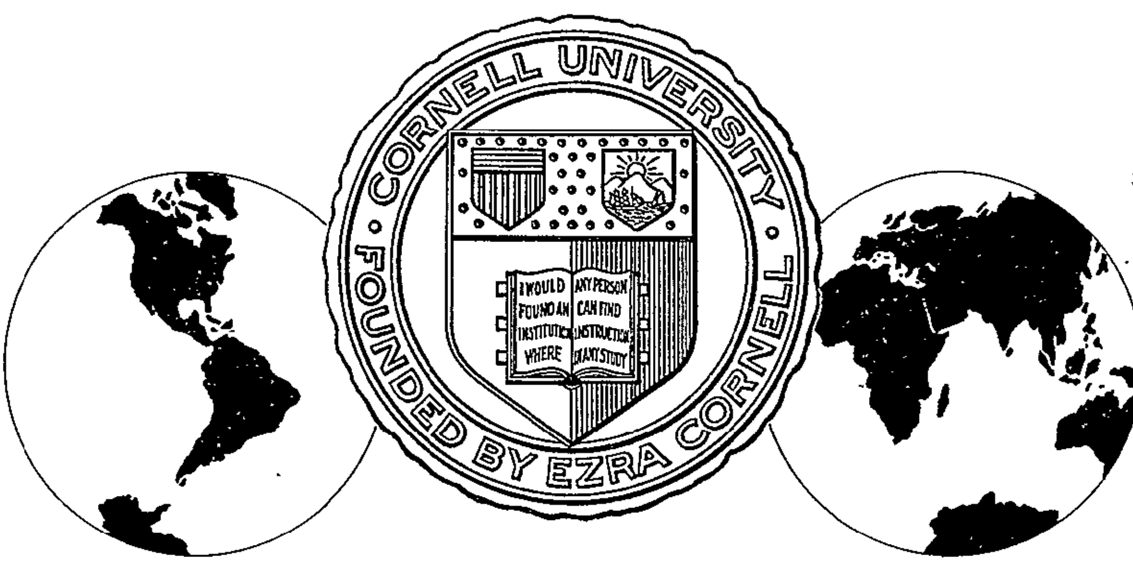
The Center for Aerial Photographic Studies

At Cornell University

Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest, and Range Resources



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POTENTIAL BENEFITS TO BE DERIVED

FROM

APPLICATIONS OF REMOTE SENSING

OF

AGRICULTURAL, FOREST, AND RANGE RESOURCES

A report prepared under terms of U.S. Department of Agriculture, Economic Research Service-Contract No. 12-17-04-1-326 for the National Aeronautics and Space Administration in conjunction with NASA/USDA Interagency Fund Transfers Numbers R-09-038-001 and R-09-038-002.

by the Center for Aerial Photographic Studies, Cornell University, Ithaca, New York

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TABLE OF CONTENTS

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, Natural Resource Economics Division of the Economic Research Service, U.S. Department of Agriculture has conducted a comprehensive study of the potential economic benefits and systems of data acquisition from agricultural resource surveys by remote sensing methods. The main objective of the overall study was to provide guides for a long-range program of research and operations in the acquisition of data on agricultural and related resources by remote sensing methods through defining potential applications, assessing the relative importance of these applications, and specifying the requirements for data in each application area. The Center for Aerial Photographic Studies, Cornell University, was asked to assist in this work and as a subcontractor to the Economic Research Service, has conducted a twelve month study of potential world-wide benefits to be derived from remote sensing of agricultural, forest, and range resources.

This investigation was conducted under the supervision of Professor Donald J. Belcher, Director of the Center, and Research Associates Ernest E. Hardy, Ronald L. Shelton, and Eugene L. Schepis. Mr. Percy R. Luney served as the Economic Research Service Contracting Officer's Designated Representative and Drs. Robert C. Otte and Simon Baker and other Natural Resource Economics Division staff members provided valuable assistance in many phases of this work.

Since the material in this report was produced through interviews, conferences and letters involving hundreds of professionals with expertise in the agricultural, forest, range, and related fields of interest, the statements and estimates of benefits made herein are based on their judgments and do not necessarily reflect the endorsement of their respective agencies. Acknowledgment of the work of the many individuals who participated in or contributed to this study are included in Appendix A.

PART ONE

INTRODUCTION

Remote sensing is a means of providing information. The justification for obtaining the information remotely lies in the demonstration that unique advantages over other means and gains in information acquisition are thereby made possible. The practical values to result from remote sensing, however, depend upon the actual values of the uses to which the information is put.

The main portion of this report explores the uses and associated values of the information which can now or in the future be provided by remote sensing from conventional and high-flying aircraft and from satellites. Supporting material, comprising technical and economic analyses of these uses (or applications), stemmed from a detailed and critical evaluation of remote sensors and of the agricultural, forest, and range resources to which they are applied. The objective of the report is to indicate the magnitude of the potential values that may be derived from remote sensing of these resources.

Remote sensing is considered to be any means of gaining information without direct contact. Remote sensing, therefore, can refer to information-gathering processes involving distances from the object of interest of a few inches or feet to a few miles or even hundreds of miles. Primary emphasis to date has been placed on applications from distances associated with space, high-altitude, or airplane operations, but some applications of great potential value can be carried out on the ground.

Remote sensing in general can provide information with unique and valuable characteristics: unbiased and accurate information, in real-time (or very nearly so), in volumes never attainable before, and in useful format. Yet, ability to utilize even the available information to the fullest extent has not been developed.

Technical capabilities of individual sensors, as they now function, have been examined and have not been found to impose an immediate barrier to our analysis. Applications have been considered in terms of what most likely will be feasible at some later date, approximately 1975. Progress in the remote sensor field is so rapid that even within the time of this study several new capabilities have been identified.

Having eliminated sensor capability as a major restriction, our approach has been to look at all activities within agriculture from the point of view of the farmer, rancher, forester, and professional agriculturist, and to ask what information is or would be of value to the individual making decisions. ("Agriculture" is considered in this report to include forestry and range management and production.) Information is the only product of remote sensing, and its major use is in making decisions. In agriculture, decisions are made at several levels: by the Secretary of Agriculture; by state and local government officials, by fertilizer, seed, machinery, processor, marketing and transportation personnel, and by the individual farmer. Each level merits separate consideration.

Varied sources were used to determine the several hundred ways in which agriculture could use information. Project staff knowledge was combined with discussions with farmers, food processors, and other agricultural industry personnel to provide an indication of advanced requirements for knowledge for operational decisions. Several weeks of interviews with government administrators and agency officials offered the background for understanding information requirements for governmental policy decisions. Basic text books on ecology, plant breeding, silviculture, forestry, conservation, range management, agronomy, plant pathology, entomolgy, agricultural marketing, and animal husbandry were used extensively to identify areas of desired information. Government publications and contractor reports concerning remote sensing and possible agricultural applications were examined. Technical papers journals, and research reports were also used. In addition, many people were contacted by letter for clarification of specific details, and several conferences and seminars were attended (see Appendix A).

From these many sources, hundreds of ideas were developed on how information could be used in agriculture. Some turned out to be of little importance. Others have potential of developing significant impact. Initially, if it appeared that there was even a slight chance of obtaining desired information by use of some remote sensor, it was considered a possible use. In addition, if an activity already engaged in by various government agencies in relation to or with influence on agriculture was identified as a possible application of remote sensing, it also was considered.

The feasibility of every application listed has been confirmed by one or more persons directly associated with the field involved. Thus, whether a use for forestry, range management or agriculture is under consideration, it is not solely the idea of the authors.

The possibilities for applications are so varied and cover such a wide range of agricultural activities that no claim is made relative to the completeness of these listings. It is believed that no major applications have been overlooked but there are certain to be new applications suggested that have not been listed in this report.

With regard to the benefits from applications, it is clear that levels of interpretation of information can have major effect on their magnitude. Automatic sensing and recording of data based on automatic discreet selectivity of key subject signatures amounts to census taking and is what we term "first degree interpretation"--that process of identifying an object or item and simply adding up the area or volume involved. Such techniques may offer many opportunities to provide information on subjects where costs previously excluded all possibilities of application. It should be noted that almost any reduction in the cost of obtaining raw data increases the number of possible economically feasible applications, thereby increasing the potential for greater benefits. However, the major part of benefits will be derived at higher levels of interpretation. Analysis and inferential interpretation are the levels at which policy, planning, development, and other types of decision-making must operate to ensure full benefit from remote sensing. Automatically-tallied census information will be a beneficial adjunct to these higher forms of use, but will not accomplish the complete, successful use of remote sensing for peaceful purposes. Accomplishing the latter require that all levels of interpretation be used to realize the potential of the information made available by remote sensing.

Underlying our assessment of potential benefits is the assumption and condition that remotely sensed information will actually be used to the fullest extent possible, for the benefit of man, through application in fields dealing with the economic, social, and cultural development of Earth's natural and human resources. It must be pointed out, however, that not all possible applications of remote sensing can qualify as benefits even when one stretches the allowances. Merely gathering statistical information amounts to an extravagant waste of money unless the information is put to use in a way that qualifies as useful or profitable. In the strictest sense, the mere gathering of census-type data does not qualify as either useful or profitable. It is only through rewards gained from the use of the information that it becomes a benefit. Knowing the type, acres, or condition of corn grown in country X does not qualify as a benefit, but using the information to improve distribution among countries or within that country, to focus yield improvement measures, or to prevent otherwise unforeseen losses can produce dollar benefits or the intangible benefits of ensuring a greater supply of food. Many of the uses that have been proposed for remote sensing do not meet our necessary conditions for qualifying as benefits. However, a far greater number of uses have previously been overlooked or omitted that do qualify.

PART TWO

REMOTE SENSOR CAPABILITY (circa 1975)

Many remote sensors have been offered by industry and by scientists from educational institutions. The various sensors fall into classes that can be grouped as (a) photographic, (b) scanners, (c) radar.

The most important aspects of these classes that remain unilluminated by discussion are the interpretation of the image information and the infinite constraints involved in obtaining reproducible or even consistent results. For example, in conventional photography a degree of familiarity exists between the physical shape of a ground object and its image. The same relationship does not exist between the color values of two adjacent plants or two areas of soil. A practically infinite amount of ground control must be amassed for each of the untried sensors. What are we measuring, and what is its significance? These are questions to be answered for each.

The benefits to be gained from remote sensing are time sensitive in terms of the stage of development of the various sensors. It is safe to say that none are fully developed as a space sensor.

entional black and white photography represents the most advanced stage of development of all sensors. Color photography takes a close second place but other photographic variations follow at a much lower level. Scanning systems and radar lack both development and interpretation support.

Photography--Panchromatic

Little needs to be said in this field. Scale; ground resolution, stereo coverage, reliability of equipment and film are well documented and time tested. Assuming that useful photography can be obtained, all of the primary applications of remote sensing can be achieved with conventional photography.

Photography--Color

Other than some minor abnormalities this sensor record closely approximates the panchromatic record. If any single film type promises more than the panchromatic type, color has the potential of being the primary recording format.

Color/Infrared

Highly useful for many specific purposes, its chief inhibitor lies in the lack of ground control related to vegetation color. The common assumption that a plant with a specific disease can be identified by this method is erroneous. Color/IR provides a degree of image enhancement for those plants lacking vigor. A plant may be withering for any one of many reasons but this film records only that fact; it does not diagnose the cause.

Infrared

This type of film has had wide usage in forestry; again to enhance the image of principal tree types. Beyond this use, much is lost related to other details. The ability to sense water content of soil in this or in thermal ranges is subject to serious question. Near IR photography (0.7-1.0 micron) introduces only confusion in wet land identification and total obscuration of under water features in lakes, ponds and rivers.

"Deep" IR of the IR scanner records thermal wavelengths (3-14 microns) and reacts only indirectly to moisture through a complex temperature function. A surface wetting of the soil by a rain shower for example, will totally mask any indication of the presence or absence of subsurface water.

Other Photographic Sensors

The "literature" is replete with examples that purport to demonstrate the superiority of one sensor or another. Most establish a basis of comparison by showing a conventional photograph of the same scene and relating it to the enhanced pattern.

One cannot examine the "evidence" contained in the majority of these examples without recognizing the wide gap between the experience of the physicist who has designed the sensor and that of an earth scientist skilled in the interpretation of earth features.

The following examples hopefully represent a composite of the story currently being told for the principal sensors.

Infrared

Two photographs, side by side. show an agricultural field. Photo No. 1 shows a much enhanced drainage pattern in the field as recorded by infra red (near or deep). The second, an aerial photograph, contains a faint corresponding drainage pattern. QED: IR enhancement is vastly superior to standard photography.

To read further is to learn that the two photographs were taken months apart in time when the natural drying of the soil subdues the contrast enhanced by the IR sensor. That this same phenomena may have been recorded equally well in panchromatic film is not acknowledged and is probably not known.

Ultra Violet Sensor (Photographic to 1975)

In this portion of the spectrum only about five percent of the sunlight is available. At present there seems little evidence to justify its consideration and there is much theoretical evidence to show that UV is destined to fail as a remote sensor. The attenuation of the ultra violet in any but the most ideal weather is so serious that UV cannot be seen as reliable. Further, its discrimination values are largely unproven. One of the citations in the literature suggests that ultra violet light permits the identification of a specific roofing material. The evidence contained in the same photograph shows that any light-colored roofing material will respond to a degree that is related largely to its angle and orientation with respect to camera and sun.

It is difficult to assign particular significance to an image emphasized by UV reflectance and virtually no ground control exists that supports an image interpretation of either photographic or scanner origin.

Multiband Sensors

This system as it is being developed forms a complex means of image enhancement adapted specifically to agriculture --i.e., crop recognition. It is based hopefully on the premise that some unique combination of limited portions of the spectrum can be related to a specific crop. At present it appears that, as dependence upon specific wave lengths increases, the many vagaries of reflectance also increase. Any one portion of the spectrum is highly susceptible to a vast array of complex parameters that include changes in ground slope, sun angle, moisture content of air and/or soil, breed of plant, degree of maturity, etc.

The fact that many sensors are directed toward image enhancement for the primary purpose of automating the information retrieval is sometimes lost in the complexity of the approach. Total automation of retrieval of information is based upon the belief that domestic and world-wide sensing is beyond human capacity to assimilate. This is an unsound premise especially since it ignores a systematized human approach that makes use of sampling methods that are inherently more economical, especially when coupled with sensor sampling in the field.

A rational combination of man and machine will undoubtedly be achieved.

Image Enhancement

To enhance is to make greater---to intensify. In remote sensing this is achieved by developing a greater contrast between an object and its background.

Natural enhancement is generally a time function; artificial enhancement is accomplished by the sensor usually based upon one or a combination of wave lengths of light or heat and is not a time function.

Natural enhancement is provided by nature or by the habit patterns of man. The planting or harvest time of grain crops, the blossoming of mountain laurel, the winter retention of dry leaves by the oak, or the separation of evergreen and deciduous trees, are examples. Using sequential or time-directed photography, almost all crops are identifiable in black and white photography by natural enhancement alone or in combination with physical or other characteristics. The early morning traffic count being a function of the total day's traffic is a form of natural enhancement· photography following rainfall provides an enhanced image of soil drainage; sequential photography following rainfall provides a means of assigning numerical values to runoff and infiltration in watersheds.

Image enhancement as a means of making it easier for an interpreter was the original intent of a military program. Even in that situation it served more as a substitute for training rather than a distinct aid to experienced interpreters; furthermore, it applied to small areas in which small objects were sought. The average degree of enhancement over standard photography is probably on the order of ten percent except in the use of heat sensing or certain types of radar that are not truly comparable. The cost of and operational time required for a small degree of enhancement of small objects of military interest is questionable.

In the case of agricultural surveillance, image enhancement is a very different matter. Basically the interest is to provide imagery that can be automatically taken off the format. Regardless of format this has a strong requirement approaching a black-or-white, yes-or-no, all-or-nothing degree of enhancement. As will be noted in a further section this offers a major handicap yet to be overcome.

Instant enhancement attempts to override many natural laws, while natural enhancement utilizes the established sequence of events in nature and man. Enhancement for military purposes must face a rapid decay of information· the half-life of a military surveillance task is very short as a rule because of the transient nature of many tactical targets. Agricultural surveillance of a crop condition may well have a half-life of from 15 to 30 days, which in the growing season is not an impossible period within which to operate.

Radar

Radar, playing the major role, shares with deep infrared, the ability to record images under lighting conditions that eliminate the usefulness of photographic components of a complete sensing system.

The radar type of supplemental sensor is obviously important as a means of penetrating cloud cover or imaging during periods of darkness. To agricultural applications, the ability to image without regard to weather takes on a degree of importance that varies with the particular benefit being considered. Further, its importance depends upon the final system selected for Agriculture's program. A system highly dependent upon radar must await some additional perfection of the equipment.

Currently, and perhaps for as much as ten years in the future, the quality of the radar image obtained during bad weather will not permit crop quality assessment nor will it discriminate some important details of identification. Some of the inherent handicaps of radar for other purposes appear to be advantages to agriculture. The fact that adequate resolution of uniform quality for specific agricultural purposes is obtainable only from side-looking radar means that a wide scan for land use assessment, for example, is available and is particularly useful in overcoming some orbital deficiencies. The side-looking aspect does introduce an attenuation of resolution as the signal passes through heavy cloud layers, but under such circumstances the critical path to the achievement of specific benefits utilizes other sensors and methods compatible with the system.

The more fundamental problems that underlie the use of radar are the weight, power requirements, and antenna characteristics. Refinements to accomplish the necessary modifications for satellite use are only a matter of effort; but these efforts will mature only in the late 1970's or early 1980's. In the meantime, those benefits resulting from radar sensing can be achieved by the use of supplemental aircraft.

The radar image is deceptively simple, and in the coming decade much can be learned by a program of image evaluation related to ground control on specific targets. High quality radar images provide such a sharp picture that their comparison with photography is somewhat misleading. The radar image is a picture of relative energy absorption. It is known that because crops have differing leaf and stem characteristics they tend to have specific signatures; however, a great amount of correlation is required to define the limits of energy absorption for individual crops. There is much potential inherent in the ability to sense this "property".

Calibrations have been made that establish fair correlations between rock and soil densities. This proposes exciting possibilities in soil mapping; at the same time it also demonstrates the complexities that must be resolved before radar imagery can be automated for recovery or for direct interpretation.

It seems inevitable that radar will act both as a supplement to camera systems and as a primary sensor with applications and benefits only partially recognized at present.

Scanning Sensors

This group of sensors is in a more primitive stage of development. The infrared scanner, because more is known regarding thermal emission, appears to offer the most promising rewards and benefits. At present none of the scanning sensors are essential to the immediate or long range benefits of remote sensing in the agricultural world. Continuing research may well develop specific applications that are not now foreseen or their use as subunits in a subsystem that may support a new method of "soil capability" mapping.

Based upon a present combination of distortion characteristics of all scanners and unsatisfactory resolution for agriculture the product evaluation of these sensors indicates that they may serve best in localized geographic scanning where guidance from other information sources has been provided. Optical scanners in particular appear to be banned from space until space assembly stations are available to assemble delicate optical systems.

