REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
SCHOOL OF FORESTRY AND CONSERVATION
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

REMOTE SENSING APPLICATIONS IN FORESTRY

STAR

POTENTIALLY EFFICIENT FOREST AND RANGE APPLICATIONS OF REMOTE SENSING USING EARTH ORBITAL SPACE CRAFT—CIRCA 1980.

By

Richard C. Wilson
Consulting Forester

Special Report 31 January, 1970

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
SCHOOL OF FORESTRY AND CONSERVATION
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTENTS

TABLES

PREFACE

This report has been prepared at the request of the Forestry Remote Sensing Laboratory at the University of California with funds supplied by the National Aeronautics and Space Administration. The primary intent of the present study has been to produce an accurate forecast of both user requirements and remote sensing capabilities of the 1980's on the basis of which future remote sensing research might be effectively planned and executed.

The writer takes this opportunity to express his deep appreciation to the number of persons listed in Appendix A who provided very helpful information. While he regrets that space does not permit recognizing the specific nature of each contribution, the writer trusts that the positions of the individuals will suggest the nature of their contributions. He emphasizes that wherever the material in this report is constructive and helpful, credit is due to the information furnished by one or more of those cooperating individuals. He also hopes that he has not made many misinterpretations of that information.

Without slighting contributions of other cooperators, the author makes the following specific acknowledgments: to Dr. A. B. Park, former USDA coordinator for remote sensing research (now with NASA), for providing the USDA-NASA guidelines in the study and to Dr. T. F. McLintock, Forest Service coordinator for remote sensing research, for providing guidelines and many helpful suggestions; to Benjamin Spada, Chief, Forest Survey Branch, U. S. Forest Service, for helpful suggestions; to Harry W. Camp, Assistant Director and Robert C. Heller,

Leader Remote Sensing Project, Pacific Southwest Forest and Range Experiment Station, for many good suggestions; to Dr. Charles E. Poulton, Director, Range Management Program, Oregon State University, for many helpful suggestions on range and wildlife aspects; and particularly to Dr. Robert N. Colwell and Gene A. Thorley, Director and Assistant Director, respectively, of the Forestry Remote Sensing Laboratory, University of California, for guidance in planning the study, for continuing administrative and technical support and for helpful reviews of the draft of this study.

I. SUMMARY

Significant benefits to the forestry and range disciplines are anticipated from earth-orbiting space vehicles by 1980. Useful data are anticipated not only from ERTS vehicles but from meteorological and communications satellites as well. This conclusion is based on the prospective state of the art and other assumptions given in the report, on rationale also given in the report, as developed from interviews with specialists in remote sensing research and with administrators and managers in land-managing agencies, and from study of current technical publications.

Sixteen remote sensing applications or groups of related applications judged to be most important of any in the forestry and range disciplines were evaluated. In one application, Major Land Classification, large amounts of useful data are anticipated to be contributed by space sensors in 1980. In four applications moderate amounts are anticipated to be so contributed. These are Timber Inventory, Range Inventory, Fire Weather Forecasting, and Monitoring Snowfields. In the following seven applications small but significant amounts of data are anticipated to be contributed by space sensors: Detailed Land Classification; Inventory of Wildlife Habitat; Recreation Resource Inventory; Detecting Stresses on the Vegetation; Monitoring Air Pollution Caused by Wildfires and Prescribed Burning; Monitoring Water Cycle, Pollution and Erosion; and Evaluating Damage to Forests and Ranges. In four of the sixteen applications no appreciable amounts of data are anticipated from space sensors in the near future either because the resolution of details will be too poor or because

the sequential coverages will be too infrequent, or both. These applications are Monitoring Large Management Units, Detecting Wildfires, Mapping Wildfires, and Monitoring Livestock and Wildlife.

In every application where space-sensed data are anticipated to be useful those data presumably must be integrated with data derived by aerial sensing and/or ground surveys to fulfill objectives of data collection. As explained in the report, objectives of each application are to collect a maximum of the large amount of data required for specific, important jobs of managing forest and related wildlands or for setting policies of managing such lands. More details are summarized in the several tables at the beginning of Section V of the report.

Recommendations for research and development to expedite and optimize use of remote sensing from spacecraft and high-flying aircraft in the near future in forestry and range disciplines include: (a) research to establish the spectral signatures needed to identify significant important land classes and variations in forest and range associations (requiring extensive investigations of plant physiology and microclimate related to sensing instrumentation); (b) development of an efficient data handling system for optimum storage and retrieval of a large amount of forestry and range data including that collected by space and aerial sensors and by ground methods, (c) accelerated development of thermal-infrared and microwave sensors capable of good resolution of details from high altitudes and (d) benefit-cost studies, whenever new experience data permit, to determine whether space sensing or improved aerial sensing provides an economical substitute or complement for current methods of data collection. A vigorous, continuing program of education is also recommended to foster prompt operational acceptance of proven research results.

II. STUDY OBJECTIVES

This study was undertaken to provide more specific information than previously available on the prospects for utilizing remote sensing to collect useful data on forest and range lands. Since conventional cost-benefit studies were not possible, in view of the lack of experience data on sensing from space, this study concentrated on interviews with two groups of knowledgeable people as bases for the conclusions reached in this report. One group represented resource managers and other primary users of data about forest and range resources; the other group represented specialists in remote sensing and related fields.

The primary objectives of this study were:

1. To define which techniques of sensing from space are prospectively technically and economically feasible within the next decade (circa 1980) and appear to be potentially efficient for collecting data necessary for sound development and management of forest and range lands.

2. To recommend research, development, and related studies to facilitate meeting the foregoing objective, with emphasis on the needs of NASA and the Forest Service, USDA.

3. To outline the rationale supporting the conclusions reached under the foregoing objectives.

Important secondary objectives were:

a. To define the important, potential applications of remote sensing over forest and range lands, including applications for which there are no immediate foreseeable prospects for use from space.

b. To define ways in which integration of space, aerial and ground systems can be used to complement each other for obtaining useful forest and range resource information.

Sections V and VI of this report entitled "The Applications" and "The Foreign Potential," respectively, are aimed to meet the first and third primary objectives and both secondary objectives. Section IV on "The Sensors" is also aimed at the first objective. Section VII, "Recommended Research, Development and Testing" is aimed to meet the second primary objective. Although careful consideration was given to inclusion of a section on benefit-cost relations this was not considered feasible due to the many imponderables which would make any such comparisons highly speculative if not unmeaningful or even misleading. The decision on this matter was in substantial agreement with the view on "cost-benefit relationships" reflected in the report of the National Research Council's Central Review Committee on "Useful Applications of Earth-Oriented Satellites" (62).[1/] At the same time, even without specific cost-benefit data, it is believed that this present study will provide the kind of definitive information which the Director of the Budget was seeking in vain when he turned down the request for funding an earth resources satellite in 1968. The most pertinent part of his message, quoted in the report on House Subcommittee on NASA oversight (19) included the statement that "Past studies have not adequately focused on the specific actions by which

1/ Numbers in parentheses refer to the list of references in Appendix B.

satellite acquired data would be used to create savings and benefits...plans for using satellites have been too vague...".

III. THE ASSUMPTIONS

There is very little information on which estimates of potentials in remote sensing from space can be based. Therefore the assumptions underlying the estimates become extremely important. The reader is encouraged to acquaint himself with the following assumptions before reading further into the report. It may be that he will choose to disagree with the validity of one or more of the stated assumptions. If this be the case he is encouraged to look further into the report and to modify the conclusions of the report in line with such changes in assumptions as he deems appropriate.

a. Relation of study to other studies and documents.

This study was generated in large part by reported results of other studies including the following reports: "Earth Resources Satellite System", a report for the Subcommittee on NASA Oversight of the House Committee on Science and Astronautics. (19); "Determining the Usefulness of Space Photography for Natural Resource Inventory", by R. N. Colwell, Proc. of Symposium on Remote Sensing of Environment, University of Michigan. (16); "Useful Applications of Earth-Oriented Satellites, Summaries of Panel Reports", by the National Academy of Sciences, National Research Council, (63). The study profited particularly by using guidelines, assumptions and conclusions emphasized in that NRC report and in the detailed report by the NRC panel on forestry-agriculture-geography (61).

This study accepted as most appropriate the rationale on cost-benefit relationships in another NRC publication, the "Report of the

Central Review Committee" (62) that: "...conventional cost-benefit analysis is not suitable for judging technologies (such as remote sensing) in the fluid formative state...cost and benefits are highly conjectural; judgment is necessarily the determinant...".

Two other important references were the USDA program document, "A National Program of Research for Remote Sensing", by a joint task force of the USDA and the State Universities and Land Grant Colleges (80) and "Agricultural Application of Remote Sensing--the Potential from Space Platforms", Agric. Information Bulletin No. 328 by the Economic Research Service of the USDA (81).

Attention is called to the very useful document entitled "Peaceful Uses of Earth Observation Spacecraft" produced by the Willow Run Laboratories at the University of Michigan several years ago (92). That three-volume publication emphasized some of the most promising sensing applications in the forest and range disciplines among others. It also discussed some possible cost-benefit relationships if sensing from space were to be used. Quite probably the writer of this present study would have made considerable reference to the Willow Run study had its assumptions of sensor capabilities appeared to be more realistic for the foreseeable future.

The present study was especially dependent on the following report as a launching platform for a deeper probe into benefits of forestry applications of remote sensing: "Potential Benefits...of Remote Sensing of Agricultural, Forest and Range Resources", by the Center for Aerial Photographic Studies, Cornell University (13).

The reader may question, then, why there is no reference in the present study to specific benefit-cost data tabulated in the Cornell publication. There are several reasons for this. Although some of those benefit-cost estimates might be defended as reasonable, were the rationale published to support them, others do not appear to be reasonable in view of the rationale given by this writer in Section V. Furthermore there are so many gaps in the estimates that potential usefulness of the tabulation is seriously weakened (indicating how really speculative the whole procedure is). Moreover that tabulation evidently shows benefits which might accrue through some indefinite period from all sensing media, in contrast to the more specific outlook in this present study. Most important, in view of the dearth of experience data on either benefits or costs of space sensing and the intangible nature of some benefits, this writer concludes that a more cautious approach is more useful. He outlines rationale behind a judgment decision on whether an application is likely to yield benefits in excess of costs rather than going into more speculative evaluations to put dollar values on judgment estimates. At the same time he suggests that the estimates published by the Cornell group merit examination in light of rationale given in the present study or available elsewhere. He also invites the reader's attention to the very few dollar values mentioned in Section V of this present study and to those in the report by the NRC panel on forestry-agriculture-geography (61), bearing in mind that those estimates are intended to be just a few illustrations of possible magnitudes of costs and benefits.

b. <u>State of the art within the next decade</u>.

Although it is assumed that there will be continuing improvements in the art of remote sensing into the indefinite future, no attempt has been made to define developments beyond the next decade--the approximate time period emphasized in a recent NASA planning document for earth surveys (60). By 1980 it is assumed that several earth-orbiting sensing vehicles will have been launched for the express purpose of gathering data useful in earth sciences. Presumably none of these will be manned vehicles. This system, comprising at least two vehicles (ERTS-D type) with overlapping useful lives of at least two years each, will have the following capabilities (37, 38, 60).

*Global coverage at periodic intervals no shorter than ten days and no longer than thirty days (assume eighteen days).

*Sun-synchronous orbit (Except for seasonal variations, sensors will look down on scenes illuminated by approximately the same sun angle at a given latitude. This will give informative shadowing of details--provided cloud cover does not obscure them).

*Ground resolution of objects or details as small as 100 feet in diameter ($\frac{1}{4}$ acre in size) on contrasting backgrounds. (See discussion under Section IV on kinds of contrasts required.)

*Sensing in at least three, probably as many as seven, spectral bands (visible-near infra-red of about 0.4 to 1.2 microns) registered with return beam vidicon TV cameras, (producing pictures of original scale of approximately 1 to 3 million, with 100 by 100 mile format and about 10% overlap, with picture center point locations accurate to within 10 miles).

*Optical-mechanical scanner registering same multispectral bands as those of the vidicon and also registering in the 8 to 14 micron band of thermal infrared.

*Sensor-gathered data telemetered periodically to ground sites for dissemination to users.

Other satellites aside from those expressly launched for earth resources observations will also be contributing to forestry and other applications. Specifically, meteorological and communications satellites may be contributing data needed for such applications as fire weather forecasting. Weather satellites may also indicate when to turn ERTS sensors on and off.