Lasers

In the field of agriculture the laser has not been proposed as a primary sensor for directly achieving benefits. In an examination of laser potentials it does not offer obvious advantages that will coordinate with other sensors other than for navigational support, elevation profiles, topographic data acquisition or information transmission.

The monochromatic character of laser light minimizes any advantage that it might otherwise have in photographic processes. The inability to sustain high energy outputs that will expose film and the accompanying power requirements are fundamental to laser operation.

<u>Summary</u>

This report has been submitted for comment and criticism to others interested in remote sensing. This has been particularly important to the final draft of Chapters II and VII because of the intense national interest in seeing every aspect of remote sensing developed.

There is a natural and keen competition in the industry/science community that strives for the recognition and reward that will focus on the sponsors and sensors that become a part of the satellite packages of the future.

We have, where it was believed justified, incorporated these comments to the benefit of the report. There remain, unresolved points of difference. These fall into categories that can be described as follows:

> The time required to perfect a sensor's performance before committing it to space missions.

We are less optimistic than some Our "immediate future" extends by definition to 1975. Few of the advanced generation of sensors appear close to this goal. We are reminded that "research is continuing in various parts of the country" to this end but do not find encouragement for early achievement of these objectives.

Physical limitations, environmental handicaps and support requirements.

We have found that weight, power requirements, excessively fragile components and a host of attending problems not always amenable to solution by further research comprise a major barrier between some sensors and their place in space. We have recommended in Chapter VII that the use of jet aircraft in conjunction with satellite missions be adopted. This will permit the on-board use of all sensors and it will provide an operational environment vastly more compatible than space.

What does a sensor see?

This remains as one of the fundamental areas of dissention. The sensor "sees" and records images without question. The problem revolves around the significance and the reasonable reproduciblity of images obtained from portions of the total spectrum. Will a heat image or an ultra violet image or even a partial-color image remain dependably constant for natural objects--for an hour, a day, a month? Heat sensing and UV are radically sensitive to micro changes in weather and lighting conditions. Current research is showing that color photography is "seeing things that we do not understand at the moment. A dying tree should be recorded in a characteristic color on an IR/Color emulsion but in a disconcerting number of instances it is not.

In looking at these problems we see the need for vast amounts of field work to give significance to sensor imagery and to derive the benefits that must justify its use.

PART THREE

APPLICATION ECONOMICS

Introduction

Emphasis during this study has been almost equally distributed between identifying and analyzing technically feasible applications and developing a reasonable and practical format for evaluation of their potential benefits. Technical feasibility has been judged at least intuitively by our statement of each application. Some of these may turn out not to be technically feasible, since we have attempted to be as unrestrictive as possible in view of the uncertain scheduling of remote sensing operations and the uncertain rate of development of remote sensor capabilities.

The procedures for economic evaluation that we have developed reflect these same uncertainties. They also reflect the unique nature of the resources involved, their extent, and the resulting requirements for remote sensing operations. In addition, limitations have been established by the availability of information for the evaluation.

Numerous alternative approaches to the evaluation were considered and, as is explained subsequently, theoretical concepts were chosen which seemed best to allow us to account for all the factors just mentioned. Our suggested evaluation precedures could have been far more complex, but this would reduce the potential for acceptance and understanding of their results and would have detracted from the essential aims of the study. Moreover, any attempt at evaluation runs the risk of serious error: it is difficult to avoid unrealistic projections, over-estimation of benefits is a certainty, and cost will almost always be under-estimated. More sophisticated techniques at this initial stage of the evaluation would simply multiply these errors. (This in part explains our lack of attention to market and multiplier effects of remote sensing applications.) Also, too few of the steps necessary in effecting a remote sensing application can be detailed to warrant a programming approach. The result is that it seems appropriate simply to establish a format within which the basic elements of the evaluation are clearly set forth, the best estimates available can be inserted, and missing data are apparent.

Concepts and Methodology

There are few, if any, direct precedents for this type of economic evaluation. Traditional economic theory offers economic logic and structure, not techniques. Administrative and planning techniques (benefit/cost analysis) developed by various federal agencies--primarily in connection with natural resource development projects--can be applied to some applications, but they are not satisfactory for developing a detailed evaluation framework for a study of the present scope. (Definitions that have evolved are useful however and are discussed in the next section.) As a result, the analysis here has been developed on the basis of (1) those theoretical constructs that could be drawn from the literature on econimic evaluation and from previous analyses of this general nature and (2) the available sources of information.

With regard to the former, the closest precedent is found in several studies of benefits and costs related to the development of irrigation projects, mostly in the western United States by the Bureau of Reclamation. Also, there have been occasional economic reports on foreign land reclamation schemes involving agricultural production.

Available sources of information are a major influence on the form of the analysis. For present governmental programs they consist primarily of the Congressional appropriation hearings, the U.S. Budget, and information from the agencies themselves. For many non-program applications, cost figures--and some benefit estimates--can be made available by contractors, firms, or individuals engaged in the operation. Special effort has been made to obtain realistic cost figures for less conventional operations involving high-altitude or satellite sensing. For all applications, present expenditures to perform tasks and to obtain information have been used as a basis for estimating possible cost-savings.

Benefit/cost analysis provides the general framework which we have elaborated in terms of agricultural, forestry, and range applications of remote sensing. Within this, we rely heavily on the planning-programming-budgeting system (PPBS) to provide a means of analyzing the benefits potentially to be derived in carrying out various programs and responsibilities of federal and state agencies. These benefits--resulting from the use of remotely sensed information--are expressed both in terms of dollars and in terms of achieving public goals. The latter may be equally as important in justifying remote sensing operations as are such tangibles as potential cost-savings.

The unique problems and conditions associated with agricultural, forestry, and range applications of remote sensing--and the uncertain nature and timing of the means by which they will be carried out--have led to several restatements of the more or less conventional benefit/cost analysis. The first of these relates to <u>objectives</u> and their role in the benefit/cost analysis.

Any set of remote sensing applications, at least as some are undertaken or initiated by a governmental agency, almost invariably involve complex objectives. An objective for some applications may simply be to increase the efficiency with which an activity is carried out, and this may have direct economic value in terms of increased output--for example, from improved crop yields or reduced losses. At the same time, the same sensor data may involve applications with entirely different types of objectives. Examples would be efforts directed toward market stabilization (through crop control activities); national self-sufficiency, or insuring adequate world-wide food supplies. These latter objectives cannot be expressed in the same terms as would be simple increases in output.*

Accordingly, we have tried to distinguish between (1) those benefits which accrue to individuals in the economy--generally from output changes--as they pursue their own objectives and (2) benefits which can only be expressed in conjunction with the objectives of a governmental program. Concepts and information from the PPBS have been inserted to express the benefits anticipated from meeting the objectives of these program applications of remotely sensed information, as distinguished from the private applications.

A second major change from conventional benefit/cost analysis pertains to benefit/cost ratios themselves, and to the basic purpose of this analysis. Benefit/cost ratios are essential in considering alternative remote sensor operations--such as those conducted with conventional aircraft, high-flying aircraft, or satellites--to acquire data for specific applications. Also benefit/cost ratios will be important in selecting application components of a particular operation/sen-

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* We are not in a position of having to compare, evaluate, or weigh the desirability of the objectives involved in a single application or among several. We do not ask whether the resources involved could be used more efficiently somewhere else by someone else or in satisfaction of an alternative need. Instead, our task is mainly to find means of expressing the benefits--related to all objectives of any one application--resulting from the use of remotely sensed information. Clearly we do not deal exclusively with economic efficiency.

sor package. In the first case, to consider alternative operations for a specific set of applications, it is appropriate to use a comparison of net benefits anticipated from the use of various operation/sensor packages· in the second, to select components of a particular operation/sensor package, maximized benefit/cost ratios would probably be the appropriate criteria. In the first, benefits are constant, with only the cost of obtaining them variable (with these almost exclusively operation costs); in the second, a relative ordering of a few applications is desired. Since our purpose is most directly tied to the first case, and for other reasons, we have expanded each application to its maximum feasible scale (with scale expressed only partly in terms of dollar costs). This generally corresponds with precedures to obtain maximized net benefits. Additional work would have to be done to estimate maximum benefit/cost ratios.

It should be noted that as a result of the form of the application statement, costs are more variable than the benefits. Having established the objective of each application in terms of its maximum feasible extent and calculated the benefits that would accrue, the problem then is just to find the least-cost method of achieving them.

The form of the application statement is a key assumption. It may not always be appropriate to assume that the objective is to provide particular information to accomplish a given objective. For example, it may be entirely appropriate to weigh the benefits from additional areas of sensor coverage against the costs of the operation and conceivably the balance point could come before maximum areal extent had been reached. Therefore, while we have calculated the full value of accomplishing given objectives--and associated cost-savings--we have also tried to indicate the unit areas and values involved.

Several additional assumptions have had to be made, although we have tried to keep their number to a minimum. We assume (1) that agencies and individuals will operate at optimum technical efficiency in both sensor operations and application procedures and (2) that a data dissemination system (including integration with other data) is available to provide the necessary link between the operations and the applications. Implied is that the applications will be carried out.

The remaining assumptions are discussed in later sections of this report. It should be mentioned that our aim has been consistency, accuracy, practicality, and usefulness, and the format for the analysis and the assumptions have all been developed accordingly. We believe that many of the assumptions can be changed without necessitating alteration of the format. Certainly some will have to be changed to increase the accuracy of the total estimates. Still, we are confident that we have begun successfully to provide a reasonable estimate of the total benefits to be expected from a broad program of remote sensing in agriculture. Equally important, the evaluation format is designed to facilitate the detailed analysis of the benefits and costs associated with using definite remote sensing devices in a particular aircraft or spacecraft to achieve a specific set of applications. As numerous analyses of this type will undoubtedly be required, we have tried--by our presentation of each application separately--to facilitate the consideration of any combination of applications desired.

Definitions: Benefits and Costs

In the conventional terminology of benefit/cost analysis, our analysis encompasses primary tangible benefits and costs with note made of corresponding intangibles where appropriate. Secondary benefits and costs have been excluded.

Tangible benefits consist of cost-savings and improvements; tangible costs are the costs resulting from the remote sensor operation, from data acquisition by the user, and from the activities necessary to effect the application. The costs of the operation may be termed "primary" or "direct" costs; user costs are equivalent to associated costs.

A. Operation Costs

Operation costs are the costs of conducting a remote sensing operation to acquire data. For a large proportion of the applications it can be assumed that the operation will be conducted by one or more federal agencies such as the USDA in cooperation with NASA.

We have defined these costs in terms of a variety of operation/sensor packages involving conventional and high-flying aircraft, satellites, and sensors for all portions of the spectrum. The costs for any one application will, of course, depend on the package desired or selected.

These costs could logically (for satellite operations in particular) be treated as consisting of developmental costs plus operational costs. We consider the former costs generally as historical or sunk costs (and assume that some sort of benefit/cost analysis has been or would be made separately in connection with the development of any one sensor or spacecraft). Only those costs resulting from the modification or adaptation or a sensor, aircraft, or spacecraft to a particular operation seem justifiably considered as part of the costs of the operation to include all the developmental costs would put new sensors and sensor platforms at a substantial and misleading disadvantage in economic comparison with existing sensors and platforms.

We assume that a portion of the costs of a sensor operation is to be allocated to each application using data acquired during the operation. (This perhaps should be done whether or not the user actually is charged.) Several alternative cost-allocation arrangements are possible: (1) The operation could be entirely charged to the federal budget with sensor output made available to federal and private users without charge or with a charge equal only to processing costs: (2) costs of each operation could be allocated to participating federal agencies who would disseminate the data to users without charge, on a cost recovery basis, or with a charge equal only to processing costs; (3) separable costs could be determined--and joint costs of equipment, launch, operation, etc., allocated--on the basis of relative proportions or costs of data output acquired for all anticipated applications or (4) cost-sharing could be arranged arbitrarily.

Whatever the arrangements, they are important because upon them will depend the exact percentage of total operation costs that should be allocated to individual applications (as well as the incidence of the costs and a portion of the benefits). Differing assumptions about the allocation of operation costs can lead to radically different evaluations of the economic feasibility of any particular application. Our analysis has been devised to allow alternative cost figures (and operation/sensor packages) to be examined; it is for this reason that user costs and benefits have been calculated separately from the costs and benefits related to operations.

It should be noted here that the actual cost to each user of obtaining data for an application may bear no relationship to the share of operation costs that could or should be allocated to the application. A portion of the data collected by remote sensing may be thought to constitute a collective good--not to be marketed but to be supplied essentially at cost (or lower than cost). Alternatively, the cost to the user may include the full allocated cost of the sensor operation for that application as well as the costs of processing the sensor records and transmitting the data to the user. This uncertainty provides additional justification for separating operation costs and benefits from the user costs and benefits.

B. <u>User Costs</u>

User costs are the costs which must be incurred to realize the full value of the potential benefits from remotely sensed data. They consist of the data acquisition cost and the cost of carrying out the application.

The <u>data aquisition cost</u> is the cost to the user of obtaining sensor data in the form needed for an application. It is closely related to the operation cost and, as indicated previously, depends to some extent upon the allocation of those costs. We anticipate that frequently it will be--as at present--not much more than the cost of duplication of sensor records such as aerial photographs. However, in view of the expanded data needs, the time limitations, the broad geographical areas specified for many applications, and the possibility of using satellites and unconventional sensors, the data acquisition cost may be substantially affected by the costs of complex means of processing and transmitting data from a sensor to the user. For example, after an operation/sensor package has been selected, several alternatives may exist for this transmission. The user may wait for physical return of the sensor record, or the record may be telemetered immediately, as from a spacecraft. Several steps may then be necessary to process the data and to dissemin-ate it to him. In some cases only a photographic print is need ed; in others, computer processing and graphic or tabular output will be required. Finally, the processed data may be sent by mail or transmitted via television (or perhaps by communication satellites) to the user, who could be in a national or state governmental agency, a county agricultural office, or on a farm. These "variable" costs thus could constitute a substantial por-tion of the data acquisition costs.

Both operation and user data acquisition costs may be incurred entirely by the same agency and may be virtually inseparable, as in the case of an aircraft photographic contract. However, it is anticipated that the sensor data from any operation can often be used for more than one application within the agency and for one or more applications outside it. In view of this likelihood, and for the reasons stated previously, we believed it essential to separate these two cost components.

Again, it should be noted that the data acquisition costs will be equal only to the actual cost incurred by the user. The cost may be almost zero when photographic prints are loaned by one agency to another, or it may include all the charges made for processing of satellite sensor data and conveying it to the ultimate user.

Most of the costs can be translated to a cost per unit area, and we have done this for the available figures.

Application costs are the costs of performing the specific tasks necessary to obtain an identifiable benefit from the use of remotely sensed information. They are the costs of production inputs, of measures necessary to prevent losses or of any other actions taken on the basis of the information provided.

The use of the information may not alter the application costs significantly from what they would otherwise have been. For example, remotely sensed information might just change the timing of the activity, not the inputs connected with it, and it may be possible to get output increases or loss reduction without a change of costs. Alternatively, application costs could increase, as when additional inputs are required to achieve higher production (made possible by better information), or they could decrease, for example, if constant or increased production can be obtained with fewer inputs or when efforts to prevent losses are made unnecessary. As a result, both application costs and application costs-savings (as a benefit from the use of remotely sensed information) can be determined only with specific reference to the application proposed, and both can be positive, negative, or unchanged.

C. Benefits

Benefits consist of cost-savings and improvements. For many applications we are contemplating the benefits of having information never before available. For others there is a possibility of providing information currently being collected at less cost or in an improved manner, perhaps also with the information available to more users and for more purposes than before. Benefits may accrue from increased accuracy or better quality results, from new activities made possible, or from decreases in the time required to obtain information on the basis of which action is to be taken. Cost-savings result if the cost to the user is reduced by any of these improvement benefits, if they have a monetary value in themselves; and intangible benefits, if no monetary value can be assigned.

Three types of cost-savings have been identified with individual applications. These correspond with the three types of costs considered previously. Each involves comparison with alternative methods leading to successful completion of the same application and consists of changes (reductions) in the expenditures necessary to be made by a user. In each case, if no alternatives presently exist, no cost-savings are calculated.

The first potential cost-saving is related to the allocation of operation costs for the application. Present remote sensor operations serve as the source of alternative cost estimates. Frequently, there will be no present operations with which to compare the anticipated costs of the proposed operation. Therefore, no operation cost-savings statements are possible. Such benefits where they do exist are usually connected with applications which involve a change from conventional aircraft operations to high-flying aircraft or satellite operations.

The second possible cost-saving comes from the comparison of user data acquisition costs with present alternative methods of acquiring the same data. There is no presumption that cost-savings of this nature will always be positive; where they are negative they are treated as negative benefits. For example, knowledge of present field and mail survey techniques with scale factors taken into account permits the derivation of unit cost figures which would approximate those in an expanded program of data gathering. It is entirely possible that a mail survey could provide certain information at less cost than by remote sensor means. However, these negative cost-savings (benefits) may be more than offset by reduced costs in carrying out the application or by improvement benefits.

If no alternative methods of providing information are presently used, no cost-savings are calculated. It would be possible to select a method hypothetically and to develop cost figures for it, but this has been judged as inappropriate. Rather, possible alternative methods of acquiring the same information are considered in defining the application. Examination of technical feasibility includes this consideration, since it may be technically more reasonable to use non-remote means. If so, a strong indication of economic feasibility would be needed to warrant its inclusion as a potential application. It should be noted that since applications are stated in terms of a need to expand data acquisition in frequency, area, or type, non-remote operations usually are unable with reasonable expenditure to obtain the same benefits for the given area or required data.

The third source of potential cost-savings is in carrying out the application, with present application costs used for comparison. These application cost-savings are composed of reductions in the expenditures necessary to obtain an identifiable benefit from the use of remotely sensed information. The comparison is with the cost of obtaining the same benefit without remotely sensed information. The benefit may be tangible or intangible. However, many applications are feasible only with remote sensing techniques. As a result, no alternative costs are available, and even estimation of the cost of the proposed application is difficult.

Improvement benefits consist of output increases and loss reductions. Estimates of both here are based on the upper limit of technological improvement that can be expected to result from an activity.

Benefits from output increases are the values of increases in output of agricultural, forestry, or range products attributable to the use of remotely sensed information. They include increases from zero. In the case of governmental agencies, output may be in terms of services provided. For example, additional services may be made possible, or present services may be improved. Insofar as a monetary value may be placed on these, they constitute a benefit of this type.

Benefits from loss reductions are the values of physical output added by prevention of elimination of losses resulting from natural and man-made factors. In a few cases they may consist simply of reductions in dollar expenditures constituting a loss. For example, it might be possible to reduce over payment of subsidies based on crop acreage determinations by improving the accuracy of these determinations, or omissions of land from the tax roll (and tax receipt losses) might be corrected in a similar manner.

The calculation of both types of improvement benefits rests on several assumptions pertaining primarily to the anticipated physical changes and their valuation. Anticipated output changes must be forecasted, along with the value of the increment of this output and the value of the corresponding changes in input. The latter two are substantially more difficult to estimate than the physical output changes. For this report we have mostly used current crop yields, agricultural product prices, and costs of production. These, of course, should be projections for the time period being considered, but such projections are generally unavailable. Acreages involved in estimates of yield increases are considered more or less homogeneous and of average fertility. (Average production figures are used to avoid any suggestion that all lands are of the best quality). In some cases variability can be accurately taken into account.