The state of the art assumed to be available for forest-range (and other earth science) applications does not include use of data obtained by classified techniques or instruments, such as those from military satellites. Presumably there will be continuing gradual declassification of techniques and instruments which will contribute to improvements in the overt state of the art--improvements of the magnitude, for example, as those which came during the last decade or so when formerly classified cameras and heat-sensing instruments became available to scientists for civilian applications. It is common knowledge that the military is now using sensing techniques which produce significantly better resolutions than any overt techniques available. Hopefully these techniques might soon become available for use outside the military, but it would appear to be unrealistic to make that very speculative assumption as a basis for analysis and conclusions of this study. If a greatly accelerated rate of declassification of such techniques comes to pass within the decade--significantly faster than the rate of declassification during the past several decades--its contributions to earth science applications may be accepted as a bonus. And if the reader is more optimistic on this point than the writer he should make such allowance as he deems appropriate for greater capabilities of remote sensing applications in the forest and range disciplines than is reflected by this study.

It is assumed that there will have been significant increases in the application of sensing from aerial platforms, also, by 1980. This will probably include the use of high altitude jet aircraft capable of sensing with a variety of instruments over great areas--systems such as proposed by Katz (49) and by the Cornell Center for Aerial Photographic Studies (13).

By 1980, also, it is assumed that a large central data handling system will be in operation with a capability for rapidly reducing, collating and storing data sensed from space and for rapidly retrieving and disseminating data to a variety of major users.

By 1980 presumably there will be significant increases in automatic processing and interpretation of raw data procured by remote sensing. Within a decade possibly as much as fifty percent of routine analysis of sensed data may be done by image analyzers and other automatic techniques for matching patterns and spectral characteristics of images. As a minimum by 1980, semiautomatic procedures should screen out the more significant parts of the raw data for human interpreters to concentrate on. Quite possibly a large volume of data will be interpreted by such procedures as the image discrimination and enhancement method developed at the University of Kansas and recently reported on contract to a military agency (22).

The foregoing discussion assumes a system which is roughly equivalent to the Global Land Use (GLU) system described in the report of the NRC panel on forestry-agriculture-geography (61). It assumes a system less advanced than that for Earth-Resources Information (SERI) proposed in the same publication for possible development by a 12-year development program.

c. <u>Relation of space applications to aerial and ground techniques of data gathering</u>.

It is assumed that no application of sensing from space will be an acceptable substitute for current techniques of data gathering without adequate development and testing. This assumption poses one of the greatest limitations of the present study. Indeed the reader may argue that the study is premature since there has been no opportunity for adequate testing of any forestry applications of space sensing and in many instances only limited development of techniques also. To counter this argument the writer underlines the wording of the first study objective which qualifies "techniques of sensing from space" as being those that "<u>are prospectively technically feasible</u>...and <u>appear</u> to be <u>potentially efficient</u>...." Furthermore he emphasizes that even though benefit-cost information is not available to indicate whether a space sensing method or some other is the less costly method of data collection, it is worthwhile to sort out the most promising from the least promising space applications of sensing. Such sorting is needed, even though it be based almost exclusively on reasoning and judgment evaluations. Otherwise the funds and effort needed for applied research, development and testing of the most promising applications may be dissipated over a welter of other possible applications including many that are unlikely to be exploitable.

The assumption is also made that, for almost all applications, remote sensing will be applied first from the air before being applied from space. A related assumption is that some most efficient applications of data gathering for forest and range purposes may rely on combinations of ground surveys and/or aerial and space techniques. For example, it is well recognized that some data needed as part of a comprehensive timber inventory may now be obtained most efficiently by aerial sensing--areas of forest by predominant species types and size classes, for example. Other data cannot now be obtained except by ground surveys--ownership of forest land and condition and quality of the wood in a stand, for example. As part of the rationale in this report, considerable attention has been given to aerial applications of sensing. Some of the discussions in later sections indicate some applications from space which promise to be technically and economically feasible in the near future; others which appear to be infeasible from space (at least in the foreseeable future) and for which aerial sensing may be the logical method of application.

Even those applications that do not appear feasible from space by the 1980's merit evaluation as possibilities of application from spacecraft at some more distant date or even within the time span of the '80's if technology develops more rapidly than judged in this study.

d. Overlapping of applications into other disciplines.

Although an attempt has been made in this study to confine discussions to applications which are of paramount interest to foresters and range managers, some overlaps into other disciplines have been accepted as necessary and unavoidable. Notably, it would be a disservice in this study to ignore the role of application no. 1 in Section V entitled "Major Land Classification", since data on land classes are of considerable importance to forest and range specialists; notwithstanding that economists and others may find even more need for such data. That application, of course, can contribute basic data needed for broad planning to develop and manage forest-range resources. It also can be an extremely useful first step to other important applications such as "Timber Inventory" and "Range Inventory". The reader is reminded that whenever potential benefits of remote sensing in forestry are added to benefits credited to other disciplines care must be taken to avoid overlapping claims for benefits from such interdisciplinary applications as "Major Land Classification", "Monitoring Snowfields", etc.

It should be noted also that some applications not enumerated in Table I of Section V, which lists important applications, are nevertheless of value to administrators of forests and related wildland. This includes applications which are of interest within forest and range disciplines but which fall primarily in other disciplines. "Monitoring Feedlots and Marketing Livestock Activities" is one such application and "Transportation Planning and/or Monitoring" is another.

e. Domestic versus foreign applications.

This study has concentrated on the potential for applications in the United States since immediate financing of earth resources satellites is presumed to be solely from domestic sources; also because for applications yielding results of transient value it is assumed that prompt action will be taken in this country to capitalize on that information. Nevertheless it is assumed that the satellites will be recording considerable data from terrain outside the boundaries of the United States and that benefits will accrue from sensing in foreign areas. The magnitude of those benefits will depend, of course, on a number of things, including how rapidly and in what volume the data obtained by sensors are disseminated to foreign users and how promptly action in foreign areas may be taken on results of transient value. Section VI of this report comments on some potential benefits of space sensing anticipated in foreign areas in the foreseeable future.

f. <u>Acceptance into operational use of proven remote sensing techniques</u>.