Many of the benefits will wholly be increases in gross farm income, ideally with the corresponding increases in farm expenses included in the application cost to allow an estimate of the potential net income. For the most part, however, application costs have not been estimated. To do so for each application will take a considerable amount of additional, detailed study. We have tried though to ensure that estimated gross benefits per acre are not less than the beneficiaries could reasonably be expected to pay for the application.

D. Intangible Benefits and Costs

The above benefits and costs have been entirely tangible: they can be assigned dollar values, at least arbitrarily. We are, however, actually attempting to determine the social utility of the various applications, and this involves more than just the dollar values we can calculate. Our approximation of this overall utility rests on assessment of the net returns due to the application, both tangible and intangible.

Intangible costs are less conspicuous than intangible benefits. They usually will involve questions of priorities among governmental programs, although undoubtedly some will occur at the local level in connection with changes arising from resource development and other applications of remote sensing.

Intangible benefits include both those which are not quantifiable and some which are, but neither of which can be valued with a market price. For example, research and planning benefits may be unquantifiable; saving lives may be a quantifiable, but unvalued benefit. Development of new programs or new management practices based on remote sensing may combine both elements. A substantial portion of these center on the goals of individual agency programs, national policy, or world-wide implications. PPBS, as mentioned earlier, is used to assess many of these. For a single application achieving certain goals may be quite intangible, while tangible benefits may result from achieving these goals at less cost--as in preventing soil erosion or providing for food needs.

Benefit/Cost: Additional Considerations

Several additional elements and assumptions of the economic evaluation remain to be considered. First, almost incidentally, it might be noted that cost estimates often will be for the total area involved in an application--the general area, for example, within which a particular crop is grown--while benefits will be only for the acreages that actually produce the crop.

Second, the point of view in the evaluation varies with each application. The general approach is on a national and world-wide basis, but individual user and regional viewpoints occasionally are expressed.

The third pertains to time periods and discounting of the benefit estimated included in this report. As explained in the next section, relevant time periods vary by application and resource area. Discounting frequently must await specification of each application and completion of the benefit/cost analysis for it. Only at that point can the scheduling of costs and the periodicity of benefits be dealt with in a uniform standard discounting framework. (It might be noted here that we have concentrated on procedures for obtaining necessary quantitative and economic data; manipulation of this data is a considerably less difficult task.)

4. Remote Sensing and Time Periods

It appears that there are five types of time periods to be considered when examining possible sources of benefits from remote sensing. The first two are (1) long range (decades of time) and (2) very short range (simultaneous coverage or only hours of lapsed time). The other three time periods apply directly to agricultural applications. They are biologically controlled and correspond roughly to forestry applications, range land applications, and crop production applications.

The long-range time cycle includes uses for macroplanning for the development or use of natural resources. Many of these applications are policy oriented and require development of information over long periods of time. It is in this major category that the value of remote sensing and its ability to provide unbiased records of conditions at known periods in time is of historical importance. Policy and planning applications most frequently depend on our ability to accurately measure changes or to determine trends. In total value, even though it cannot be measured or even estimated, policy and planning applications will likely prove the most beneficial area of application of remote sensing information.

Countering the highly valuable long-range time cycle is the very short-range period. This includes the demand for information for immediate use. Weather, disasters, and their control all call for "real-time" or simultaneous cycles of cover. This will be operational from space only with time synchronous orbiting satellites.

Of the three periods directly associated with agricultural production, (1) is based on the time cycle of production of forest products. Management needs much information of present conditions to make decisions, the results of which will not be forthcoming for 10 to 70 years. In addition, foresters will make use of much information based on much shorter periods of time, including instantaneous coverage for fire control.

Range land management decisions (2) are frequently designed for implementation annually in cycles of 3 to 5 years. The decisions of range managers require much background information, deal with large land areas, and for the most part, are responded to through control of livestock use of range resources. Response by the range resources to this type of control usually requires at least a short period of years. For disaster purposes, range management also will have need for instantaneous information.

The agricultural sector (3) requires information over the shortest cycle of time and is of major importance because most all food and fiber producing crops are included in this sector. Most of the economically important crops are planted, harvested, and often consumed within 180 days; so obviously to be of any value, applications in this area demand remotely sensed information to be obtained in cycles of 20 to 30 days or less. This is particularly true in the case of diseases that develop and spread rapidly. In fact, there are many cases where such information would have to be received almost daily to be of great value. If, for example, we hope to aid farmers by forewarning of the rate of spread of a disease that is capable of moving hundreds of miles in a period of days, we will need information covering that distance on a daily basis. Otherwise the "preventive" techniques commonly used by farmers for control of certain diseases will still be more satisfactory than controls based on inadequate information from a sophisticated space satellite system.

From the above considerations it is obvious that one satellite covering the earth's agricultural areas infrequently is not adequate but for a few beneficial applications. However, provision of enough satellites to obtain coverage on a 5 to 10 day cycle may not be an economically realistic solution. What does appear most beneficial would be a program that combines the use of satellites for certain general applications with high-altitude systems for broad area uses and conventional altitude coverage for specific highly selective uses. This would help resolve the problems of timeliness of satellite coverage and extremely high costs of adequate time-accurate coverage for the many time-specific applications in the agricultural sector.

One other major factor should be considered. While it will be impractical to use satellites to cover all the area of a certain crop during critical times, it would be feasible to obtain daily coverage of a sample area--perhaps only along an advancing disease infestation front--from conventional or high-altitude equipment. There is a great potential for the use of properly designed sample systems for the applications demanding frequent and timely cover.

It is entirely possible that alternative combinations of operation/sensor packages and sampling techniques will enable application benefits to be achieved within a considerable range of operation and user costs. Also, benefits may vary according to the timeliness of the information. As a result, discounting will undoubtedly require special analysis of each application to determine exact economically relevant time periods.

B. Eenefits: Practical Problems

As defined previously, estimates of the value of increases in production, savings from losses, and reduced costs of obtaining information or carrying out an activity are considered to be benefits. Early in our study it became apparent that for most of the applications such figures simply were not available. As a result, estimates had to be developed, often based on arbitrarily but judiciously assigned values. The basic data necessary for highly accurate estimations do not exist in the majority of cases. For example, there are major deficiencies in information on the areas of land uses and the extent of agricultural resources. An acceptable map of the forested areas of the world is not available. Also, the values of various governmental services are not calculated. No one has ever placed a dollar value on agricultural census information beyond stating that it is at least worth what it costs to obtain it.

The benefit figures most readily calculated are estimates of the value of the increased production that could be achieved through the use of the information believed to be obtainable through remote sensing. U.S. data are readily available, and world figures can be developed from various sources in some cases. However, in many cases where estimates were made, they should not be considered more than an indication of the magnitude of possible benefits.

It might be noted here that the calculation of such benefits on a world basis is not only difficult but can be considered premature. Other countries may not permit the development of information about their agriculture from remote sensors. Without full cooperation, it will be difficult at best to attribute benefits to remote sensing by U.S. sources in other parts of the world.

Most of the estimates developed in this study are of gross benefits only; they are not the net returns to producers after costs of production, marketing, etc. have been defined and deducted. The costs of production can be estimated, but effort must first be made to determine exactly how to put the information retrieved from the newer remote sensors into a usable format, to identify those who can use the information, to find ways of delivering it to them, and to insure that it can be used successfully. We will then know the extent to which costs of production may be affected; at present there is less information about the inputs required to achieve a beneficial output than on the value of the output itself.

There have been suggestions that attention ought to be focused on the effects on the market when increased production is anticipated. This approach was rejected for this study for several reasons. First, the market reacts to short-run changes, and the increases in production anticipated through remote sensing frequently are definitely long-run. Second, we are looking ahead to the technical capabilities of the 1970's, and the market situation in that period cannot easily be projected. Third, we have assumed that any increase in production is desirable (or will--in the case of food products--be needed)· otherwise the normal short-run reaction in the market to increased production is most often negative, which would indicate that negative benefits can be expected from the application of remote sensing. Fourth, the market encompasses the private sector of our economy, and the initial costs of developing remote sensing are being borne by the public sector.

In like manner, application of the "multiplier" to the anticipated benefits has been rejected. Not enough information on the multiplier effect could be found to make a working model for this study. Also, there was clear evidence that the magnitude of the possible benefits was sufficient to insure sustained interest in remote sensing without inflating estimated benefits through the use of a (highly controversial and easily contested) multiplier effect. (See Appendix B).

Even with clarification of the concepts and methodology appropriate to our analysis, it is still a major problem to attach actual values to anticipated savings and improvements. Other investigators have said, "If we assume a (saving) (Improvement) of (5%) (10%), then total benefits would be ....," and this often is almost all that can be done. However, an assumption of a standard 10% increase is less acceptable than an estimate by an expert based on an understanding of the resource or product and its market. Consequently, we have relied on these estimates---and often cited their source---where our own analysis was insufficient.

For subsequent investigations, we have developed a summary form composed of the necessary elements of a complete benefit/cost analysis. This form follows on the next two pages.

APPLICATION: ____

Summary:

Present Information Acquisition Method

Frequency of Application: Present __________
Desired __________

I. Alternative Costs

Present operation costs:

Area involved __________
x
Cost/unit area __________ = $__________

Present user data acquisition costs:

Area involved __________
x
Cost/unit area __________ = $__________

Present application costs:

Area involved __________
x
Cost/unit area __________ = $__________

Intangible Costs	Intangible Benefits

COSTS	BENEFITS
	III. Improvements
	Output increases:
	Output change_____ x Unit value _____=$_________
	Loss reductions:
	Loss change _____ x Unit value _____=$_________
II.a. Operation Costs	IV. Cost-savings (I-II)
Operation/sensor package#_____:	
Separable costs =$_____ + Joint costs =$_____	$_________
II.b. User Costs	
User data acquisition costs:	
Area involved_____ x Cost/unit area_____ = $_________	$_________
Application costs:	
Area involved_____ x Cost/unit area_____ = $_________	$_________
TOTAL TANGIBLE COSTS $_________	TOTAL TANGIBLE BENEFITS$_________

PART FOUR

REMOTE SENSING OF AGRICULTURAL, FORESTRY, AND RANGE RESOURCES

Agricultural Applications of Remote Sensing

Applications of remote sensing for agricultural use cover the widest range of the three major areas studied. The range varies from intensive use at a close distance (i.e., a few inches) to extensive or continental mapping of resources from satellites.

To identify possible applications, investigation was made of the many types of information about agriculture needed or now gathered for use by planners, administrators, professional agriculturists, and farmers. This was followed by determination of the feasibility of obtaining desired information by remote sensing. It was then decided whether or not needs for these types of information constituted a worthwhile application. Many supposedly important applications are difficult to justify in competition with existing methods of information acquisition.

The unique characteristics of agricultural applications--as distinct from range or forestry applications--require that certain specific considerations be made. For example, (1) the number of people involved is far greater; (2) the land and capital managed by the individual farmer are usually much smaller; and (3) the farmer, due to the smaller size of area involved, has a more intimate knowledge of his local situation than is possible in forestry or range management. Thus, as (3) implies, if an application is to be of any value, it must improve upon that information which the farmer already can gather from frequent inspections of his small land area.

Problems of communicating remotely sensed information to the farmer, as ultimate user, are multiplied many times over because of the great numbers involved. The complication increases when we consider that obtaining the potential benefits from a remote sensing operation often depends entirely on whether or not individual farmers take action to resolve a situation evaluated through the use of remote sensors. Attempting to estimate the degree of response to be expected in even one country is an extremely complex problem and currently is essentially impossible on a world-wide basis.

There are, however, general circumstances that will prevail on a world-wide basis. Many countries have much more control over land resources than in the U.S., and implementation of programs to take advantage of remotely sensed information will be comparatively easier in such countries, provided their technical capabilities will have advanced to appropriate levels. There appear to be three broad classes of countries to be considered in terms of economic and technical levels of agricultural development, and varying degrees of value will accrue to the use of remote sensing in each class.

Among countries with highly developed agricultural technology, with high levels of employment, and where major advances in the efficiency of agricultural production continue to keep pace and balance with economic development, we can expect high rates of use and very significant rewards from remote sensing. Such countries, to name a few, include the U.S., Canada, Australia, Nationalist China, New Zealand, and many more. At the other extreme are countries struggling to make major rapid strides in their agricultural and economic development. They are aware of the need to take advantage of all possible technical development to increase their rate of improvement. In spite of labor surpluses and low capital per farm in many of the emerging countries (e.g., Nigeria, Mexico, Costa Rica, Venezuela, and some Communist countries), they are receptive to the ideas and possibilities new tools offer, and they will probably be the second large group to show major response. The third group includes the countries that show little or no interest or concern for major advances in agricultural development or that have resources that would not respond favorably to technological changes. Many of the economically stable countries fall in this third catagory along with the undeveloped countries that have a stabilized economic activity at a low level. It is therefore equally difficult to envision that the results of remote sensing will have any significant effect on the management decision of dairy farmers in the mountains of certain European countries or in the tribal or semi-nomadic agricultural areas of Africa.

It seems obvious then that we will never be able to accomplish complete world-wide acceptance and use of information derived from remote sensing. The methods of operation; the ability of human, natural, and capital resources to respond to new information; and the desires or goals of the agricultural sector of the economy are so varied throughout the world that the effect on global agricultural applications is essentially impossible to evaluate. Because of this situation, the estimated values for world-wide use of certain applications are offered only as an indication of the magnitude of the possible benefits. Estimated values were often developed by using the best known value of an application of a unit basis and simply multiplying up to the level of world-wide use on the basis of available figures. Considering the variability and questioned accuracy of world-wide figures for almost any form of agricultural information, these estimates are not vigorously defended. The basic area figures were taken from the annual USDA publication, "Agricultural Statistics", from FAO "Production Yearbooks", or from other FAO publications.

For all applications, there is almost a complete lack of benefit estimates that trace the value of benefits directly to remote sensing. Consequently the best approach has been to work through such techniques as those employed in farm management surveys to determine what information could be of value. By doing this, many highly publicized applications lost importance, while a great number of other applications were brought to light.

The sensing of diseases on grain crops is a good case in point. As far as the U.S. is concerned, farmers rarely treat a grain crop for disease control--due to the simple economics of the situation and perhaps to lack of effective control measures. Therefore, knowledge that a rust is infecting farmer Y's wheat field does not result in benefits attributable to remote sensing, since farmer Y does not make any attempt to control rust.

The usefulness of this knowledge is not found at the point of on-farm decisions. It becomes useful as a means of prediction of yields, as an indicator of spread of disease, as a means of selecting disease-free seed stock, as a decision factor for farmers who can still exercise an alternative and choose between grain or hay uses for their crop, and most important, as an indication of areas that may be producing a disease-free or disease-resistant strain of wheat. The last use is by far the most significant one. Success in finding a disease-resistant strain of only one of several of the more important food crops could conceivably justify the cost of the entire space operated remote sensing program. (In New York State, it is estimated that the value added to that of one year's production of corn by increased yields resulting from research in plant breeding is greater than all the funds expended in New York for the purpose to date.)

The available literature on remote sensor applications to agriculture was not of great value in developing the lists of uses. Most of it pertains to a specific technical quality of an individual sensor in serving a specific purpose. Much of the literature is primarily concerned with research problems or techniques. None of it provides satisfactory guidance for determining the benefits to be derived from sensor applications. Few of the authors showed very great interest in this part of the problem, as indicated at least by their failure to answer queries as to how we might determine the value of the specific application they had written up for publication.

Agriculture was considered to include all economic crops, though many were grouped together. Thus, field crops, forage crops, vegatables, etc., are not reported as individual crops, but collectively. In like manner, diseases were not looked at individually, nor were insects. Studies of greater detail will have to be done at a later date.

There appears to be a major area of misunderstanding about the nature of remote sensor coverage required for agricultural use. Practically all applications can be accomplished at conventional or high altitudes. Satellite coverage will be necessary only for a few unique uses and so will low-altitude coverage.

The timing of coverage (or acquisition) for agriculture is another area of major misunderstanding. Complete coverage of the U.S. or the world in one short time-span will rarely be needed. Certain uses, such as mapping forest areas or soils, will call for large areas of simultaneous coverage; but for most applications we will be looking at certain features under specific conditions. There will be no need to measure snow depth except at certain times during the pre-run-off period. There is no point in covering all the eastern United States to determine the extent of frost damage to the Florida citrus crop. There will seldom be a use that will not be related to the seasonality of a crop, activity, or need for knowledge.

In this respect, the prospects for using high-altitude coverage are very inviting. The frequency and control of time of acquisition are critical features that may not be well served by satellites. Most of the world's annual food supply is planted, grown, harvested, and stored or consumed in less than 6 months. To trace the development and migration of potato blight along the eastern U.S. seaboard, for example, may require information as frequently as every 3 to 5 days, depending on wind, moisture, and temperature conditions. The ultimate goal for continuous information would have to be synchronous orbiting satellites. Short of that, high frequency of availability of satellite coverage would be helpful, but the efficiency of high-altitude jet aircraft should be given a thorough examination first. Because of the singular need for mobility over parts of the country, they may well prove to be the most efficient source of acquisition of remotely sensed information for the present and near future.

There are certain types of specialized farming where crops are so intensively managed that it is doubtful that remote sensing from great distance will be of any value. But this suggests the possible use of very short-range sensors, in the form of cameras, for example, which would allow the farmer "on the farm" access to pre-visual information about plant conditions. This area may prove an extremely beneficial approach to the uses of remote sensing. Many who raise intensive crops, especially for fresh market consumption, work on the basis of preventive care in the control of insects and disease. To inform them that their crops have a disease is in itself the disaster, not the warning they need. By monitoring the spread of disease or insects they can prepare more appropriately (in greater or smaller amounts) their preventive care measures, thus generating a major benefit from remote sensing.

The other major reason for considering aircraft is the marked feasibility of carrying out applications with a significant real-time value on a sample design basis. Complete coverage can easily result in an excessive cost for handling and data processing, with little or no gain in accuracy over and above that obtained from sample areas.

Serious pitfalls are generated by the desire to use every sensor, whether or not a need for its information really exists. Every proposal must be vigorously scrutinized and only advanced if real benefits can be gained. The mere gathering of more information does not qualify as a benefit. If it can be put to use in a profitable manner, it may qualify as a benefit. One proposal was recently reviewed that called for remote sensing to identify the maturity and harvest time for apples. This is not a justifiable use, since farmers raising crops requiring intensive management are adequately informed of such matters. In addition, color was to be used as the indicator of maturity, but, of course, color is not indicative of the ripeness of many fruits, apples in particular.

Another questionable application, and one for which gains are often claimed, is the use of remote sensing information to generate changes in the market. Short range rewards to market operators might be generated, but these are not the same as direct benefits to the farmer. In addition, in the long-run the positive and negative market responses will about off-set each other, raising the question of whether or not there is any lasting benefit from such an application, although this is not to deny that people can profit from such knowledge. Over many years, we could logically expect to see supply and demand remain closer together when better information becomes available. But it does not appear appropriate to make claims of benefits on the strength of changes in market situations of only one direction. If both directions are used, as they should be, then the positive reactions will most likely be cancelled out by the negative ones.