It may be argued that almost any technique is technically feasible--given enough effort and time. Through contacts with research workers and examination of the literature, particularly current reports by researchers in forest and range sensing (29), this study has aimed to evaluate prospects for achieving technical feasibility of applying a technique within the next decade. Consequently only techniques which appear to be feasible of technical achievement within the next ten years are considered for economic feasibility. Just as with the prospects of technical feasibility, potential economic feasibility of applying a technique from space has been estimated primarily by logic, bearing in mind that improvements in technical efficiency favor prospects for economic feasibility. Thus techniques which may not be economically applied today may be economically feasible in some tomorrow.

Although it was speculative enough to judge whether a technique might be technically feasible within the next decade it was more speculative to estimate whether a technique might be economically feasible within that same time period. Partly this was due to difficulty in making a balanced tradeoff between the judgment of the typical researcher on one hand and that of the typical administrator on the other. Provided the researcher was optimistic and enthusiastic about prospects for developing and proving a technique to be technically feasible, understandably he tended to view the problem of attaining economic feasibility as a minor one which should not delay application of his research contribution. The administrator, understandably, anticipated a long, hard look at alternatives before applying a technique which was not operationally proven.

It is assumed that remote sensing techniques which are proven by testing to be economically feasible will be integrated into the data collecting procedures of major users of forest and range resource data. The validity of this assumption is contingent upon effective procedures for disseminating results of remote sensing research and development and upon a strong, logical, continuing campaign to inform and educate potential users in the advantages offered by new techniques. There is danger that adoption of new and effective remote sensing techniques may be subject to significantly greater lag than the usual one which virtually all new techniques encounter due to normal human resistance to change. This greater than normal resistance is anticipated for at least three reasons. For one, potential users may have to reorient their objectives to expect kinds of useful data which formerly seemed economically unattainable. For example, without unreasonable expenditures, they may set their sights on getting data on a repetitive basis (such as phenological monitoring of vegetation) which would hardly be feasible without remote sensing techniques now in the offing. Secondly, apparently the potential benefits of remote sensing have been oversold. Thus many practical administrators of resources tend to look at all applications of remote sensing as skeptically as they do at the ones which unfortunately have been extravagantly advertised as panaceas for almost any data collecting task. Back of this view, understandably, is the resistance of practical administrators to accept any techniques which offer neither significant savings in collection effort nor significant gains in quality of data. Thirdly, some of the potential users may have much information within reach which they hope may provide many answers they seek but which may not be evaluated until more effective techniques of analysis are developed.

g. <u>Fractional cost of satellite operation chargeable to forest and range applications</u>.

It would have been purely speculative to estimate the cost of remote sensing from space without experience data to go on. Nevertheless some judgment of sensing costs from space seemed desirable as a framework against which prospective additional benefits might be projected and examined even if that examination must be subjective. In particular it appeared desirable to make an approximation of the annual cost of ERTS vehicle operation and data handling that might be chargeable to forest and range disciplines in the year 1980. This assumes that, although the basic research and development costs for satellites have already been written off against the overall mission of NASA, there will be special development and launching costs chargeable to ERTS. It also assumes that costs of handling (for reduction of acquired data, collation and storage at a central NASA center and retrieval service to primary users) will at least equal the annual cost of the collecting effort (49). According to assumption "b" there will have been launchings of approximately half a dozen ERTS vehicles by 1980, each with a lifetime of two years and with overlapping lifetimes so that at least two vehicles will be in orbit at all times. Since the assumed system (designed to provide coverage of the United States) approximates that assumed for the GLU System described in the NRC panel I report (61), it is appropriate to use the cost estimates for that system: $39 million for development costs and $22 million per year for operation. Assuming the system is used four years without major modification, the charge would be about $32 million annually.

In rationalizing what part of this cost might be charged to forest and range disciplines, one approach is to assume that the costs should be charged proportional to benefits received by all earth resources disciplines. Although a number of disciplines stand to benefit, the primary ones may be geology, geography, oceanography, hydrology, meteorology, agriculture, and forestry-range. It is assumed that <u>geology may be a large beneficiary of data obtained during the initial</u>

passes of ERTS vehicles, but that the other disciplines will probably benefit more from sequential coverages. It is further assumed that agriculture will be the largest beneficiary since estimates of amounts and quality of food are related more directly to the economy than estimates of soil, water and fiber, and sequential coverages (and crop calendars) are very useful in agriculture. Thus, over half the cost is charged to agriculture -- arbitrarily between 50 and 75 percent. Also--arbitrarily--half of the remaining 25 to 50 percent (12.5 to 25%) is allocated to the forestry-range disciplines. This means that costs of somewhere between $4 million and $8 million annually are charged to the forestry-range disciplines. Therefore it must be assumed that the total annual value of benefits estimated to accrue from space sensing over forests and related wildlands in 1980 will exceed such costs. The total benefits are anticipated from those applications listed in Table 3, Section V, which are estimated to be applicable from space by 1980.

h. Only important, economically significant applications are considered.

The applications subsequently discussed and tabulated in Section V are those aimed to provide substantial amounts of data needed as bases for decisions and actions by two main groups of people: (a) those setting policies or planning for use of forest and range resources (e.g., heads of agencies or corporations responsible for administering large areas of such resources), and (b) resource managers. The approach to the study has been to examine major needs for data collection and analysis necessary for setting the policies, doing the planning, or doing the managing just referred to; then to determine what part of the data collection might be effectively done by remote sensing.

To indicate how the approach in this study tended to focus upon economically important data collecting requirements, the following is cited. During the course of interviews with representatives of two of the largest land-managing agencies in the country--the U.S. Forest Service and the U.S. Bureau of Land Management--it became evident that one of the biggest jobs facing these resource managers was to protect and maintain the healthy condition of the vegetation resources. Furthermore those resource managers pointed out that to do this job adequately required very substantial amounts of data collection, periodically. From this basis it was not difficult to conclude that one important potential group of applications of remote sensing can be described as "Detecting Harmful Stresses on the Vegetation". In this instance there is little doubt concerning the kind of data required to be collected by sensors: signatures to indicate both healthy and unhealthy condition of the vegetation.