There are many instances of secondary and tertiary benefits that could legitimately be claimed. These are not generally included. In one instance it was possible to obtain a rough estimate of benefits to the canning industry, which would result from better timing of crops, better knowledge of irrigation needs at the farm, etc. The savings to the canning industry through the availability of better quality raw products, better timing, etc., would be substantial and would amount to a major economic improvement. Other industries also would benefit, and in like manner we could claim that better production leads to more capital investment, which leads to more taxable real estate, which leads to a better school system, which leads to a higher education level... This circle of events would be generated, but it is not included as part of the benefits assigned to remote sensing in agriculture.

There are additional problems to be met in deciding whether or not remotely sensed information is necessarily better. It will be very difficult to improve on the low-cost methods used to gather much of our useful data. For example, the very inexpensive, efficient postcard reporting system used by the Statistical Reporting Service is a strong competitor of remote sensing. The low cost of that program allows little room for a new approach unless it has major improvements to offer. Undoubtedly a combination of remote sensing with existing techniques will prove more beneficial than either one alone.

Currently it appears that there is one major gap in the approach to remote sensing in agriculture. Due to the biologically short cycle of the products involved, and the timeliness and accuracy required for many of the applications, it will be necessary to develop an outstanding, accurate, and fast information service to get the information to the farmers or other decision makers. Merely gathering impressive volumes of data is not beneficial. It becomes of value only when it is used. The lack of effort, currently recognized, in the process of retrieval and dissemination of information is the major area of necessary investigation left to be attacked by the program. Impressive advances have been made in all other phases of the work, but the processes necessary to get the information sorted out and distributed to the user are still relatively unknown. There are new approaches that show great promise such as the use of communication satellites, and there are some very effective services already operating, such as the U.S. Post Office and the Extension Service that might economically play a leading role in this necessary step.

The work presented here does not attempt to consider the cost of developing and operating services that will solve these problems. Instead, the uses are given, and an estimate based on the best information or advice available is given for the gross value of each application, in terms of either the value of the product or the lower cost of gathering information.

In most cases at least one other person concurred with us as to the amount of production or value that could be claimed. These are not net values, but they do indicate the magnitude of the return from resources we can expect to gain through the use of remote sensing.

<u>Forestry Applications of Remote Sensing</u>

Many forestry applications of remote sensing are already operational. In many respects, forestry applications have been advanced further than those in other major areas. This results from the nature of demands for information by foresters, and from the extent and locations of our forest resources. Without some form of remote sensing, much of the information we desire about forests is too expensive to obtain and remains essentially unavailable.

The biological processes involved in forestry are such that one would expect benefits to be far inferior to those from applications of remote sensing in agriculture and range management. Considering the land areas involved, benefits are not as great on a square mile or annual basis as they are in range management or agriculture. The harvest cycle ranges from 25 to 30 years in the rapid growth areas to over 100 years for certain species. Because of the long cycle involved, most forest applications will have usefulness on an infrequent basis, with certain specific exceptions such as fire, disease, insect, and disaster applications. For much of the United States and the rest of the world, mapping and inventory will not be necessary more frequently than every ten to twenty years. For a few of the applications, certain areas must be covered annually, and coverage on an hourly basis or less (in the case of forest fire surveillance) may even be necessary.

The range of applications in forestry is as broad as in any of the other areas of application: the delineation of of forest areas of the world represents one extreme, while detailed knowledge about parts of individual trees represents another. Surveys on a world-wide basis will be considered on a relatively long cycle. At present, an inventory of the world's forests that is considered comprehensive and adequate for professional planning is not readily available. The world's forests never have been mapped by reliable means.

The greatest value of any one application will be derived over long periods of time and will result from use of the information as a basis for major planning decisions. Thus the mapping of the world's forest areas in itself becomes one of the major benefits in the area of forestry applications. The steps leading to detailed inventories next become significant, with quantity and quality evaluations the major information derivable. As progressively smaller areas are considered, additional inventories can be carried out, management practices enhanced, and more localized planning activities relating to forestry become feasible. These include reforestation, compliance checking, harvest operations, and public policy and planning.

The management and operation of the forests in relation to harvesting activities, growth, and control will benefit from many of the possible applications. Knowledge of diseases, insects, disasters, and hazards becomes a part of the information needed for the management procedure at this point. In addition, forestry researchers will find many uses for remote sensing; and it is expected that other researchers will, in the future, develop many more applications than those covered in this report.

As in all applications, the only thing foresters will get from remote sensing is information. Therefore, the savings and improvements credited to remote sensing must be derived through practices carried out because of better information. Not all possible applications will be profitable simply because remote sensing can be applied. There are many areas and activities where improvements will not be made by the use of remote sensing.

There are two main channels through which benefits can be derived. One is to provide by remote sensing the kinds of information we now obtain, but at less cost. The second is to provide information we could not previously afford to get. The management of forest resources depends upon ability to obtain and interpret information. The kinds of information needed for this purpose fall into a few broad categories, including natural conditions of (a) where the forests are located, (b) what forest types make up the forest, and (c) what the site qualifications are. From these sources of information, management proceeds to enhance conditions wherever and however possible to maximize one or another of the benefits forests may provide.

Considering the capability of scientists to develop rapidly the new instruments necessary to carry out many of the technical aspects of remote sensing, technical capabilities for remote sensing have not been treated as a restraint. Any known source of information, regardless of current stage of development, has been considered as potentially beneficial. If information that could conceivably be obtained from remote sources would be of help to foresters in meeting their desired ends, its usefulness was considered. These could not always be evaluated in economic terms, but many may be at a later date. Thus, the effects of air pollution on forest growth rates, for example, are mentioned as a possible use of remote sensing, even though we are not certain at present that it will be possible to measure air pollution from satellites or airplanes, or that it will be cheaper to do so in that manner.

The total range of applications considered was broader than the range of activities of the Forest Service and other government agencies. Included are such activities as forest fire control, recreational use of forest lands, and information desired for policy decisions. The one basic requirement was that the use be beneficial. Thus, fire is treated both as a beneficial tool and as a destructive hazard to be prevented.

Three basic sources of ideas for applications of remote sensing in forestry were used: (1) governmental reports, (2) basic textbooks used by professional foresters and academic institutions, and (3) interviews and conversations with experienced foresters, researchers, and administrators.

The available reports provided the background necessary to determine the kinds of information now considered useful and, by tracing certain activities through the appropriate budget reports, the amount spent to obtain the information. Basic textbooks (preferably a little older than those considered current) provided suggestions on the fundamental problems of forest production and management. Many suggestions for uses emerge from the unavailability of answers to important questions.

Conversations and interviews with experienced foresters gave insight into the feasibility of using many possible applications. Often it seems less expensive and time-consuming just to do certain jobs than to complicate them with an untested new method. Researchers gave important suggestions and verification of the worth of some of the untested ideas. Administrators were an excellent source for ideas concerning things that need to be known for better programming and long-range planning.

Range Land Applications of Remote Sensing

The management of range land combines qualities of both the sciences and the arts in the process of obtaining maximum yields while conserving range resources. Range management does not have the same opportunity as does farming to develop, or to change the character of, the natural resources employed; rather, range management is directed toward maximizing production from the innate productive capacity of the range resources, much as in forest management. Also unlike agriculture, range land must be considered in management units of thousands of acres, with the smallest mapped units often five acres or more. This creates unique information requirements, involving patterns of relative differences instead of accurately measured differences. Great opportunities for value to be derived from remote sensing as a tool in range management result, since ranchers rarely spend much money on a per-acre basis attempting to adjust the quality of the resources. However, they are required to manage the existing resources to the most advantageous degree of performance, and understanding of relative differences among various areas may be their initial interest.

A basic consideration in range management is the existing ecology of the range. Essentially all range land is developing toward a climax situation, controlled by the natural factors associated with the resources. Range management, with the use of ecological knowledge, can accelerate or retard the rate of biological transition in a manner allowing advantageous use of the plant production of the range over long periods of time. There has been little financial success in attempts to change or to modify the production from range resources once they have gone beyond the point of marginal return in the biological transition. Accordingly, range management is continually concerned about the "trend in condition" of the range resources.

The requirements for information are broad. Detailed ecological analysis demands sampling the plant population on the basis of very small units, such as a few square yards. Yet the other extreme requires knowledge of plant, disaster, and livestock conditions for thousands of acres. There are great numbers of significant applications of remote sensing possible in supplying the desired information. The need for broad area coverage is particularly acute because of the urgent requirements for knowledge for decisions in management about areas that are expensive to view or investigate in other ways.

Depletion of the range is a major problem. Because of the nature of the climate combined with the innate habits of the range stock (both wild and domestic), depletion can occur rapidly over small and large areas of range resources. In addition, management requires dealing with complex biological cycles. with some parts of the cycle on an annual basis, some on a 3 to 5 year basis, and the ecological features of the range on perhaps a 50 to 100 year cycle. Additional unique situations arise in the policy areas affecting ranch management through zoring, unusual leasing and title arrangements, and in the compliance checking and controls necessary to insure those arrangements.

There is no question about the need for better information as a basis for obtaining more production of both wild and domestic range products. Of the three major types of industry considered in this report, range operation has shown fewer major steps in technological development than the other two. Many ranch operation practices have never changed and demand the same number of man-hours as they did 100 years ago. Rounding-up and branding cattle are sufficient examples.

It has been estimated that technology is available for increasing production from existing U.S. range resources by 70 to 100 percent. Of this increase, about 60 to 75 percent could come from better range operation, while the remaining 25 to 40 percent would be credited to improved stock and breeding. Remote sensing can play a major part in generating the increase of 60 to 75 percent in the production of range products by better range operation. In many other parts of the world, the opportunity for increases due to improved management of range land is several times that of the U.S.

There is sufficient demand for the increased production. The American Meat Institute has indicated that the demand, especially for beef products, is increasing much more rapidly than the supply. The increased demand is at least from two sources: increased population and increased individual purchase of beef products as a society becomes more affluent.

The production of wildlife is considered a range use, and although there are large parts of the country that produce wild game from farm and forest areas, the management practices involved resemble those of range management much more closely than either farm or forest management. The demand for wildlife has also shown pronounced increases in recent years. Estimates have been made by professional wildlife managers that 20 to 30 percent more wildlife could be harvested due solely to the use of better information for management. Some estimates go much higher.

Range applications of remote sensing are considered in terms of their applicability to policy, management, physical development, and disasters. There are many readily understandable examples of how information alone can become a major source of increased income to ranchers. Perhaps the best example is found in the use of remote sensing to monitor the carrying capacity of range land. Currently accepted management practices call for stocking range land to only 85 percent of its carrying capacity. With better knowledge of range conditions (as may be possible from remote sensing), the range could be stocked to 95 percent of its carrying capacity. The increase of over ten percent in production amounts to an annual increased value of production of hundreds of millions of dollars.

Other illustrations are based on the fact that the range country in all parts of the world is prone to disaster. Range land and its flora and fauna, is subject to floods, fires, wind, erosion, wild and human predators, insects, diseases, and a wide variation of climatic conditions. All of these are management problems requiring good information of conditions over large areas of relatively inaccessible land.

Other very useful information that would offer early rewards includes the location and management of water in range areas. Currently, less than half the amount desired, is available, and the ultimate control of stock numbers in range country often is the availability of water. Also, irrigation water is often stored or impounded from range areas, and more and more it is a necessity within the area itself. Present management practices call for large amounts of supplemental feeding, and the limiting factor on the carrying capacity of range land in many areas is the capacity to produce supplemental feed. A recent development in warmer climates is the intensive use of irrigated grazing land, allowing production at much higher rates per acre of land.

As a result of the lack of economic alternatives in much of the range country, success or failure of management practices has greater economic and social consequences than in agriculture, although, depending on the range resource, they may be quite similar to those in forest areas. It seems certain that the major improvements anticipated for range land use will create significant effects on the entire economy of the area.

One of the most valuable tools for range management that remote sensing could provide would be a more efficient means of mapping the ecology of the range. With better knowledge of the ecology of the resource, inappropriate expenses could be prevented. This will not be an easy task for remote sensing, but it should be undertaken. The heat sensors should be of major importance, especially in uses such as census taking, locating diseased stock, identifying unique forage areas, and assisting in round-ups. There are many direct applications to the physical development of ranch facilities as well. Estimates have been made that suggest this use could easily account for annual benefits of $5 per head of stock.

In the case of ecological mapping, remotely sensed information will be needed from lower altitudes than most forestry or agriculture applications, unless new techniques can be developed. The other applications could generally be from higher altitudes. There is unlikely to be as much demand for specific crop applications, but there will be greater demand for disaster applications. The frequency of cover will be more uniform than for farm applications, with large areas to be covered for estimation of range carrying capacity. Also, it will not be as effective to use sample areas for many range land applications, such as inventorying stock, as will be the case for crop purposes.

Of the three major areas of application, range management might easily benefit the most on a proportionate basis, mainly because there is so much room for improvement, and because so much of the management of range land depends primarily on the one product of remote sensing, information. The total value of benefits will be greater for farm or crop applications, but many of the range applications will likely be operational at an earlier date.

There will be some efficiency gained in the related secondary industries, but not nearly to the extent estimated for the farm sector of agricultural production. The quality of range stock production is not expected to be affected to as great an extent as is anticipated for agricultural crops. Instead, the benefits to range management will be in the form of lower costs of production and a much larger volume of production from existing resources.

PART FIVE

APPLICATIONS

The following tables contain lists of selected applications for which there appears to be a probability of financial reward. Many other applications were considered but did not show sufficient promise of benefits to warrant attempts at further analysis at this time.

The tables indicate whether the application was suggested from activities already carried out, from management or research-oriented people, or from personnel working on the project. The second column generally indicates at least one U.S.D.A. agency that would be expected to be concerned with the particular application considered. In many cases there are other agencies that have, or will develop, an interest in the application.

The dollar estimates are based on anticipated annual gross returns to resources through both savings and improvements. Whenever possible, the estimates are supported by published data of various agencies of the U.S.D.A. Other sources also have been used. Estimates of dollar benefits have not been attempted for a number of the applications because it was not possible to find any source of dollar values to use as a base. In many other instances the estimates are based on judgments of staff members. The benefits listed for applications on a world basis have been held to very low levels because of the extreme uncertainty of their being carried out and the lack of supporting figures. In most cases the world benefits are based on data similar to those used for the U.S. benefits.

Certain assumptions had to be made in order to generate figures for savings and improvements of practically all applications listed. Basic assumptions applied primarily in relation to economic considerations included:

1. That any presently information procurement and dissemination activity is worth the cost incurred.
2. That information obtained from remote sensing will be used.
3. That benefits can be derived from savings and/or improvements.
4. That there is a need (domestic and world-wide) for increase(production of food and fiber.
5. That the reduction of land, labor, and capital necessary for production of supplies of food and fiber constitutes a benefit.
6. That the value of savings and/or improvements generated through the use of remote sensing will be applied to gross benefits.

There are other costs and benefits that could be establishe(and these figures also could be based on figures published by various government agencies. The figures presented here indicate at least the magnitude of the potential values, and they are usually supported by data. Obviously, many of the applications may have greater values, while some may be overvalued.

It should be made clear that the values, where indicated, cannot be summed to obtain a total gross benefit to agriculture from remote sensing. There is overlap of applications among the three resource areas, and no values can yet be stated for many of the applications. In many instances one application would provide the information considered as a separate application in other instances. Thus a complete land resources inventory might fulfill many of the requirements listed separately in the following tables. Also, as indicated in Part Three, complete economic analysis will require specification of operation/sensor packages, data dissemination procedures, and exact applications to be considered. In addition, much more detailed examination of potential cost-savings and improvements will be required. The figures here are simply a first approximation of gross benefits derivable from applications of remote sensing.

Experts were consulted in many fields of study where applications showed promise of value. Their judgments were relied upon in making estimates of the value of savings and improvements. Their opinions were offered under circumstances that do not fairly permit them to be quoted. Backup material based on notes made during discussions with the experts has been prepared and is on file.

This report considered a large number of applications in relation to the production of food and fiber. The project was carried out at the request of the U.S.D.A., but this should not be construed to mean that the applications considered would be of benefit only to agencies of the U.S.D.A. There are many other departments, especially the U.S. Department of Interior, the U.S. Department of Health, Education, and Welfare, and the

U.S. Department of Housing and Urban Development, that would find sources of benefits from many of the applications listed.

Table I. Agricultural Applications

Estimates of annual gross benefits of remote sensing to agriculture, based on value of savings and/or improvements.

N = no source of estimate available

P = based on project staff judgment

H = supported by published information or from experts in the field.

* = no estimate of savings or improvements attempted.

The values estimated are based on anticipated savings and/or improvements. They were established on a unit basis, and then multiplied to represent the sum of all units within the industry. World benefits, when claimed, were generally calculated on the basis of values assigned for the U.S., with the unit value of benefits reduced.