IV. THE SENSORS

In line with its first objective, this study aimed to determine what specific kinds of sensors and spectral windows might be most applicable from space to the forestry and range disciplines within the forseeable future. No attempt was made, however, to explore the subject of sensors in depth. For recent, informative evaluations of this, insofar as it affects agricultural, forestry and range applications, the reader is invited to the following materials in particular: Volume III on "Sensor Requirements..." of the Willow Run study on "Peaceful Uses of Earth Observation Spacecraft" (92); Part II on "Remote Sensor Capability" of the Cornell study (13); and pages 4-16 of Agric. Info. Bulletin 328 (81). Although those publications and others provided much information helpful in arriving at the conclusions of this study, prime attention was given to results of contract research studies in the forest-range disciplines funded by NASA, to related research studies and to views of the various individuals engaged in that research.

The consensus appears to be that the most useful windows of the electromagnetic spectrum will be one of approximately 0.4 to 1.2 microns, one of 3 to 6 microns and another of approximately 8 to 14 microns for sensing applications in the forestry and range disciplines. The first window, open to the visible and near infrared part of the optical spectral regions, should be useful for registering the reflectance signatures of a number of significant natural objects and phenomena. The other windows, open to the thermal part of the infrared spectral region should be particularly useful for registering emitted signatures of the heat from fires and temperatures of water and ground in forest and range areas and for census of livestock and wildlife. As explained in Section V, all three windows are now used for aerial applications of sensing by forest and range scientists. However, under the present state of the art thermal sensors are relatively bulky and heavy. Also requirements for cryogenic cooling limit their use from space platforms (60). In effect, through the 1980 time period the visual and near infrared window should be the really important one over forests and ranges. This window will probably be exploited virtually exclusively by photographic cameras, return beam vidicon (particularly from space) and optical-mechanical scanners doing multiband spectral reconnaissance.

It should be noted that a number of worthwhile investigations have been made to determine how useful other spectral windows may be in forestry and related fields, specifically those utilizing the ultraviolet and the microwave spectral regions. There is no good prospect that these windows will be useful in forest and range applications in the near future from space. The ultra-violet window, open to the short wavelengths of approximately 30 to 300 angstroms, is likely to be clouded so much by scattering, reflectance, and other forms of atmospheric interference that it offers little promise of application from space, or even from high altitudes in the atmosphere (15). Eventually, the window open to radar and other sensors in the microwave spectral region (approximately 0.1 to 30 cms. or more) may be a useful one for such space applications as detection and mapping of forest fires and to penetrate cloud cover that restricts use of other sensor application. For immediate, foreseeable time periods, apparently its usefulness is precluded by difficult technical problems. One of these problems which is magnified in space application, under either active or passive systems, pertains to the size and weight of the sensor package, including antennae. Thus no all-weather capability is assumed for sensing from space by 1980. The voids caused by weather-obscured views from television and thermal space sensors may be filled only by aerial sensors including airborne radars.

It should be noted that radar is now judged by some to be an ambiguous sensor of vegetation. It is not clear whether the contrasting responses picked up by that sensor are influenced to significant degrees by variations in vegetation patterns or, as seems more likely, by the landforms. Nevertheless, when operated from aircraft, radar can be very useful for forestry purposes, along with other sensors in the microwave regions, in at least one respect. It will reveal contrasting boundaries between forest and open land and water when cloud cover precludes success by photographic and thermal sensors.

Although the direct sensing techniques just discussed will be stressed during the remainder of this report, there are indirect techniques which deserve mention. These are the kinds implied in the first of the "three basic approaches to the problem of deriving earth resources data from an orbiting satellite" described in the report of the House Subcommittee on NASA oversight (19). Those three approaches, or systems, are: (a) to collect, by satellite, data sensed by instruments situated on the ground and to transmit such data to users on the ground (a variation of a communication satellite), (b) to record imagery from sensors in space and transmit the hard copy to the ground via reentry capsules (a most expensive system), and (c) to record and transmit imagery from space sensors via telemetry. In this study, the writer emphasized the third system but also anticipates some applications under the first system. It should be noted that a satellite stationed in geosynchronous orbit may perform an extremely useful function in picking up and relaying data sensed by stations situated in remote locations on the ground. Two applications in particular should benefit from communication service provided by satellites: These are applications number 9 and 13 (fire weather forecasting and monitoring water cycle...) discussed in Section V and tabulated in Table 1.

Since for the near future sensors registering in the visual and near infrared appear to be the ones most useful from space in the forestry and range disciplines, it is appropriate to examine some advantages and limitations of imagery from space. An excellent reference on the various factors governing quality of photographic images is given in Chapter 2 of the Manual of Photographic Interpretation (2). Emphasis there is on three characteristics governing image quality: (a) the tone or color contrast between an object and its background, (b) image sharpness characteristics (essentially, "ground resolution"), (c) stereoscopic parallax characteristics. Although this enumeration may have been made with aerial imagery primarily in mind, the listing evidently is applicable to all kinds of imagery including that from space. It is instructive to briefly examine each of these characteristics insofar as they may be affected as the range of photography is increased to space altitudes.

Contrast. Results of research by Carman and Carruthers about a decade ago (10) indicated that contrast, or luminance range, of a ground scene decreases as altitude above the ground increases. That study showed that the contrast range for some common scenes viewed from the ground might be on the order of 40 or 50 to 1. When viewed from an altitude of about 4,000 feet the range seldom exceeded 10 to 1 for the same scenes, and when viewed from hyperaltitudes it could be expected to be only about 5 to 1. The reasons for this are discussed in detail in a recent ITEK publication by Brock, et al. (9) and may be summarized by the following quotes: "The...effects on ground objects viewed from above the atmosphere are a reduction of reflected, image-forming light and an increase in the overall luminance of the objects due to scattering in the atmosphere. The random scattering of light gives the atmosphere a luminance of its own, and as particle concentration in the atmosphere increases more light is scattered and less is transmitted directly..."

An example given in the ITEK publication indicates how the atmosphere reduces the contrast of objects viewed through it and why bright objects are affected much less than dark objects even though their contrast ratios are the same. Assume an object with a luminance of 600 foot-lamberts surrounded by a background with a luminance of 200 foot-lamberts. The contrast at ground level would be 600/200 or 3:1. If the luminances of both object and background are increased by a uniform atmospheric luminance of 200 foot-lamberts, the contrast is 800/400 or or 2:1. If, also, the luminance of both object and background are reduced 50 percent due to transmission losses there would be a further reduction of contrast to 500/300, or 1.7:1.

The reader will appreciate that if there is no contrast, or if the contrast drops below the detection threshold of the interpreter (human or device), there is no image to interpret.