Disaster Applications	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
1. Flood control planning	H	SCS ERS	*	*
2. Flood damage evaluation	H	SCS ASCS FCIC	*	*
3. Evaluation of storm damages	P	ASCS FCIC	30	120
4. Drought prediction systems	P	ARS	200	600
5. Air pollution control	H	ARS	500	1,000
6. Epidemic analysis and mapping	P&H	ARS	500	1,500
7. Control of wildlife habitat	P	---	10	*
8. Weed control	H	ARS	885	2,400
9. Famine control	P	CCC	56	*
10. Disease damage assessment & control	H	ARS	1,659	4,000
11. Insect damage assessment & control	H	ARS	2,000	6,000
12. Evaluation of damage to ornamentals	H	ARS	400	*
13. Water pollution control	N	ARS	*	*
14. Identification of perimeter areas of nematode infections	N	ARS	*	*
15. Survey of damage from wildlife browse	N	---	*	*
16. Census of non-crop weed areas	H	ARS	50	*
17. Conservation needs inventory	H	SCS	*	*
18. Disaster warning	H	---	200	600

Resource Evaluation Applications	Source of Esti-mates	Interested USDA Agency	Annual U.S. Benefits (Millions	Annual World Benefits of Dollars)
19. Soil mapping (improvements)	H	SCS	863	5,000
20. Soil mapping (savings)	H	SCS	10	30
21. Analysis of soil deficiencies	H	SCS	125	375
22. Resource evaluation	H	SCS	4	*
23. Recreation resource analysis and development	N	ERS SCS	*	*
24. Watershed planning and control	H	SCS	*	*
25. Evaluation of applications of new technology	P	ERS	10	*
26. Topographic studies	N	----	*	*
27. Detailed plane leveling for intensive cropping	P	SCS	125	*
28. Erosion hazard analysis	H	SCS	500	*
29. Irrigation needs inventory	P	ERS SCS	250	1,000
30. Plant ecology analysis	N	----	*	*
31. Detection of salinity & other special soil features	P	ARS SCS	100	*
32. Seasonality studies of growth rates	N	ARS	*	*
33. Recreation site evaluation	P	SCS	10	*
34. Surveillance of algae and aquatic weed plant growth	H	ARS	15	*
35. Bird cover and habitat analysis	P	ARS	100	300

Resource Evaluation Applications (Cont.)	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
36. Detection of areas of unusual plant growth	P	ARS	100	500
37. Water impoundment area studies	H	SCS	5	*
38. Runoff and seepage analysis	H	SCS	500	*
39. Sedimentation studies	H	SCS	1	*
40. Water quality evaluation	N	ARS	*	*
41. Climatic analysis	N	---	*	*
42. Agricultural geography	N	---	*	*
43. Crop inventories	N	SRS	*	*
44. Census applications	H	SRS	1	*
45. Drainage planning	H	SCS	2	*
46. Calculation of discharge capacity of valleys	P	SCS	10	*

Agricultural Policy Applications	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
47. Land classification	H	ERS	12	40
48. Land cover mapping	H	----	14	*
49. Tax assessment mapping	H	----	82	*
50. Ownership mapping (see plat mapping)		----	*	*
51. Nuisance mapping	N	----	*	*
52. Compliance control mapping	H	ASCS	13	*
53. Regional planning and development	H	ERS	2	*
54. Sequential urban agricultural contact analysis	P	ERS	2	*
55. Watershed development studies	H	ERS	10	*
56. Agricultural --Sociological applications	H	ERS	2	*
57. Rural & suburban zoning	P	ERS	5	*
58. Rural area development	H	RCDS	1	*
59. Land use comparison and trends	H	ERS	6	*
60. Market needs surveys	N	C&MS	*	*
61. Plat mapping	H	----	150	300
62. Population density maps	N	----	*	*
63. Adjudication	N	OIG	*	*
64. Highway route planning	P	----	1	*
65. Mapping world agricultural land area	P	FAS	*	*

Agricultural Management Applications	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
66. Crop prediction and inventory	P	SRS	*	*
67. Analysis of planting dates	H	ARS	*	*
68. Harvest production information	H	SRS	*	*
69. Transpiration analysis	P	ARS	*	*
70. Site classifications	P	SCS	10	
71. Predetermination of irrigation requirements	H	ARS	1,190	3,000
72. Control of transportation of irrigation water	H	SCS	890	3,000
73. Capital needs mapping	P	ERS	10	*
74. Field patterns and organizations analysis	N	----	*	*
75. Water supply location	P	SCS	50	*
76. Farm practices analysis	P	ERS	5	*
77. Commercial farm field layout	P	SCS	180	500
78. Tree crop area census	P	SRS	*	*
79. Intensive localized uses (egg counts, livestock disease identification, etc.)	P	ARS	200	*
80. Water-borne and water-related insect control	P	ARS	50	*
81. Large area landscape planning	N	----	*	*
82. Domestic animal census	N	SRS	*	*
83. Farm building layout studies	P	----	125	400

Agricultural Management Applications (Cont.)	Source of Esti-mates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
84. Census of land improvements	H	---	50	*
85. Location of structural materials	N		*	*
86. Mechanization feasibility studies	N	---	*	*
87. Rural road maintenance	H	---	140	500
88. Locating disease and insect resistant species	N	ARS	*	*
89. Controlling spread of noxious plants	N	ARS	*	*
90. Prediction for processing industry	H	SRS	375	*
91. Forecasting climatic changes	P	---	100	300
92. Reduction of losses from misuse of insecticides, fungicides, etc.	H	---	35	*
93. Detecting heat in storage	N	---	*	*
94. Inventory of grain storage	N	CCC	*	*
95. Livestock disease identification	H	ARS	750	3,000
96. Predetermination of egg hatch-ability	N	---	*	*
97. Prevention of marketing losses of agricultural products	N	C&MS	*	*
98. Reduction of soil erosion losses from water and wind	H	SCS	400	*
99. Evapotranspiration control	N	ARS	*	*

Agricultural Management Applications (Cont.)	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
100. Off-shore temperature measurements	N	----	*	*
101. Scheduling field crop storage & processing	P	----	160	*
Miscellaneous Applications in Agriculture				
102. Rural roads--Maintenance & construction	H	---	*	15,000
103. Educational uses of remote sensing	N	----	*	*
104. Operation of World Food Budget	N	ERS	*	*
105. Integrated transportation systems in developing agricultural economies	N	IADS		*
106. Recording agricultural history	N	---	*	*
107. Planning cultural development projects	N	---	*	*
108. Sample design	P	SRS	1	10
109. Publication uses	N	SCS	*	*
110. Plant species exploration	N	ARS	*	*
111. Development of aquatic agriculture	N	ARS SCS	*	*
112. Weather prediction and modification	N	---	*	*

	Miscellaneous Applications in Agriculture (Cont.)	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
116.	Veterinary research--based on heat sensors	N	ARS	*	*
117.	Selective breeding of stock	N	ARS	*	*

Table II. Forestry Applications

Estimates of Annual gross benefits of remote sensing to forestry based on value of savings and/or improvements.

N = no source of estimate available.

P = based on project staff judgment.

H = supported by published information or from experts in the field.

* = no estimate of savings or improvements attempted.

The values estimated are based on anticipated savings and/or improvements. They were established on a unit basis, and then multiplied to represent the sum of all units within the industry. World benefits, when claimed, were generally calculated on the basis of values assigned for the U.S., with the unit value of benefits reduced.

Forestry Policy Applications	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
1. Assembly of historical records	N	FS	*	*
2. Water pollution control--related to forestry	P	FS, SCS ARS	1	10
3. Forest areas evaluation --for purchase, exchange, etc.	P	FS	3	*
4. Transportation planning	N	FS	*	*
5. Cadastral applications	H	FS	*	*
6. Evaluating sociological aspects of economic development	N	ERS	*	*
7. Wildlife management	N	FS, SCS	*	*
8. Watershed analysis and control programs	P	FS, SCS	1	*
9. Ownership mapping	N	FS	*	*
10. Tax mapping and evaluation	H	FS	8	8
11. Evaluation of change in land use	P	FS, ERS	3	*
12. Mapping forest areas	N	FS	*	*
13. Compliance investigation and control	H	FS	2	*
Forest Resource Applications				
14. Forest land use survey	P	FS, ERS	7	98
15. Forest soil survey	H	FS, SCS	98	300
16. Forest inventory	H	FS	9	125

Forest Resource Applications (Cont.)	Source of Esti-mates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
17. Recreational resource evaluation	N	FS,ERS	*	*
18. Forest site classification	H	FS	10	150
19. Forest mensuration	N	FS	*	*
20. Forest ecology classification	N	FS	*	*
21. Fish habitat classification	H	FS,SCS	300	*
22. Fish Inventory	N	FS,SCS	*	*
23. Heat classification of plantation sites	P	FS	20	*
24. Stream pollution analysis	P	FS,SCS ARS	*	*
25. Snow depth measurement (included in agriculture)		FS,SCS		
26. Studies of near-tundra areas	N		*	*
27. Valley discharge analysis	H	FS,SCS	*	*
28. River basin planning	H	FS,SCS	*	*
29. Scenic area evaluation	N	FS,ERS	*	*
30. Planning vegetative types for game production	P	FS	5	50
31. Documentation of climate	N	FS,ARS	*	*
32. Offshore temperature analysis	N	FS	*	*
33. Mapping mineral-deficient & toxic areas	N	FS,ARS	*	*
34. Land use inventory	H	FS,ERS	3	39

	Forest Management Applications	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
35.	Forest cover mapping	H	FS,ERS	3	39
36.	Site evaluation for reforestation	H	FS	6	*
37.	Accessibility rating	P	FS	*	*
38.	Delineation of disaster-prone areas	P	FS	20	*
39.	Topographic evaluation	P	FS	2	*
40.	Engineering aspects--roads, mill sites, etc.	P	FS	*	*
41.	Inventory of disease and insect damage	H	FS ARS	150	2,000
42.	Control of harvest operations	P	FS	*	*
43.	Location and design of tree windbreaks	P	FS	10	100
44.	Recording mist levels	N	FS,ARS	*	*
45.	Mist level as indicator for spray programs	N	FS ERS	*	*
46.	Measurement of recreational use	N	FS ERS	*	*
47.	Stream flow control	N	FS	*	*
48.	Locating desirable seed sources	N	FS ARS	*	*
49.	Inventorying harvest of specialty products	P	FS,ERS CMS	*	*
50.	Location of recreational use sites	N	FS ERS	*	*
51.	Maximization of recreational use	N	FS ERS	*	*
52.	Location of major disturbance uses, such as pipe lines	N	FS	*	*

Forest Disaster Applications	Source of Esti- mates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
53. Fire detection	H	FS	120	*
54. Inventorying fire damaged areas	H	FS	39	*
55. Studying patterns & forms of fires	N	FS	*	*
56. Directing fire con- trol work	N	FS	*	*
57. Tracking thunderstorms (covered under fire de- tection)		FS		
58. Evaluation of combus- tion levels (predeter- mination of fire hazard)	N	FS	*	*
59. Location and evalu- ation of insect damaged areas	H	FS	60	*
60. Location and evalu- tion of erosion areas	P	FS SCS	*	*
61. Evaluation of storm damage	P	FS	50	*
62. Disease detection, sal- vage and control	H	FS	50	*
63. Air pollution damage evaluation and control	H	FS ARS	20	*
64. Location and evalu- ation of wildlife browse	N	FS	*	*
65. Analysis of areas of specialized control	P	FS	14	*
66. Location and evalua- tion of parasitic plants	P	FS	1	*
67. Delineation of sites for restocking	H	FS	28	*

Forest Disaster Applications (Cont.)	Source of Esti-mates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
68. Studying relationships between forest areas & climate	N	FS	*	*
69. Detection of diseases and insects at critical points	P	FS	*	*
70. Monitoring volcanic activity	N		*	*
71. Search & rescue operations	P	FS	*	*

Table III. Range Land Applications

Estimates of annual gross benefits of remote sensing to range land, based on value of savings and/or improvements.

N = no source of estimate available.

P = based on project staff judgment.

H = supported by published information or from experts in the field.

* = no estimate of savings or improvements attempted.

The values estimated are based on anticipated savings and/or improvements. They were established on a unit basis, and then multiplied to represent the sum of all units within the industry. World benefits, when claimed, were generally calculated on the basis of values assigned for the U.S., with the unit value of benefits reduced.

	Range Resource Applications	Source of Esti-mates	Interested USDA Agency	Annual U.S. Benefits (Millions	Annual World Benefits of Dollars)
1.	Range land classification	H	SCS,FS	8	40
2.	Area inventory	H	SCS,FS ASCS	25	250
3.	Locating irrigable areas	H	SCS	1,500	10,000
4.	Running inventory of range	H	SCS,FS	4	40
5.	Livestock inventory	H	SCS,FS	130	1,000
6.	Delineating crop production areas	N	SCS,FS	*	*
7.	Monitoring shifts in land use	N	ERS,FS SCS	*	*
8.	Reconnaissance soil surveys	H	SCS	15	150
9.	Soil classification	H	SCS	220	25,000
10.	Soil salinity analysis	P	SCS	10	100
11.	Estimating range carrying capacity	H	FS,SCS	500	5,000
12.	Analysis of soil moisture conditions	N	SCS	*	*
13.	Compliance control	H	ASCS,FS		
14.	Providing census information	N	SRS	*	*
15.	Providing hydrologic information	N	FS,SCS	*	*
16.	Range resource inventory	P	ERS,FS SCS	10	100
17.	Conservation needs inventory	N	SCS	*	*
18.	Plat mapping of ranches	N	---	*	*
19.	Boundary identification	P	ERS	5	*

	Range Resource Applications (Cont.)	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
20.	Mapping global range areas	H	---	*	*
21.	Estimating ultimate yield potential	H	SCS,FS	*	*
22.	Determination of trend in condition	P	SCS,FS	10	100
23.	Improving weather forecasting	P	---	20	200
24.	Wildlife inventory	H	FS,SCS	75	*
25.	Mapping areas of mineral imbalance	P	SCS	10	*
26.	Mapping vegetative zones	N	---	*	*
27.	Mapping cover and condition	P	FS	*	*
28.	Identifying areas of high response to inputs	N	ERS	*	*
29.	Evaluating tundra range	H	---	*	300
30.	Identifying areas of high oxygen consumption	N	ARS	*	*
31.	Monitoring soil moisture utilization	N	ARS,SCS	*	*
32.	Monitoring feedlot and marketing activities	N	CMS	*	*
33.	Assessing plant population changes	P	ARS	6	50
34.	Classifying the ecology of plant populations	N	ARS,SCS	*	*
35.	Wildlife habitat studies	P	FS,SCS ASCS	50	250
36.	Quantitative and qualitative improvement of water supplies	N	SCS	*	*

Range Resource Applications (Cont.)	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions	Annual World Benefits of Dollars)
37. Mapping biomes	N	---	*	*
Range Land Hazards				
38. Locating and mapping disaster areas	P	ASCS	50	250
39. Locating and controling insect epidemics	H	ARS,FS	160	800
40. Detecting diseased livestock	H	ARS	90	500
41. Locating and controling plant diseases	H	ARS,FS	23	120
42. Fire control	N	FS	*	*
43. Controling noxious plants	P	ARS	4	40
44. Rodent and predator control	N	ARS	*	*
45. Weather modification	P	---	1,000	10,000
46. Locating and monitoring air pollution	N	ARS	*	*
Range Management Applications				
47. Locating temporary grazing areas	H	FS,SCS	110	1,000
48. Selecting wintering areas	H	FS,SCS	55	*
49. Detecting loss of crop vigor	H	FS,SCS	55	*
50. Planning physical setting of ranch facilities	H	FS,SCS	350	*

Range Management Applications (Cont.)	Source of Estimates	Interested USDA Agency	Annual U.S. Benefits (Millions of Dollars)	Annual World Benefits (Millions of Dollars)
51. Grazing cover enhancement	P	SCS	300	1,500
52. Overgrazing and compaction	N	SCS	*	*
53. Management of range stock movement	P	---	50	250
54. Integrated pasture use and development programs	N	---	*	*
55. Determining land trafficability for range use	N	---	*	*
56. Stock handling and transportation development	N	---	*	500
57. Assessing maintenance needs of facilities	H	---	4	*
58. Evaluating compatability of stock to range	N	SCS,FS	*	*
59. Locating special use areas	P	SCS,FS	10	*
60. Financial reliability mapping	N	ERS	*	*
61. Measuring of light intensity (ecology)	N	ARS	*	*
62. Wildlife research	N	FS,SCS	*	*
63. Analysis of sand (and surface) movement	N	---	*	*
Policy Applications				
64. Land use inventory	P	ERS	6	50
65. Planning	P	All	2	10

Range Policy Applications (Cont.)	Source of Esti-mates	Interested USDA Agency	Annual U.S. Benefits	Annual World Benefits
			(Millions	of Dollars)
66. Analysis of range development potential	N	FS,SCS	*	*
67. Tax base mapping	H	---	*	*
68. Legal aspects - adjudi-cation, etc.	N	FS,OIG	*	*
69. Economic classification	H	ERS	1	*
70. Irrigation resource analysis	H	SCS	*	*
71. Utility planning and development	P	REA	1	10
Miscellaneous Applications				
72. Identification of narcotic plants	N	ARS	*	*

PART SIX

UNUSUALLY PROMISING APPLICATIONS

In developing the lists of applications of remote sensing information for this report, we were impressed by a small number of uses that are, or soon will be, feasible which offer unusual promise of truly great benefits on a world-wide basis. These applications are of greater than ordinary significance because of their effect on human suffering, economic development, or because they promise outstanding beneficial returns in relation to the cost of the problems involved.

The following areas of application appear to have possible benefits that would qualify them uniquely as of outstanding significance to the well-being of man:

1. Resource evaluation and planning
2. Rural transportation development
3. World food budget
4. Educational applications
5. Soil classification and mapping
6. Disaster applications
7. Discovery of new species of economic plants with tolerance or resistance to diseases and insects
8. Medical research, through applications to unique problems in fields of veterinary medicine

Resource Evaluation and Planning

As population increases, and as the demand for goods makes scarce commodities out of resources that were once plentiful. the need for constantly improving evaluation and planning for the use of our resources has become imperative. The area of the world that produces most of our food and fiber amounts to about 7 percent of the land area. Seventy percent of the land is considered non-agricultural, while the remaining 23 percent is used at varying degrees of intensity for pasture and range.

The most important single long-range use for remote sensing is in planning the use of the earth's resources. Remote sensing offers unique capabilities for planning purposes. It is inexpensive, readily available, can be used at frequent intervals, is unbiased, and allows equal access to all parts of the world. It has not been possible to find any source indicating the value of planning, but it is obvious that we are rapidly approaching the time when much more attention must be paid to planning. Simply to inventory the world's natural resources by traditional methods would be so time-consuming that reports when published would be essentially meaningless. Yet there is hope that remote sensing could accomplish this job quite routinely. If the information can be acquired by remote sensing, then it becomes possible to plan for the wise use of resources on a scale broader than national in scope. Ultimately, a world-wide scale may become feasible.

As a result of the degree of technical competence in remote sensing anticipated for the near future, resource evaluation and planning on a continental or world-wide basis should be a feasible application within the next quarter century. The availability of such information should lead us to the most worthwhile use of remote sensing that man could undertake, the evaluation and planning of the use of the world's resources.

A multi-purpose resource survey of New York State is currently being carried out at a cost of about $2.50 per square mile. Presumably, automated data processing should cut this cost. A world figure for initial information might be $1.50 per square mile. For the forested, range, and arable land areas of the world at an estimated total cost of from $45 million to $60 million (plus cost of photo acquisition), an inventory could be carried out in very great detail compared with any resource inventory now available. For parts of the world it would be desirable to have frequent re-surveys. In this manner a running inventory of earth resources could be maintained.

Rural Transportation Development

The development of rural transportation is an area of capital input that has been evaluated by many economic studies. The term means different things to different people. In the U.S. and Canada it means year-round farm to market roads. In most areas of the world it means simply a road "of sorts" that connects a village to the outside world.

There are those such as William and Paul Paddock, (Hungry Nations, Little, Brown & Co., 1964) who argue against the importance of rural roads. But their arguments, although in part justified cannot stand entirely against the need for roads in developing economies. The kinds of roads that often could be most useful need not be of a quality much above a jeep trail. The world needs many thousands of miles of such roads.

Information on vehicles (Russia, China, and certain other Communist countries excluded) indicates that the number is increasing rapidly throughout the world, although the U.S. still reports more than half the cars, trucks, and buses inventoried. In 1960 the number in the U.S. was 73,868,000 vehicles and for the rest of the world, 43,359,000 vehicles. Comparable figures for 1966 were 94,179,000 in the U.S. and 86,830,000 for the rest of the world reported. The rate of increase of vehicles is rapid, but the development of road mileage is not taking place at comparable rates.

Remote sensing could be a major asset in aiding the development of transportation systems in developing countries. Although it is of value in countries already economically advanced, it would have much more significant value in developing economies. Even the most conservative estimates indicate that the use of remote sensing for locating new roads, and for engineering and maintenance purposes, would save 10 percent of the construction costs in highly developed countries, while other estimates indicate savings of 50 percent (which can result in twice as much mileage constructed for the same funds) in the developing countries of the world. When we consider that the expenditures for roads in the free world outside the U.S. amounted to an estimated $13.6 billion (U.S.) dollars in 1966, even a 10 percent improvement becomes a $1.4 billion direct benefit.

There are other major considerations. The construction of roads as a government capital investment is one of the few cases where the multiplier effect has been clearly identified. Economic studies have revealed that even low quality single-lane roads can account for increases in production and reductions in marketing and transportation costs amounting to several times the cost of the road annually. In addition, there is documented evidence that by using self-help methods of building feeder roads, benefits--in terms of miles of roads constructed--can be nearly tripled. If these conditions hold, then the $1.4 billion direct benefit of remote sensing applied to roads could amount to a multiplied benefit of $9 to $10 billion annually. These are only the estimates based on minimum benefits. There are numerous studies that show benefits of three hundred percent or better from production in areas where new roads are opened. Other benefits, not measured in dollars, also are numerous. Thus if we considered the possibility that road expenditures might generate values at two to three hundred percent of their cost in developing economies, we could claim benefits annually of several times those stated above.

Since much of the world is still considered to be in the process of economic development, and in considering the great need for even the simplest road to allow the marketing of agricultural and other resource products, the use of remote sensing for development of better transportation systems is undoubtedly one of great potential benefits to the world.

It may be argued that the Department of Agriculture is not in the business of building roads. It can also be argued that it probably should be very much interested in encouraging the development of roads, especially in programs to assist economically developing countries of the world. The following table compares the miles of roads of varying classes for the U.S. and countries of the non-communist world that reported mileage for 1966.

Miles of Various Classes of Roads Reported by the U.S. and Countries of the Free World, 1966.

	Paved Roads (miles)	Gravel or Stabilized Surface (miles)	Earth-Graded or Drained (miles)	Unimproved (miles)	Total (miles)
U.S.	1,454,600	1,321,457	448,365	449,984	3,689,666
Percent	39.4	35.8	12.2	12.6	100.0
Rest of World	1,680,534	1,365,150	1,843,129	1,449,984	6,338,697
Percent	26.5	21.5	29.1	22.9	100.0

Source: Available on request.

The World Food Budget

It has long been the hope of many that the time would come when information on crop conditions could be obtained in time to allow the transfer of food from surplus to deficit areas of the world. With the capabilities anticipated for the near future in the field of remote sensing, we now can start work on developing technical ability to operate a world food budget.

The dollar rewards of such a program could be estimated, based on the current costs of transporting food into deficit areas and distributing it to those in need. But the dollar benefits seem of minor importance in this instance, for the true reward would be the alleviation of human suffering.

The task of developing an operational world food budget is not as great as one could expect. The difference between surplus and deficit is realistically small and manageable on a world basis. Most frequent deficit areas are already known, as are surplus areas. The operation could be established initially using high-altitude aircraft and developed to the point of being operational by the time remote sensing from satellites is operational.

Preliminary work could be carried out on the basis of sample areas, using information of planting dates and subsequent climatic and growth conditions as the basis for forewarning of shortages or surpluses. From this, patterns of expected demand should be forthcoming, and also the location of surplus production. This information could be available in time to make the necessary decisions to have food available when needed in deficit areas.

Educational Applications

The use of various forms of remote sensing as educational tools has been almost completely overlooked by most nations of the world. The best example of the application of remote sensing as a regular part of the school teaching program was found in Ontario, Canada, and the original work was started by Mr. Barry Sully in Arnprior.

This application could make it possible for any school science class to study the earth's resources for any part of the world. A great number of approaches appear feasible. Using air photos for analysis of socio-economic patterns; learning how to do census counts and locating, mapping, and evaluating forest resources are but a few possibilities. Comparable applications should be forthcoming when applied to outer space as well.

In addition, the development of appropriate teaching techniques for assistance to developing countries could prove a major aid in increasing the rate of economic development.

If remote sensors can produce the kinds of information expected of them, then it is not out of order to anticipate various ways of putting that information to use. There needs to be a thorough study of how information obtained by remote sensors can be used for educational purposes. This could be an activity of the Department of Agriculture, for its most likely application would be in the agriculturally developing countries of the world.

A first step toward implementing this work would be a survey of the educational requirements of various groups and analysis of the fulfillment of such requirements through applications based on remote sensing.

Soil Classification and Mapping

There are two major sources of benefits from remote sensing in relation to soil classification and mapping. One is the greatly reduced cost of making the maps, and the other is the value of soil map information to the users. Few of the world's agricultural areas have soil maps suitable for use in planning or management of agricultural activities.

For the U.S. direct annual savings of costs in producing maps (based on a 25 year cycle of survey) amounted to an annual saving of $10,250,000 for the 50 states. With annual benefits from the use of soil maps calculated at the nominal values of $5/acre for irrigated land, $1/acre for nonirrigated farmland and $0.15/acre for range land and woodland, the conservative benefit for the 50 U.S. state is $863,589,000 annually. The value of cost-savings in producing soil maps and benefits from the use of soil maps is about $874 million annually.

If similar figures are applied to the world agricultural areas, the use benefits alone would amount to $7.1 billions annually. This is based on annual values of $5 per acre for 285 million acres of irrigated land, $1 per acre for 3,205 million acres of arable land and $0.15 per acre for 16,398 million acres of forest and range land. This does not take into account any of the secondary benefits to be expected. Nor does this estimation consider the possible feasibility of future soil maps being made more accurately from remote sensing and with far less field work than is now the case.

Soil mapping is one of the great uses of remote sensing, and the far-reaching benefits are only partially measured in dollar terms. None of the secondary values were included here, but they would be substantial.

Applications Relative to Disaster Problems

Disasters in agriculture develop from many causes, not all of which can be adjusted. Better information could play a major part in many types of disaster situations, from search and rescue operations to control of livestock epidemics.

Assessing damage to crops from weather, climatic variability, disease, insects, or wildlife migration evaluation of flood damage monitoring thermal activity of volcanoes with histories of eruptions fire control, earthquake damage evaluation, limiting disease epidemics, correcting pollution problems, and many more all come under the broad listing of disaster-related activities for which more information would be useful.

No figures are available on the total cost of disasters to the world, nor are there estimates of the potential dollar value of better information about disasters. There seems to be no adequate approach to identifying values for these uses. However, disaster applications, according to our best considerations, are one of the most rewarding possible uses for remote sensing.

Detection of Economic Plants Resistant to Disease and Insect Damage

One of the unique capabilities of remote sensors is the ability to locate areas of economic crops affected by plant diseases and/or insect damage. The corollary situation is the ability to select areas of economic plants that do not show the effects of attacks by disease or insects. This ability leads to the use of remote sensing to select plant breeding stock from disease-free areas or, more significantly, to select strains of species that have natural immunity to diseases or insects.

If, for example, a major breakthrough such as locating a disease-free strain of rice, wheat, soybeans or peanuts could be credited to remote sensing, it would have major annual benefits. It is important to identify diseases. But it is more important to find plant species that do not have diseases. This could easily be the most important single application for agricultural use. It could offer major increases in yields and relief of population pressure on the land and could develop major economic consequences in many parts of the world.

Diseases of major field crops accounted for annual losses to U.S. agriculture of close to $2 billion in 1951-1960. Losses to alfalfa and hay plants were similarly estimated at about $615 million, and other disease losses to economic plants amounted to an additional $961 million. Not all of these losses could be avoided but the effect of finding a disease-free strain of wheat for example, could create annual savings from losses due to that cause of over $300 million. Considering that the U.S. produced only about 15 percent of the world's production of 8,987 million bushels in 1965, a comparable annual benefit on a world basis could amount to $2 billion for this one crop. Certain other crops (rice, for example) offer even more dramatic possibilities.

Veterinary Medicine Research

One of the very valuable, unique capabilities among the many types of remote sensing is the ability to measure heat or temperature to very narrowly-defined levels. The possible use of this capability with regard to range cattle and wildlife is obvious and is often mentioned. But other uses are of much greater long-range significance.

Since our definition of remote includes very short distances (of only a few inches), the use of this capability could greatly change the results of medical research, especially where small laboratory animals are used. In addition, it is possible that early determination of illnesses in domestic stock could be done right on the farm. Also, new fields of research may be approached through the use of this sensor, such as pre-selection of sex in breeding domestic livestock.

Commercially beneficial uses of this sensor may include such things as identifying fertile eggs prior to incubation, evaluating energy output of various livestock feeds, identifying localized temperature changes on injured or diseased animals, or sexing of domestic commercial and research stock. If these applications prove feasible, it could effectively double the rate of improvement of domestic stock through existing breeding programs. Its use in major eradication programs should be tested. For example, would heat sensing prove an efficient means of implementing a nation-wide mastitis control program?

There is one major use of this sensor, however, that could lead to major improvements in veterinary and medical research that would prove directly beneficial to all mankind. One of the major problems of conducting medical research is that of obtaining non-infected small animals for laboratory purposes. It is not possible adequately to test the health of individual laboratory mice, for example. As a result, research data is often confused or its accuracy diluted by the fact that many of the test animals were simultaneously affected by other diseases. Research is slow and often misleading under such circumstances.

With extremely accurate heat sensors, it would be feasible to monitor populations of laboratory animals to determine their health condition prior to their use in research projects. To overcome this major restraint on success of our medical research programs would be a substantial breakthrough.

PART SEVEN

REMOTE SENSING OPERATIONS AND COSTS

I. Alternative Operations

It is seldom, if ever, that a single general solution proves adequate in developing the full potential of some broad methodology. It is not even reasonable to expect such an all-round capability. The gasoline engine, for example, is housed in many forms to develop its potential as a mover of goods, wares, and merchandise as well as passengers.

The propeller-driven aircraft likewise has proven less than adequate to develop the full potential of aerial reconnaissance. In the same manner we find that improved carriers such as the jet-powered aircraft and the satellite also have limitations as vehicles of surveillance.

Similarly, the conventional aerial camera does not develop the full potential of remote sensing. As a result, other sensors are being developed to complement and supplement the aerial camera and a full rounding-out of the remote sensing field is at least beginning. A remote sensing system is inevitable.

In examining the field of remote sensing it is therefore necessary to consider:

(1) the performance characteristics of the vehicles,

(2) the specific system controlling the capacity of each sensor, and

(3) the needs and uses for remote sensing data.

The cost and related returns are implicit in each.

Piston/Propeller Aircraft

The capabilities of conventional propeller-driven aircraft as vehicles for remote sensing are well known and need not be discussed in detail. Relatively speaking, they are extraordinarily slow and otherwise inefficient in performance, and they are costly to operate in terms of unit-area accomplishment. Their airframe configuration, susceptability to modification, and load factor are advantageous.

High-Performance Aircraft

Jet-powered aircraft overcome many of these disadvantages. It is a surprising fact that there is no known commercial use of jet aircraft in today's aerial survey operations. This appears to be partly related to the tax structure that favors low capital investment and minimization of high operating cost. Equally, there is today no market demand that will utilize the regional mobility and the high performance of these vehicles. The latter may change drastically with the assumption that regional, national, and perhaps international surveillance of our croplands and forests will be undertaken in the near future.

Spacecraft

The earth orbiting satellite as an agricultural surveillance vehicle introduces but does not guarantee up to 1975 the ability to sense at frequent intervals the productive capacity of the land. At the same time it introduces problems of sensor supply and retrieval of information that leap beyond the universe of airborne vehicles to create a totally new operational environment.

Although the weight and size of equipment are, today, among the strictest constraints, we can assume that ultimately this will become technically and economically feasible. Power and film, for example, require a constant and dependable supply. If manned, the satellite will also require supplies, crew exchange, etc. These too are predictably surmountable in the middle future.

The transmission of aquired data to ground stations for processing, conversion and distribution may take place in several ways. The physical relaying of film, for example, may appear cumbersome. But when we consider that twelve rolls of 9 x 9 aerial film will provide U.S. coverage it becomes less formidable and certainly given time, technically feasible. Telemetry in its various forms is less satisfactory as a method of imagery transmission. Telemetry introduces quality problems that seem today to offer inherent handicaps. It is here that a distinction between reconnaissance and detailed mapping becomes important. If we seek forest cover in terms of square miles, telemetry may offer the least-cost form of transmission. It is safe to say that telemetry will not now transmit imagery of a quality that will permit a tree count, tree typing or a disease survey, nor will small scale coverage that is the likely product of satellites through the 1975 span of this survey.

The earth orbiting satellite offers compensating characteristics as well. It does offer a fixed schedule that places the satellite over any given target (comparably sun-illuminated) at intervals of, say, 22 days. At the same time this becomes a rigidly inflexible schedule that cannot be accomodated to weather conditions. Thus, conceivably, we expose ourselves to the ancient law that says that if anything can go wrong it will. To achieve the benefits on which such a surveillance program must be based we find this inflexibility to be a major handicap. Light-dependent sensors, and especially those that seek a sun-illuminated target, are vulnerable. The more sophisticated versions of photography require a high degree of constancy and are therefore especially vulnerable to the incompatible combination of a fixed-cycle satellite and infinitely variable weather conditions.

It is clear that the single system satellite as a surveillance vehicle will not possess the capacity to achieve the rewards and benefits that would accrue to a balanced agricultural resources remote sensing program.

A well designed and carefully integrated system including spacecraft and aircraft can achieve the objectives of the agricultural program in the near future.

II. Conventional Programs of Aerial Photography

To serve as a basis for comparison, the present study examined the cost of executing surveys, comparable to that of the satellite program, by means of today's conventional aerial photography programs.

Certain limits to such a comparison are evident:

(1) We must assume that only photography is included in the comparison of satellite capability compared to the yield from conventional aircraft programs. No other remote

sensors have been used significantly in piston-propeller aircraft on a production basis.

(2) The agriculture "mission" of the space program diverges widely from that of the present day (ASCS) program.

(3) The scope of an enlarged conventional program is vastly greater than that of the basic program that has been in effect since 1936.

(4) The scale of photography, e.g., the number of prints per 100(square mile unit produced by each system will differ in a major degree.

(5) The system that utilizes the information provided by today's system will not be comparable to the system needed to assimilate and distribute information in the anticipated agricultural program.

The following comparisons are offered with these limitations in mind:

II.A. The Present Agricultural Aerial Photography Program

1. United States

In the United States there are nearly 478 million acres of cropland. In 1936 the USDA began an aerial photography program that was designed for the sole purpose of monitoring crop acreage, particularly those crops involved in price support programs. Today, this remains the chief purpose of the program.

Some 350 million acres are considered to be significantly active agriculture and these are rephotographed once each five to ten years. Consequently, in the cropland areas of this country, historical records of all areas are available on a maximum interval of ten years. Historically this may offer time-lapse photography but not in any way does it offer the benefits of intra-seasonal time-lapse or sequential photography inherent in the new programs that may be developed.

The scale of the conventional photography has been established at the ratio of 1:20,000. This scales to 1 inch = 1,660 feet or approximately 2.8 inches equal 1 mile. Stereoscopic coverage is provided which requires 60 percent overlap within flight lines. Fifteen percent overlap between flight lines assumes complete stereoscopic coverage.

These photographs are taken during the growing season, and, since the growing season is a function of latitude and altitude, some advantage accrues from the staggered time requirements that range from south to north and from east to west.

It should be recognized that the growing season and the period of optimum photographic conditions coincide. This fact exerts great influence on the feasibility of all agricultural surveillance programs.

The USDA through its ASCS program now spends more than $500,000 on its annual photographic surveys. The unit acquisition cost per square mile is about $2.00, which is almost one-half of the original 1936 cost of $4.00.

To accomplish total U.S. coverage annually--which would not achieve the full benefits available--would cost a maximum of $1,762,920. Reducing it to significantly active agriculture only would indicate a cost of $1,322,000. The present capacity of the industry both in terms of aircraft, supporting services, and personnel could not meet this demand.

During 1968 New York State proposes to acquire state-wide photography (50,000 square miles), and this is requiring an extraordinary effort to achieve some assurance of success. Matched against the nearly 750,000 square miles of U.S. cropland, the magnitude of the problem can be seen.

It is recognized that some lowering of the unit costs would be achieved on a long-run basis, but the capital costs would be so great that this cannot be justified for the purpose of establishing a base figure. Therefore, we will use the value of $1,322,000 as a base cost of once-a-year photography obtained by conventional means.

Once-a-year photography is insufficient to serve as a basis of comparison with the satellite program. To obtain the benefits accruing to a satellite program we make the basic assumption that the satellite can repeat coverage at no more than twenty-two day intervals. Within a 100-day growing season it would be possible to monitor the crop type and vigor at a minimum of three intervals. This would provide a reasonably adequate base for achieving maximum benefits.

To compete with a satellite program, conventional coverage would require an annual expenditure of $4 million for domestic cropland alone.

In addition, the FAO (Production Yearbook, 1960) estimates that there are 640,600,000 acres of forest land and 632,000,000 acres of rangeland and permanent pasture in the U.S. Together these approximate two million square miles of area. Because forestry has several special requirements for coverage, and with range land requirements equal to or less stringent than the ASCS standards currently used, we assume an average of $2.36 per square mile for these applications. Photographic coverage for these land use areas is needed less frequently. Photography of gross forest areas will be adequate if obtained once in five years. Active forest areas (amounting to perhaps ten percent) would be better served on a two-year interval. Range land changes are more rapid than those in forest areas, and an average three-year interval is considered appropriate.

The cost for recording quality and activity of forest and range lands of the U.S. by conventional means can be reasonably established at $1.3 million annually.

2. A World Program

Croplands

The FAO Production Yearbook, 1960, indicates that the world possesses 3,470,350,000 acres of arable land or 5,422,420 square miles. Disregarding political problems and operational difficulties, to photograph this only once would call for an astronomically large and expensive program. A conservative estimate that acknowledges the added costs of overseas operations is a rounded-off $27 million. The additional cost of providing data on crop yield would exceed $20 million dollars, for an annual total of $50 million.

Range and Pasture

The world devotes 6,347,900,000 acres to range and pasture uses. To photograph this area of 9.9 million square miles would cost $50 million. Spread across a ten year period this would amount to a $5 million per year effort. With such a time lapse a reasonably good world census could be obtained, and general capability data, soil surveys, and management practices could be approximated. To optimize the benefits to range and pasture, an initial three to four coverages across three seasons would be necessary, followed by perhaps two relatively closely-spaced coverages at the ten year interval. This would approximate the information needed in an agricultural surveillance program and would entail a commitment of $30 million per year.

Not only is this a physically impossible task but it should be noted that the unit cost comprises a substantial proportion of the value of the land being photographed.

Forestry

The earth's forest cover extends over 15,700,000 square miles. A large proportion of the forest is relatively unknown and/or inaccessible. Photography of appropriate scale is needed for general classification at least. Therefore, it is purposeless to obtain large scale coverage until an inventory can be made at a suitable scale. Subsequent photography at a larger scale may be practical. To obtain such coverage of the world's forest outside of the U.S. would cost in the range of $6.20 - $6.80 per square mile or nearly $100 million. (USAF costs are presently $12/square mile.)

The <u>initial</u> coverage of world agriculture, range, and forest excluding the U.S. would cost not less than $180 million. The physical problem of making the inventory with such photography dwarfs the initial cost. It should be recognized that directed photography* while possible from conventional aircraft is impractical for such large areas. The efficiency of satellite coverage is based upon the ability to record seasonal changes in the forest: blossoming, leaf fall, etc. Photography directed at the blossom time of specific trees records the enhanced image of those trees and therefore an automated count procedure is possible. Thus the two are scarcely comparable.