Since that part of the atmosphere containing light-scattering particles (water, dust, smoke, etc.) doesn't extend above 30,000 feet altitude, both high-altitude aerial imagery and space imagery are penalized approximately the same by effects of atmospheric scattering. Another quote from the ITEK publication is given to emphasize why clear, dry air provides the best photographic conditions. "The...scattering and transmission is affected by meteorological conditions. As the relative humidity increases...scattering increases....In industrial areas, smoke and other impurities increase the particle concentration in the atmosphere, causing increased scattering. In arid regions, dust will have the same effect but the relative humidity will be less." This suggests that forests and rangelands offer somewhat better sensory conditions than more developed areas; also that ranges may offer some of the best conditions, since so many are situated in arid regions.

Resolution. The characteristic termed "image sharpness" in the Manual of Photographic Interpretation is essentially an equivalent of the commonly accepted current term of "ground resolution" defined by Katz (48) and standardized in the Space Handbook (68). "Resolution" is the preferable term. The ground resolution of details of objects is directly dependent upon the specifications of the sensors, such as camera lenses, the sensor platforms, the processing of the data and the flight altitude of the sensor above the objects of interest. During the past decade or so various tables have been published to indicate resolution requirements for identification of certain features or objects. These tables unquestionably have been useful to those designing and developing sensing systems to produce the imagery needed by various scientific disciplines. Yet the usefulness of such information has been limited because too often the "contrast" characteristic has not been specified.

It may be pointed out that the choice of one of the parameters governing resolution is limited for space imagery--the flight altitude for long-lived space vehicles is generally limited to that above three or four hundred miles. For aerial imagery on the other hand, there is more latitude for tradeoff between altitude and camera specifications to meet given requirements for resolution and contrast. It may be emphasized, however, that space vehicles offer one notable advantage over aerial vehicles in meeting resolution requirements--they are more stable platforms for acquisition of data.

Stereoscopic parallax. For some important remote sensing applications in the forest and range disciplines parallax is not vital. For others it is. For instance, measurement of parallax may be necessary as the most practicable remote sensing procedure for estimating heights of stands of trees, which in turn are good indexes to timber volumes. In such instances space photography is seriously limited. As explained by the writer in a recent publication (96), the effective use of parallax for height estimation of objects or features on space imagery is limited to those with heights in excess of the normal for timber or other vegetation types. Due in part to difficulties in perceiving features three-dimensionally on overlapping images taken from space, none of the ERTS flights scheduled for the near future, apparently, is designed to procure stereoscopic imagery. The specifications for overlap are only to insure complete, nonstereo coverage (60, 37, 38).

As a practical test of the considerations just discussed, it is instructive to note some results of interpretation of Apollo 9 photography. This test, limited though it was, is the best test of space photography available to the forest and range disciplines to date. From the report on interpretation of the photography made by the Forestry Remote Sensing Laboratory (18) and from interviews with personnel who contributed to that report and with others who worked with that photography, the following conclusions may be made pertaining to contrast and resolution.

The contrast range is evidently within that anticipated. For most scenes, apparently, it does not exceed the 5:1 ratio mentioned above, although contrast between a few objects and features in the desert areas of the southwestern United States appears to exceed that ratio.

The resolution of areas (as distinct from that of linear features such as roads) varies considerably depending primarily upon the contrast. Some high-contrast features as small as 100 feet in diameter are clearly resolved, while some low-contrast features at least 300 feet in diameter are not. Contrasting features in the Salton Sea area with dimensions no greater than 100 feet in diameter are recognizable. Undoubtedly those identifications are facilitated not only by the contrasting patterns of crops but by the linearity of boundaries between features and the clarity of the atmosphere in this desert oasis. In Arizona, where much of the background is light, desert landscape, images of such features as corrals, farmsteads, agricultural clearings and timbered areas are resolved where dimensions are no greater than 100 feet. Here, too, in some instances identification is facilitated because of linearity in boundaries. The photography over the southeastern United States (over Mississippi and adjacent states) also exhibits instances where images of features as small as 100 feet in dimension are resolved--borrow pits, for example. To some degree recognition of these features also is simplified by some linearity of boundaries, but apparently the prime reason for the good resolution here is that the contrast is relatively high. Many of the borrow pits are situated within dark-toned stands of coniferous timber. On the same photography, fields considerably larger than 100 feet in each dimension are not generally recognizable in the Southeast, even though many of these are surrounded by coniferous timber and most of the field boundaries are rectangular. Although there is some contrast between fields and timber, the contrast ratio is not as great as that between borrow pits and timber.

It may be inferred that one reason for the relatively poor contrast in the photography of the Southeast as compared to that over the Southwest is because of the greater scattering of light due to more particles of water, smoke, dust, etc. in the Southeast.

The Apollo 9 photographic examples indicate why it is desirable to discuss both contrast and resolution when specifying the kind of imagery desired for a particular purpose. To an appreciable degree these examples indicate that good quality imagery may be easier to obtain over range lands than over forest lands. The foregoing are photographic examples of some of the most important ranges and forests in the Nation. The kind of land use pattern and contrasts in one region tend to emphasize some significant details--those of the ranges. In the other region they tend to de-emphasize some significant details--those of the forests.

Before concluding this section one of the disadvantages of sensing from unmanned satellites should be noted. It may not be directed, as in aircraft flights, to take advantage of favorable weather conditions. This disadvantage is of considerable significance over many parts of the country. As emphasized in a report in 1966 by Lent (55), cloud cover can cause significant interference over forested areas. For example, it is probable that in any given year the relatively few passes of a space sensor may not have a single opportunity to register ground detail in some parts of the Pacific Northwest. Even in areas, as in midcontinent, where cloud cover may not appear to be a serious obstacle it must still be reckoned with. For instance, according to a study reported to NASA in 1968 (69) there is a strong probability that it would require 28 passes of a satellite to insure a cloud-free pass over a 1000 square mile area of Indiana in the vicinity of Purdue University.

An important offsetting advantage of optical sensing from space is that broad synoptic coverages taken with similar sun angles (often within spans of only hours or days) can provide uniformity and consistency in tones and patterns of images. This synoptic cover cannot be duplicated by aerial sensing, which may exhibit many variations in images for similar objects caused by variability in conditions during the long periods required for acquisition of data over large areas. This advantage of space sensing obviously facilitates reliable interpretation of imagery by humans and by machines.

In summary, advantages of space sensing are (a) a synoptic view amenable to analysis by machines and sensor signatures, (b) a stable sensing platform, (c) sequential coverage opportunities not available from aircraft. Advantages of aerial sensing are: flexibility in directed coverage in (a) timing (to take advantage of weather, for example) and (b) resolution (due to free choice of altitude and scale).

V. THE APPLICATIONS

A. General

The rationale in the section, covering more than a dozen applications (or groups of applications in turn), aims to explain (a) the kinds of data needed to meet requirements of a job in resource management or to set policies for such management and its importance, (b) how remote sensing may contribute in collection of such data, (c) what constraints there are on sensing in terms of resolution and frequency of application, and (d) conclusions on the prospective feasibility of the sensing application from space by the 1980 time period.

Table 1 itemizes the important applications and indicates which ones appear to be applicable from space by 1980 (summary of point d, above). This is a very compressed listing as compared to more than a hundred forest and range applications itemized in the study on "Potential Benefits..." made by the Cornell Center for Aerial Photographic Studies (13). This compressed listing is to eliminate those applications for which there appeared to be no significant economic justification in the foreseeable future (according to assumption "h", Section III) and to combine a number of closely related applications into groups.

It may be argued that a further consolidation of the applications listed in Table 1 is possible, since some of the applications require collection of similar, if not identical, items of data. Indeed some phases of some applications overlap into other applications (or groups of applications). It seems appropriate, however, to identify these 16 applications separately to point up problem areas and to focus clearly on prospective economic benefits. Bearing in mind that budget requests are best framed explicitly, even though benefits may not be justified in specific dollar terms, it may be argued that rather specific benefits are anticipated from such applications as "Timber Inventory" and "Forest-Range Damage Surveys". Contrast this with a comprehensive but vague "application" such as "Census of Natural Vegetation" which conceivably would include not only the foregoing specific applications but others as well. Such a vague application would be unlikely to attract financial support without detailed explanation. In this connection it is pertinent to note the experiences of one research administrator in a resource agency during hearings before committees on congressional appropriations. Responses to requests for funding research in remote sensing were negative or apathetic unless related directly to some specific problem such as that of reducing damages by forest fire.

The applications in Table 1 are comparable with those listed and discussed in Agricultural Bulletin No. 328 (81) which is focused on important applications of sensing in the field of agriculture. Indeed some of the applications are identical to those listed in Table 4 of Bulletin 328. In part this indicates that similar criteria were used in both studies to determine "applications" of economic importance. In part it illustrates some of the unavoidable overlapping applications between scientific disciplines, recognized in assumption "d", Section III.

The subtitles in Table 1, "Resource Classification and Inventories" and "Monitoring and Protecting the Resources" not only suggest the kinds of functions served by the applications grouped under each subtitle, they also indicate two distinct categories of application based on required frequency of application. The applications in the first category are normally required only infrequently (at intervals of a few to several years), just often enough to determine long term trends. Those in the second category, however, are required at much shorter intervals (of months, weeks, or days) or continuously at some seasons, or on a directed basis as the need arises.

As emphasized by Colwell in his paper No. AD163 for the 19th Congress of the International Astronautical Federation (17), one great advantage of space sensing is a sequential mode lending itself to the detection of changes in the earth resources. Colwell defines five variations of mode which correspond to five different intervals of sequential coverage. His first four variations (ranging from detection of changes occuring within seconds to those within several months) fits within the second broad category in Table 1. His other variation (detection of changes occuring in a period of several years) fits generally within the first broad category in Table 1. Data obtained from applications in the first category are useful over relatively long periods. In contrast, data from most applications in the second category, (such as fire detection data) have transient values and quickly become obsolete.

Applications in the second category tend to be considerably more costly, for equivalent areas surveyed, than those in the first category--essentially because more frequent applications are required. It will be noted from subsequent discussion that some applications in the second category are deemed to be infeasible from space by 1980 because of the requirement that they be applied frequently or continuously. The reader should bear in mind that this rating is contingent upon the state of the art that has been presumed under assumption "b" in Section II. Any modification in that assumption with respect to mode of operation of sensors in space by 1980 can have a significant effect on that rating. So that the reader may more easily judge how a modification of that assumption may modify the rating of any application, the first column of Table 2 indicates the required frequency for each application. It will be noted that this table also summarizes various criteria for rating prospective feasibility of applications from space approximately a decade from now.

Every one of the last four columns in Table 2 represents subjective material. The material shown there depends on the information obtained during interviews with researchers and resource managers and in current publications. Such material was evaluated to arrive at the summary "judgments" of prospects for feasibility of space sensing applications by the year 1980. Column 2 shows the prospective feasibility of registering a response from space from the most applicable sensor(s). This does not mean that the response is an identifiable signature for a particular phenomenon or object. Column 3 shows the estimated feasibility of differentiating responses and establishing signatures to identify the particular data items (objects and/or phenomena) necessary to be collected during an application. Column 4 indicates whether the required frequency is estimated to be realizable within the state of the art in 1980.

Column 5 indicates whether space sensing is prospectively more efficient that other data collecting techniques such as aerial sensing or ground work (by providing at less cost the data now collected by other methods, or by providing data infeasible of collection except from space). It also indicates where space sensing might be effectively combined with another data collecting method(s). Thus the information in column 5 should be of interest to anyone who is interested in designing an efficient data collecting system. It will be no surprise to those who have recently wrestled with problems of survey design that in every instance where a "yes" is shown in Column 5 to indicate that space sensing is applicable there is also the qualifying note that space sensing should be integrated with other data collecting procedures.

Two things merit emphasis that may be self-evident from this table. Unless all criteria in columns 2-5 inclusive are met there appears to be no prospect for an application from space by 1980. Also, in trying to visualize prospects in the future beyond the next decade, or in the event the reader wishes to liberalize the assumptions made in Section II, it may be helpful to focus on those applications which have favorable ratings for some, but not all, criteria. For example, for "Detecting Wildfires" the "some" in column 2 and 3 might be a cautious "go" signal for the application--the feasibility in the next decade for at least some fire detection by space sensing devices. The "no" in column 4 is a "stop" signal, however, during the 1980 time period; but whenever the requirement is met for the frequency of application specified in Column 1 there may be a bright green light for this application from space.