II.B. Conclusion

In summarizing the conventional agricultural surveillance program, it must be acknowledged that there is neither an aircraft capability nor a physical plant backup that could handle an expanded program in the near future. Given time and funds an effort of this magnitude could be mounted, but the unit costs could not be maintained.

The conventional system is efficient only in terms of the present market requirements. Throughout the world the era of large area photographic programs has passed, largely because planimetric and topographic mapping have been accomplished where it has been financially feasible to do so. The industry is largely keyed to large-scale, small-area surveys related to photogrammetric surveys. In rare instances there are indications of a revision in methodology--using photography for other than standard mapping purposes. An agricultural surveillance program differs so greatly in concept that, except for utilizing the same media for some of its data acquision, it has little in common with today's system.

*" Directed Photography--A Fourth Dimension in Aerial Photography' by D.J. Belcher, presented at ASP Annual Convention, Washington, D.C., 1960.

It must be considered that the use of current photographic methods would also degrade the economic basis of comparison. For example, the array of sensors planned for the agricultural surveillance program could not be mounted in the same aircraft carrying today's cameras. Current photography is usually obtained from a single engine aircraft or a small twin-engined type. These are deficient in both weight and cubic capacity.

The piston-propeller-driven aircraft is slow. It has a limited ability to reach a project area from its base of operation, thus it is greatly handicapped by its inability to take advantage of short periods of photographic weather. Further it can make comparatively little progress when its cruising speed is limited to the 130-160 knot range. For this reason the limited effectiveness of this aircraft requires a proportionally larger number of units to accomplish the stated mission. We assume a rational distribution of these aircraft within the cropland regions and an ability to shift base seasonally.

III. Intermediate Altitude Remote Sensing Operations

Except for military purposes, there are no jet-powered aircraft converted to remote sensing purposes. Propeller-driven aircraft lose time and efficiency in operating at high altitudes; as a result, 20,000 feet is an average maximum operational altitude and 10,000 to 15,000 feet is common. Short focal-length lenses, the 3-inch, for example, enable conventional aircraft to obtain small-scale (broad coverage) photography at these elevations. Thus, given adequate periods of good photographic weather, large areas can be photographed economically. However, except in dry regions, the weather, even in the growing season, does not endure dependably. The conventional aircraft centrally based requires so much time to reach the target area that it cannot acquire photography in brief periods of good weather.

The pure jet operating at some 600 knots can reach the target and accomplish on an average mission many times the coverage possible by today's system. Assuming both aircraft to be based at the same station, an open weather situation 200 miles away would indicate possible photography for both. If the clear area endured for three hours following the advisory, the jet would accomplish nearly ten times the coverage of the slower aircraft--roughly 1,250 line miles of coverage versus 150 line miles.

The pure jet operates economically at altitudes of 30 - 40,000 feet as opposed to the ordinary 12,000 of the present system. Since it accomplishes more at lower operating costs, the economics of the investment for the agricultural program seem highly advantageous.

Higher operational altitudes were studied but these offer few advantages and many disadvantages, especially in that non-conventional aircraft are required for such an altitude range.

III.A. A Domestic Program

Croplands

The 350 million acres of active cropland in the U.S. are expanded to approximately 600,000 square miles in our calculations because of the inevitable inclusion of border areas in this type of coverage. A wide range of estimates has been considered for unit costs in this category. Data from remote Canadian projects, large-scale overseas projects, and from professional commercial sources indicate that a program of this scope using jet aircraft on a more or less continuing basis, would achieve a unit cost as low as 25 cents per square mile. To avoid pressing for the lowest possible figure, we have selected the unit rate of 50 cents per square mile as realistic, readily defensible, and above the threshold of controversy.

At this rate, active cropland coverage on a once-a-year basis would cost not more than $300,000. To provide a 4 times (annual) coverage that would be equal to or better than satellite coverage, the cost would be $1,200,000 annually or somewhat less than the assumed once-a-year coverage by conventional aircraft.

Forests and Range Land

The inventory of U.S. forest lands on a once-over basis would cost $500,000. To develop an inventory of the forest based upon directed or time-sequence photography would require perhaps three coverages in the initial year. The benefits of this method of inventory appear to justify the multiple initial cost of $1.5 million. This modified forestry program is totally impractical with conventional aircraft, and its feasibility when totally dependent upon satellite timing of coverage is questionable.

Since forestry coverage would be spread over a five year period the annual commitment would be $300,000.

Range land in the U.S. also approximates 1 million square miles of area and $500,000 photographic costs. The assumption that one coverage in a three year span is adequate would require an annual expenditure of $167,000.

III.B. A World Program

The use of jet aircraft at intermediate altitudes in overseas programs raises the concept of agricultural surveillance into a practical realm. Lower fuel and maintenance costs are basic. A much wider range of operations permits these aircraft to be based at the more widely scattered airports where adequate maintenance support can be had and better weather information is available.

Two aircraft in India and three to four in South and Central America form a pattern of distribution. The annual climatic cycles offer an opportunity for a few aircraft to concentrate in important areas during the growing season, to move to, say, tropical forests and then, like migrant workers, to follow the harvest as it relates to the season.

A single great advantage in the use of such aircraft in the surveillance system is that they can be used selectively for those countries desiring such information, thus minimizing political conflict.

Croplands

The world estimates of cropland approximate 5.5 million square miles. This breaks down into a crop-type distribution in which principal crop areas are reasonably well defined. Overlooking adverse political situations the cost of this coverage annually would be $2.75 million. For a world inventory aimed at forecasting yield and delineating distress areas a three times coverage of the gross area (one less than U.S.

coverage because of more generalized requirements) would amount to $7.25 million. Under this type of program the agricultural surveillance system would inevitably convert to a one-time base coverage followed by sampling of type areas, thus reducing the annual cost to a small fraction, say $0.75 million.

Range and Pasture

Together range and pasture comprise nearly 10 million square miles· often they are contiguous in massive regions. Their value, relative to comparable areas that are more closely associated with transportation and the consumer market, is less. A sum considerably less than $5 million is indicated for the reconnaissance level of coverage: this, across a period of ten years for the major portion of the area, establishes a reasonable cost of $500,000 per year. Photography at special intervals and at larger scale where activity warrants is estimated (when combined with other photographic activity) to cost $300,000 or $100,000 per year, making a gross expenditure each year of $600,000 for a range land-pasture program.

Forests

The world's forest lands, comprising 15.7 million square miles, could be incorporated into a world-wide natural resources inventory that would constitute the initial objectives of the agricultural and counterpart programs. The cost of this over a ten-year period (interval) would be $750,000 annually, or an expenditure of $15.5 million each decade. As in the range land program more specific coverage will be needed in "active" areas. With this increment added, an annual cost of $1.2 million is forecast. In this computation, special photographic missions are considered necessary rather than, as in the case of range land, considering it feasible to gather the data in conjunction with other missions.

III.C. Conclusion

There are some distinct advantages inherent in this alternative remote sensor operation:

1. Selectivity related to area photographed, time of photography, and weather conditions. The cost of this operational method is low and its results suffer a minimum of dilution by non-useful coverage.

2. Its rate of accomplishment is impressive. One jet aircraft could obtain U.S. cropland coverage in about 25 days. This does not approach the satellite gain under nearly ideal conditions in which 4 passes would approach total coverage. However, one cannot abort a launched satellite because of intervening unfavorable weather.

3. The economics of this method are at present highly favorable, especially on the domestic scene and for realization of some important benefits.

4. Sensor load capacity, in-flight maintenance, film type flexibility, film recovery and re-use of equipment for future missions are inherent advantages. Virtually any sensor known today can be carried in these aircraft.

IV. Satellite Photographic Operations

Cameras will be used in the EROS mission and in at least one of the missions of the Apollo program to record data suitable for use in the agriculture program. These, obviously, are trial missions, and yet they give realistic material on which to base specific agricultural missions. They also provide the only basis for cost estimates of data acquisition.

It is reported by NASA that a total mission cost will be $15 million: this equals the total cost of the data acquired. The benefits from such a mission must be based wholly upon the data thus acquired in the lifetime of the satellite.

A satellite, equipped with one 12-inch (f.l.) camera can photograph 9 million square miles from a 125 n.m. altitude. This would be daylight photography regardless of weather. Depending upon the season we can expect various degrees of cloud cover. During the growing season 100 percent cloud-free coverage may be acquired at a cost of approximately $1.85 per square mile or about $1.72 for useful coverage. In this program we would be acquiring photography of all illuminated areas: cropland, range and pasture, and forest land. We cannot expect to share costs significantly, so the assigned mid-value is about $1.80 per square mile.

Other flight characteristics more suitable to other types of data acquisition yield larger coverage. A polar orbit at 160 n.m. would provide coverage of more than 30 million square miles in a 3-week period. While this would produce a unit cost of coverage of 50 cents per square mile, it must also include the tundra and ocean coverage of no value to agriculture, and with the incidence of cloud cover north and south of 50° North and South latitude respectively it becomes a misleading value.

The sensor system and the orbital characteristics of an agricultural satellite will require much study before an optimum system is achieved. Agricultural needs differ markedly from the needs of other agencies. It is conclusive, however, that satellite coverage is to be available at unit costs far below today's conventional coverage. It is equally conclusive that only by astute management can present satellite coverage compete in costs with an equally well-managed jet aircraft data acquisition program.

The satellite, in its survival time must obtain the record available to it. It is inflexible with respect to weather, and it is inflexible outside of its orbital characteristics. For these reasons the flexibility of the intermediate-altitude jet aircraft provides some outstanding advantages for agriculture.

In the early orbital missions, unmanned space craft are planned. Film loads of up to 200 pounds are realistic, and the film recovery via a separated re-entry capsule has been virtually perfected.

The disadvantages related to malfunctioning of any of several stages of the mission are apparent.

Although numerous cameras, scanners, and radars are proposed for presently programmed flights, any one satellite will carry only a limited selection of the following:

<u>Cameras</u> (Frame and TV)

120 mm focal length, 70 mm format (multiband)

6" focal length, 9" x 9" format

6" focal length, 9" x 9" format (multiband)

12" focal length, 9" x 14" format (mapping)

2" Return Beam Vidicon High Resolution (100') TV Cameras

1 Image Orthicon Low Light Sensitivity TV Camera

Dielectric Tape TV Camera

Scanners

Infrared (thermal) or

Optical Mechanical (ultraviolet through thermal infrared

Radar

Scatterometer/Altimeter

Synthetic aperture imaging (X band). (Possibly C&P band)

In the agricultural concept of mapping, which includes a wide variety of purposes, the camera-carrying satellite alone will escalate the mapping capability of today's system more than did the introduction of the first aerial photography. Considering the extension of uses along known desire-lines, and adding to these the capabilities provided by selective reading of sensors, an exponential expansion is probable.

From the Gemini photography we are provided with an insight into the many valid applications that are now developing. Considering the many photographic limitations of the Gemini operation, the results are equivalent to the rubbing of Aladdin's lamp: the distribution of moisture precisely related to crops, to specific farms, and to runoff and storage; the positive (100%) inference of grain size distribution in South African soils; the precise inventory of land devoted to cotton in the Nile and to cotton and sugar beets in Southern California· and even the man-to-land ratio approach to the determination of agricultural population in various areas. All of these determinations and many more can be vastly upgraded and perfected by satellite photography combined with an ability to achieve repeated coverage at reasonable intervals.

Soil mapping provides an excellent illustration of the benefits to be derived. Three decades ago agricultural soil maps were completely ground-based operations. From 1915 to 1939 soil science was in a formative stage, and many broad generalizations were incorporated in the mapping program. By 1940 the AAA program had introduced aerial photography to the counties and to the Soil Survey Division of the U.S.D.A. Pioneering attempts began in various areas and by 1950 the minimum planimetric value of airphotos was utilized across the country. In all instances, the photography enhanced the quality of soil mapping and simplified costly and time-consuming field efforts. A paradoxical counter-balance to this advantage was often expressed in the criticism that <u>too much</u> detail was being brought into the resulting maps.

Since 1960 the annotated aerial photograph has become the dominant medium for portraying the extent, distribution, and association of the pedologic soil units. The introduction of aerial photography (entirely as an unintentional by-product of commodity control programs) has been a major force in shaping the process of mapping and the format of the county and regional soil reports.

Satellite photography and sensing now offer much and promise more. It is realistic to recognize that the characteristics inherent in the proven 'sensor package" will raise the soil mapping program of the U.S. and the world to new levels of accomplishment, to new concepts of soil mapping, and perhaps to vastly more functional applications. In cost alone we can be assured that initial space photography, comparable to that produced by conventional aircraft will be competitive with today's costs in the U.S. and will reduce the cost of overseas coverage to one-third or as much as one-sixth of its present level.

The on-rush of events based upon expanding population demands new values from the soil map; yet with a projected 60 year time period needed to complete the presently conceived soil mapping, we seem to be enmeshed in negative progress--for each step forward we slide back two. The taking over of agricultural land for urban development is an irrevocable process with the earliest phases serving as nuclei for the ultimate takeover of large areas. Modified soil maps or special land use forecast maps of areas on the urban fringe should be updated each year as land use changes and urban penetration takes over agriculturally suitable soils.

In all areas of concentration of population, the penetration of urban growth into rural areas progresses so rapidly that knowledge of its impact and consequent demands on urban services lag far behind. The lack of knowledge results in lack of direction and control. Currently, we are simply aware of the problem: to solve it without the benefit of satellite or supplemental coverage appears impossible with the potential capacity of the industry.

Land use mapping except for small areas has not been carried out. As a result watershed, state, regional, and national policy is framed on uncertain knowledge. In 1967, New York State embarked upon a pioneer effort directed toward a state-wide land use map--the first of its kind, with information extracted from current aerial photography serving as the principal data to be processed and mapped via computer graphics (in the SYMAP program).*

IV.A. Frequency of Coverage

Some of the agricultural uses of space sensing will be predicated upon an ability to view various areas at well-defined intervals. To validate the benefits of such uses it is necessary to demonstrate that such an ability will be available. One of the primary controls is the orbital characteristic of the satellite.

Orbital altitude, inclination and eccentricity determine the frequency of coverage. An altitude of 125 nautical miles represents a generally accepted balance that favors an extended satellite lifetime. Orbital inclination may vary from a near polar orbit to strongly inclined orbits that would better enable coverage of the earth's agricultural regions. Although this study has not included a determination of orbital characteristics optimum for agricultural surveillance, it is evident that an orbit other than polar would serve these interests best. Since world agriculture falls between 50° N and 50° S Latitude, a 40° inclination would minimize time loss of the equipment and also be helpful in narrowing the time-lapse between repeated coverage.

The polar orbit has been widely considered as the most desirable. Agriculture of course has special needs that are geographically (climatically) restricted. For its specific

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* A State-wide Natural Resources Inventory, New York State Office of Planning Coordination and Cornell Center for Aerial Photographic Studies.

purposes major compromises with the polar orbit are indicated for serious near-future study.

At acceptable altitudes the polar inclination completes one orbit each 1.5 hours. In that period the earth rotates beneath it at a rate that moves the surface 2,500 kilometers eastward, or roughly half-way across the country if the first pass centered on the east coast. Since no camera compatible with the hoped-for program will cover a span of 2,500 km., the life span of the platform must be great enough to fill the gaps on subsequent orbits. The gaps will vary in amount depending upon the field of view of the camera. To reasonably complete world agricultural coverage with a 60-mile-wide field would require 42 orbital days; a 20-mile-wide field (average county width) would require a 125-day orbital life. Since the time-lapse between planting and harvesting ranges from 90 to 120 days this becomes a strong factor in planning the orbit, the related instrumentation, and the realization of benefits.

Again, agriculture has built-in characteristics that make its sensing task somewhat unique. Timeliness of coverage is important to all natural resource sensing and, next to orbital characteristics, cloud cover offers a high degree of uncertainty. Fortunately, agricultural sensing is most important in the growing season when cloud-free passes of the sensors are at a maximum.

Conflict between complete coverage and cloud-free passes can be seen. A detailed study has not been made as yet, but sufficient evidence is present to allow the conclusion that the detailed benefits can be achieved in any event. A compromise between orbit inclination geared to reduce the 2,500 km. gap and the use of side-looking (E & W) cameras to scan a larger field offers one solution.

A second departure suited to the needs of agriculture lies in the concept of statistical sampling procedures. Assuming that a polar orbiting satellite had previously obtained coverage of all significant crop areas, then an "agricultural" satellite can probably satisfy the demands of its mission by the acquisition of large-scale photos of sample areas. Photography during periods of as much as 50 percent cloud cover would offer acceptable samples. Only those benefits relying upon repeated coverage of a specific site are time and weather-dependent. As we have seen, agriculture's growing season is also largely a period of maximum photographic days per month. (The nine-tenths probability of one or more cloud-free passes during four overflights is more than 98 percent.) Therefore, the potential of an adjusted orbit combined with favorable weather conditions prior to harvest allows the reasonable inclusion of those benefits related to the detection of abnormal events.

IV.B. Resolution Related to Benefits

Once coverage-frequency and weather constraints are considered, the question of what can be seen and at what scale must be answered. The scale is a lens and altitude relationship. A short life satellite at 125 nautical miles may carry either 6", 12", or 24" cameras, or some combination. The EROS mission contemplates a 300 nautical mile orbit and the Apollo mission a 140 nautical mile orbit. The latter is to be equipped with a 6" cartographic camera with a 9"x9" film format. EROS is to be equipped with a 2" Return Beam Vidicon camera with a ground resolution of 100 - 200 ft., covering slightly more than 9,000 sq. miles in each exposure. The Apollo Earth Orbit mission will produce a ground resolution of perhaps 30 meters. A 12" (f.l.) camera would improve this to a 15 meter resolution.

The relationship between benefits and resolution is fairly clear and must be looked at realistically. The important benefits as they are identified in this report are not the benefits that require high resolution. Resolution as it is defined is a necessary basis of comparison, but for purposes of many agricultural uses it loses meaning because it relates to point data rather than linear data. Fields and soil areas, for example, have "linear" boundaries and any line with continuity over-rides resolution deficiency to a marked degree. Many are familiar with the fact that resolution inherent in today's aerial camera absolutely eliminates the possibility of detecting a 2-ft. object on the ground. In spite of this one sees 1/4" - 1/8" high-tension lines in any photograph of reasonable quality. War-time photography in Europe recorded high-tension lines from 30,000 feet. The Gemini photography showing the Nile Delta and the Salton Sea area demonstrated that crop identification and aerial coverage are completely feasible with the assumed levels of resolution to be achieved in the near future satellite missions.

Many detailed studies and their related benefits will depend on more sophisticated camera systems. For example, a 24-inch panoramic camera would produce a 2-meter ground resolution. Although this type of camera is not a mapping camera, its recording quality promises to be more than adequate for most of the agricultural surveillance requirements.

In summary, those who look forward to data collection from space and the application of it to agricultural and forestry programs of the U.S. and the world can be satisfied that on the first orbital missions devoted to this objective the results will have immediate and far-reaching application. The coverage and quality will be such that the major benefits to be gained will obtain from these early efforts.

V. A Proposed System of Remote Sensing for Agriculture

An analysis of satellite characteristics, orbital patterns and jet-powered aircraft capability, when viewed in relation to remote sensing for agriculture, suggests a workable system to achieve early benefits.

Much of the sensing instrumentation is in the developmental process. Many man-years of time in the field will be required to establish the significance of image characteristics produced by sensors proposed for space surveillance. This phase lags far behind equipment development and financial support, qualified staff to undertake the studies and general interest in the subject. And yet without these supporting studies the value of many sensors in the sky is minimal.

These steps toward perfection of the new family of sensors and the regional ground support will come but the decade of the 70's will be required. In the meantime most benefits to agriculture may be obtained using established equipment and methodology.

In broad outline, the net benefits from the principal applications described elsewhere in this report may be achieved through the utilization of conventional photography obtained from orbiting satellites combined with a jet aircraft supporting program in which the aircraft carries an array of sensors required to supplement the satellite.

During the initial stages of satellite acquisition of information it would be essential to accomplish world-wide photographic coverage that would serve as basic reference information for long term supplemental data acquisition. Of ultra small scale, this base coverage would serve as an initial inventory of world-wide land use in cropland, range land and forestry as well as other land and sea applications. The storage and retrieval of this coverage based upon the UTM grid and a computer graphics program removes much of the need for automated information processing when the system includes a regional breakdown and a systematic handling of sub-regional coverage.

As domestic and world coverage is accomplished, the availability of this reference material will make it possible to design subsequent sampling programs to reduce the need for massive sensing or to give validity to random "looks" through cloud cover or random time sequence coverage that may be off of a desired time schedule.

The ultra-small scale coverage would permit concentration of subsequent sensor effort on a large scale format of highest resolution that will be essential to many application benefits.

A total system is feasible; it should initially utilize information that is acquired by or shared with other non-agricultural applications. But the ultimate system for the agricultural applications delineated in this report must be styled for the many specific and unique requirements of remote sensing for agriculture.

Appendix A

INDIVIDUALS FROM WHOM SUPPORTING INFORMATION CONCERNING APPLICATIONS AND BENEFITS WAS OBTAINED

Name	Institution	Field
Allee, D.J.	Cornell University	Resource Economics
Anderson, M.S.	Central N.Y. Planning Project	Planning
Arnold, Kieth	Univ. of Michigan	Resource Economics
Arnold, R.W.	Cornell University	Agronomy
Barringer, A.R.	Barringer Research Ltd.	Remote Sensors
Baumgardner, M.	Purdue University	Agronomy
Bloom, A.L.	Cornell University	Geology
Bongberg, J.W.	USFS	Pest Control
Boyer, C.I.	Cornell University	Vet. Medicine
Breen, J.T.	Census Bureau	Agric. Census
Brunk, M.E.	Cornell University	Marketing
Buck, C.C.	USFS	Fire Research
Burgess, L.	EMR, Canada	Watershed Studies
Chandler, C.	USFS	Fire Research
Clausen, R.T.	Cornell University	Taxonomy
Cline, M.G.	Cornell University	Agronomy
Coleman, G.T.	Cornell University	History
Colvocoresses, A.	NASA	Satellites & Sensors
Colwell, R.N.	Univ. of Calif., Berkeley	Photo Interpretation

INDIVIDUALS FROM WHOM SUPPORTING INFORMATION CONCERNING APPLICATIONS AND BENEFITS WAS OBTAINED

Name	Institution	Field
Cooke, K.B.	ARDA, Canada	Rural Sociology
Conklin, H.E.	Cornell University	Land Economics
Croney, W.F.	Cornell University	Agronomy
Cummings, G.J.	Cornell University	Rural Sociology
Day, J.H.	Dept. of Ag., Canada	Resource Economics
Dill, H.	ERS	Photo Interpretation
Drosdoff, M.	Formerly USDA	Agronomy
Drysdale, D.	Ont. Dept. of Lands & Forests	Forest Economics
Dunford, E.G.	Dept. of Interior	Water Resources
Dworsky, L.B.	Water Resources Center Cornell University	Water Resources
Eipper, A.W.	Cornell University	Fishery Biology
Erb, D.K.	Univ. of Waterloo, Canada	Geography & Census
Fedkiw, J.	USDA	Budget Analysis
Fener, R.	Cornell University	Agronomy
Ferguson, D.S.	Cornell University	Int. Ag. Devel.
Foote, R.H.	Cornell University	Animal Husbandry
Freebairn, D.K.	Cornell University	Int. Ag. Devel.
Gardner, K.V.	N.Y. State Ext. Ser.	Resources Development
Gimbarzevsky, P.	Sparton Air Services	Forest Soils & Trans.
Hogan, R.	Census Bureau	Geography
Hair, D.	USFS	Forest Economics
Haley, R.	NASA	Nimbus Satellite Progr.

INDIVIDUALS FROM WHOM SUPPORTING INFORMATION CONCERNING APPLICATIONS AND BENEFITS WAS OBTAINED

Name	Institution	Field
Halsema, J.	Purdue University	Photo Imagery
Hamilton, L.S.	Cornell University	Forestry & Recreation
Hansel, W.	Cornell University	Animal Science
Harris, K.P.	ASCS	Aerial Photography
Held, B.	U.S. Dept. of Int. BOR	Outdoor Recreation
Heller, R.C.	USFS--Berkeley	Forest Applications
Hells, A.A.	Ont. Dept. of Lands & Forests	Classification Systems
Henning, R.	SRS	Raisin Lay Study
Hilborn, W.H.	Univ. of New Brunswick, Canada	Forest Management
Hockensmith, R.D.	SCS	Soil Survey
Hollis, W.	Nat. Canners Assoc.	Processing Industry
Jackson, K.B.	Toronto Univ. (Ret.)	Education
Jensen, N.F.	Cornell University	Plant Science
Johannsen, C.J.	Purdue University	Agronomy
Johnson, P.G.	Cornell University	Science Education
Johnson, R.	U.S. Dept. of Interior	Fish & Wildlife Studies
Kalter, R.J.	Cornell University	Economics
Kelly, R.W.	SRS	Crop Reporting
Kerr, H.A.	Cornell University	Soil & Water Conserv
Kinsinger, F.E.	U.S. Dept. of Interior	Range Management
Kerchner, O.	USDA, PEP	Budget Analysis
Koechley, C.W.	SCS	Soil Mapping

INDIVIDUALS FROM WHOM SUPPORTING INFORMATION CONCERNING APPLICATIONS AND BENEFITS WAS OBTAINED

Name		Field
Landgrebe, D.	Purdue University	Sensors
Lehlbach, A.M.	Dept. of Int. BIA	Rural Roads
Liang, Ta	Cornell University	Tropical Soils
Linton, R.E.	Cornell University	Land Economics
Loustalst, A.J.	CSRS	Crop Census
Madsen, E.L.	ASCS	Aerial Photography
Manger-Catz, S.	FAO, Latin America	Land Economics
Marden, P.G.	Cornell University	Demography
Markwardt, E.D.	Cornell University	Agric. Engineering
Marston, W.J.	SRS	PPBS
McAllister, A.S.	San Jose State Coll.	Electrical Engineering
McLellan, J.B.	Brock Univ., Ontario	Geography--Land Use
McLintock, T.F.	USFS	Forest Research
Meade, C.S.	BLM (Ret.)	Forestry
Mellor, J.W.	Cornell University	Int. Agric. Development
Moen, A.N.	Cornell University	Conservation
Mollard, J.D.	J.D. Mollard & Assoc.	Civil Engineering
Moore, R.K.	Kansas State Univ.	Sensors
Moxey, W. Jr.	U.S. Dept of Int.	Water--Irrigation
Mulligan, H.F.	Cornell University	Aquatic Studies
Murtha, P.A.	Cornell University	Conservation
Myers, V.	USDA, ARS	Sensors, Agronomy
Nicholson, G.	Dept. of Int., BIA	Range Management

INDIVIDUALS FROM WHOM SUPPORTING INFORMATION CONCERNING APPLICATIONS AND BENEFITS WAS OBTAINED

Name	Institution	Field
Olson, G.W.	Cornell University	Agronomy
Orvedal, A.C.	SCS	Soil Survey
Pardee, W.D.	Cornell University	Plant Breeding
Payne, T.	County Tax Assessor	Tax Mapping
Phillips, E.S.	Cornell University	Visual Aids
Phillips, T.	Purdue University	Data Processing
Piko, R.	Eastman Kodak Co.	Aerial Photography
Place, J.	U.S. Dept. of Int.	Geography
Poleman, T.T.	Cornell University	Int. Agric. Devel.
Poulton, C.E.	Oregon State Univ.	Range Ecology
Preston, J.C.	Cornell University	Extension Service
Ragatz, R.L.	Cornell University	Recreation
Raymond, L.S.	Cornell University	Rural Sociology
Rice, J.V.B.	Cornell University	Ag. Economics--Poultry
Robinson, J.M.	Canada Dept. of For.	Forest Management
Rogers, C.E.	SRS	Ag. Survey
Rose, R.H.	U.S. Dept of Int.	National Parks
Rourke, J.D.	SCS	Soil Survey
Simonett, D.	Kansas State Univ.	Sensor Research
Simpson, O.B.	USDA, SRS	Data Processing
Sisler, D.A.	Cornell University	Ag. Geography
Sorem, A.L.	Eastman Kodak Co.	Research
Snow, R.	U.S. Dept. of Int.	Recreation Accounting

INDIVIDUALS FROM WHOM SUPPORTING INFORMATION CONCERNING APPLICATIONS AND BENEFITS WAS OBTAINED

Name	Institution	Field
Spado, R.	USFS	Forest Survey
Spencer, J.W.	Cornell University	Highway Engineering
Steinhardt, F.P.	Cornell University	Ag. Economics
Stevens, C.E.	Cornell (Vet. Coll.)	Vet. Medicine
Stone, E.L.	Cornell University	Agron., Forest Soils
Story, H.C.	USFS	Water, Range, Recreation, & Wildlife
Stout, N.	Dept. of Int., BOR	Recreation & Taxation
Sully, B.	Arnprior School, Ont.	Education
Suter, G.	USDA, SRS	Ag. Survey
Thompson, D.Q.	Cornell University	Wildlife Management
Thompson, J.	Nat'l Center for Air Pollution, Cinn.	Air Pollution
Thorley, G.A.	Univ. of California, Berkeley	Photo Interpretation
Turk, K.L.	Cornell University	Int. Ag. Devel.
Wagner, J.A.	U.S. Dept. of Int.	Recreation Economics
Warren, S.W.	Cornell University	Farm Management
Weber, R.M.	Cornell University	Linguistics & Anthrop.
Wessel, K.L.	Cornell University	Int. Ag. Devel.
Wharton, C.R.	Ag. Devel. Council	Ag. Geography
Wilson, R.C.	USFS--Berkeley	Forestry
Winch, F.E.	Cornell University	Forestry Conservation
Winters, R.K.	USFS	International Forestry
Wood, H.A.	McMaster Univ., Canada	Geography

INDIVIDUALS FROM WHOM SUPPORTING INFORMATION CONCERNING APPLICATIONS AND BENEFITS WAS OBTAINED

Name	Institution	Field
Wright, M.J.	Cornell University	Agronomy
Young, F.W.	Cornell University	Rural Sociology
Zwerman, P.J.	Cornell University	Agronomy

CONFERENCE GROUPS

U.S. Department of the Interior

Avery, Harry F.	Bureau of Reclamation
Boyd, Roy H.	Bureau of Reclamation (Irrig.)
Brink, Bill	Bureau of Reclamation
Cabrera, Sylvia	BOR
Forleet, Groll B.	Engineer, BLM
Held, Burnell	BOR
Howard, Paul	Land Operations, BLM
Johnston, John E.	EROS, USGS
Jones, David	Real Estate Appraisals, BIA
Jones, Fred L.	BOR
Jones, Robert A.	OPD, BLM
Kinsinger, Floyd E.	Range Management, BLM
Knoll, John E.	BOR
Lehlbach, Arnold M.	Branch of Roads, BIA
Metzger, Bob	Forestry, BLM
O'Brien, James J.	BOR
Pitner, Will J.	Bureau of Indian Affairs
Surrett, Lonnie E.	Bureau of Indian Affairs
Turner, Mary Ann	BOR
Voorhees, G.D.	Engineer, BLM
Wilson, D.G.	Research Coordinator, BLM
Woll, Arthur M.	Forestry, BIA
Wyatt, Jim	Lands & Minerals, BLM

APPENDIX B

NOTES ON THE MULTIPLIER EFFECT

by

Ernest E. Hardy

The multiplier effect has long been a standard topic in basic economic theory and as such has often been accepted de facto without adequate questioning of the reason and logic of its application. There are circumstances that must be considered if it is to be applied. It is a temptation to look at every increase in production of basic agricultural goods as being credited with added benefits to our economy through the expedient application of a multiplier. But is this a legitimate approach?

First, the almost complete lack of ready-made tables of multipliers makes this whole field suspect. If the multiplier benefit can be claimed so freely, surely ecomonists would have developed the necessary tables to aid us in magnifying our reports. Also, it appears that variables of scales and types of macro-economic control severely affect the authenticity of the multiplier. Thus, there appear to be certain conditions which must apply to allow its legitimate use. And the most common problem faced by one who wishes to apply it is how to eliminate the effects of substitution. It is interesting to note that wheat production of a small area in Nebraska seems to support business transactions that amount to more than the value of the wheat. But if wheat production increased rapidly elsewhere or if the consumer demand for wheat diminished, surely the rate of multiplication would be affected. Thus it seems that any one multiplier when applied to a specific marketable commodity is only applicable under conditions of supply and demand that exist as of one place, at one point in time.

Boulding, in Economic Analysis (1955), clearly states (pp. 296-297) that the multiplier is the increase in income (output) which would result from a unit increase in investment, investment being assumed to be independent of output, so that the multiplier is the amount by which the initial increase in investment multiplies itself in producing income. If this is the case, then application of the multiplier effect on increases attributable to remote sensing would be legitimate only in relation to the value of all investments in the various producing sectors of our economy that would benefit from remote sensing.

Boulding later refers to the multiplier effect in relation to exports and foreign investments. These appear to be more legitimate explanations and approach consideration of the few situations and circumstances under which the multiplier effect might be legitimately considered. These illustrations, by dealing in an international situation, eliminate the problems of substitutability. But substitutability remains a problem in this theory if free trade is assumed.

Stonier and Hague in Economic Theory (1959) consider the multiplier effect in circumstances reflecting major differences, but which do allow for an effective multiplier in certain instances. These conditions include a closed economy, underemployment, and government expenditure on a public sector use (roads). Under these conditions a substantial multiplier can be developed for a known expenditure, but in their presentation it involves only the public sector generating the input on a public sector activity. Although applicable, this is not a multiplier based on increased production of economic goods, their illustrations are confined to government spending on major capital goods. They point out that the effect of the multiplier varies according to the marginal propensity to consume. Thus it may vary from zero to several times the value of the investment.

Samuelson (Economics, fifth edition, 1961) points out that the multiplier is a two-edged sword. It will work for you in amplifying new investment (the two cases presented above), and it is just as effective against you in cases of improvements in times of less than full employment. In the case of improvements in agriculture to be derived from remote sensing, we have assumed full employment was a necessary feature of economic conditions in order to claim benefits. Samuelson also discusses the use of government expenditure as a source of generation of the multiplier effect. But again, this is money being introduced from outside the private sector of the economy.

More recently, work by R.L. Heilbroner in Understanding Macro-economics (1965) more clearly states conditions about the multiplier that apply to our situation. His original illustration defined the impact of increased spending by outside influences or agencies. In this respect, there would be a multiplier effect from the expenditures of the USDA remote sensing program, as it amounts to an investment in research and development.

In addition, if we increased production of agricultural goods and prices remained constant; then there would be a multiplier effect attributable to all increased expenditures. But we cannot make this claim for two reasons. In the long run situation the demand for food is relative to the desired diet and the number of people to use it. And we have assumed one of our benefits must be the reduction of resources of land, labor, and capital to produce our food and fiber needs.

Heilbroner is very clear in stating the problems of attempting to identify the multiplier. Leakages through savings, taxes, and imports dilute the maximum possible effect from a theoretical 13 times to a more realistic 2 times under conditions of the 1960s. Another consideration he makes is that the multiplier is most effective when idle resources are available to be brought into use. Benefits of increased production from remote sensing will result in many cases in putting resources into the idle category, and presumably we could claim some of the effect of the multiplier when and if these resources are brought into use. But this is a future benefit to the program.

The most significant statement of Heilbroner's is the following:

> The multiplier is only a relationship, not, in itself, an empirical fact of the real world. You cannot go out and directly find the multiplier the way you can go out and

> directly find the multiplier the way you can go out and directly find levels of prices or flows of expenditures. Rather, to track down the multiplier, you must go in search of the underlying realities of economic behavior [behavior in regard to spending or saving additions (or subtractions) to our incomes] that give rise to the relationship itself. (p. 91)

According to Heilbroner's presentation then, it would be permissable to allow a multiplier of some magnitude on the money invested in the remote sensing program, but not much could be added in support of the benefits anticipated in agricultural production. At most a magnitude of only 2 could be allowed.

Other attempts were made to identify specific multiplier relationships. They were not generally fruitful. W.R. Maki in "Projections of Iowa's Economy and People in 1974" reviews a series of multiplier relationships, but they are designed for the Iowa situation, and are not necessarily transferrable to other applications or locations.

There was also an earlier study (1958) by University of Nebraska researchers on The Community Economic Base and Multiplier, but that too is applicable only to a wheat producing town in Nebraska. Correspondence with the author indicated he felt there was no more reason to accept the multiplier developed for that study than any other, and as a guess he suggested a fairly good multiplier for wheat might be about 2. He was quite sure that when considering a specific location and the multiplier effect, the size of the population was significant. Other important factors stressed were nearness to large cities and special types of industries. He was reluctant to give any indication of verification of any figure as a general base.

The November 1964 "Survey of Current Business" (U.S. Department of Commerce) provides tables related to input-output based on Liontief's techniques developed in the decades of 1920 and 1930. These offer an opportunity to trace the effects of increasing or decreasing production in any particular sector of the economy. It would be difficult to develop them to a useful level for all applications of remote sensing anticipated in this report, but they do offer a possibility for such study.

There is much confusion between the theories of the multiplier and the contributions to our economy usually considered under value added. It is difficult in much of the literature to separate the two approaches. Part of the confusion stems from the fact that the multiplier can be considered in relation to any particular area the economist wishes to isolate at least theoretically. Thus it is common to find a country and its economy referred to as the unit in one study, while the state or towm may be the unit in others.

In summary there are few characteristics about the multiplier that are agreed on by many writers. But for this study, several must be considered. Greater production of a good will either allow for a price reaction or substitution effects to occur. We are dealing with the entire economy, and the most acceptable application of the multiplier effect would be in terms of the new capital inputs to our system. If we increase production while not approaching full employment, the multiplier effect could become negative. One author states that it is very difficult if not impossible to calculate the multiplier effect, and due to "leakage" it is really a magnitude of only about 2. For the purposes of this study, it would be desirable not to have to apply the multiplier in any form, but if it must be taken into account, then a magnitude no greater than 2 possibly could be defended.

APPENDIX C

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