Table 3 summarizes the relative usefulness, to resource managers and planners anticipated in the time period of 1980 of space sensed data and of data collected by other media. The indications of "small", "moderate" and "large" amounts of data shown in the table are relative ratings. The reader is invited to discussions of individual applications for explanation of what is involved for each. As very rough approximations it may be inferred that with total current effort (or cost) for an application as the base, the relative proportions of the base that might be replaced in 1980 by data collection from space are as follows: for "small" about 5 to 10%; for "moderate" about 10 to 25%; and for "large" about 50% or more.

In Table 3 the emphasis is on the work function which justifies the need for specific data rather than, as in Table 1, on the data collecting application, per se. Hopefully, Table 3 indicates the prospective reliance that various users will place on the several methods of data collection a decade from now. If assumption "f", Section III, proves to be valid (that the majority of users will accept new methods of data collection offering reasonable prospects of greater efficiency than older methods), the material in Table 3 should prove helpful to administrators and managers of forest and range resources and to their staff specialists who collect resource data. It will be evident from this table, just as from Table 2, that for no application may all data collection be done solely by space sensing. Integration with aerial and/or ground work is the optimum procedure.

The subdivision in Table 3 "Use for policy planning" pertains to such persons as legislators and administrators responsible for policies and plans at national, regional and state levels. Their needs are obviously for summaries of resource situations over large areas to point up problems which are wide in scope. To some degree the national and state administrators of forest and range resources are presumed to be interested also in the more detailed data implied under the subdivision "Use for detailed planning and managing-protecting". Mainly, however, this column of the table refers to governmental representatives at local levels (such as counties), administrators and managers of such governmental units as national forests and state forests, heads of forest industrial companies and the staff specialists who do the detailed planning and participate directly in management of resources. Table 3 is in general agreement with Table 4 of Agric. Info. Bull. 328 (81). The several applications which were common to that study and the present report are rated essentially the same in terms of feasibility from space. For example, a classification of major land uses is rated as feasible from space and monitoring livestock and wildlife is rated infeasible.

It should be noted that an application may collect only one specific kind of data, as in "Mapping Wildfires". Here raw data collected by a sensor on the location of a fire perimeter can be translated quickly into information needed by a fire boss in directing his fire fighters. On the other hand, the application may collect a variety of data, as in "Timber Inventory". Here the sensor may collect data on the extent and location of forest types, on stand heights, tree-crown diameters, stand density, etc., which may be translated into part of the package of information needed by a forest manager as a basis for his decision on the allowable cut of timber for a working circle or by those who determine the forest policies for a nation or one of its political subdivisions. Some data needed for those decisions must be collected by on-the-ground surveys coordinated with sensing operations; other data for that package of information must be generated, largely, by planning decisions made by resource managers or policy setters. For instance, decisions on the locations of tracts where timber cutting must be restricted or prohibited due to existing or planned recreational developments may not be influenced necessarily by data collected by sensors.

Some data collected for one application may be identical to data needed for another application. For example, much of the data collected in "Major Land Classification" is useful in both "Timber Inventory" and "Range Inventory" applications. Furthermore something stated in the USDA program document (80) may be noted; items of data, per se, are not necessarily useful items of information until they are collated and evaluated.

For reference by those concerned with drafting specifications for sensors and sensing vehicles in the forest-range disciplines, Table 4, "Ground Resolution Requirements...", has been included. The reader will appreciate that these summations are only approximate guides to requirements which, for any specific application, depend upon a number of factors. These include the feature-background contrasts of the particular environment being surveyed and specific objective of the survey. As some entries in the table indicate, if survey objectives call for detailed information the resolution requirements tend to be more restrictive, at least for some needed data.

In considering the following summations in Tables 1-4, and discussions of the various applications, the reader is urged to bear in mind that <u>data collection and handling on any particular geographic unit may be done most efficiently as part of one integrated task serving the purposes of a number of applications and disciplines.</u> This is implied by assumptions "c" and "d" of Section III.

Table 1: POTENTIALLY IMPORTANT APPLICATIONS OF REMOTE SENSING OVER FOREST AND RANGE LANDS 1/ (Prospective application from space by 1980 indicated)

A. RESOURCE CLASSIFICATION AND INVENTORIES

Application or Group of Applications	Prospective Application from Space: Substantial application 2/	Limited application 2/	Application unlikely
1. Major Land Classification (Includes charting trends in such major land use classes as forests, grasslands, marshlands, cultivated and other developed areas; snowfields, rocky barrens and other wastelands).	X		
2. Detailed Land Classification (Includes: in-place mapping of such significant forest associations as the mixed conifer type in the Sierra Nevada Mountains, spruce-fir type in the Rocky Mtns., oak-hickory type in the East and bottomland hardwood type and Longleaf-Slash Pine types in the South; also soil-vegetation surveys).		X 3/	

1/ See text for discussion of criteria for separating "important" from other applications and for rationale supporting information in this table.
2/ In a "substantial" application, space sensors provide a large proportion of the data needed to meet information requirements of a job. In a "limited" application, space sensors provide only a small proportion (far less than half) of the data requirements.
3/ Information on "major land classification" contributes indirectly but significantly to facilitate these six applications. See discussion in text on how "land classification" data obtained through space sensing facilitates "Timber Inventory", for example.

	Substantial application	Limited application	Application unlikely
3. Timber Inventory (Includes estimating and charting long-term trends of volumes, growth, removals, mortality and condition of timber by key species and by species type and timberland productivity classes).		X[3/]	
4. Range Inventory (Includes estimating and charting long-term trends of amount, growth and condition of forage by species or palatability groups).		X[3/]	
5. Inventory of Wildlife Habitat (Includes charting long-term trends in condition of habitat for game and fish).		X[3/]	
6. Recreation Resource Inventory		X[3/]	

B. MONITORING AND PROTECTING THE RESOURCES

	Substantial application	Limited application	Application unlikely
7. Monitoring Large Management Units			X
8. Detecting Stresses on the Vegetation (Includes detecting, prior to serious or epidemic stages, incidence of damage or loss of plant vigor from various temporal impacts such as from insects, disease, air pollution or lightning; also monitoring survival rate and condition of plantations, windbreaks and shelterbelts).		X	
9. Fire Weather Forecasting (Includes prediction and detection of cloud-to-ground lightning contacts and recording other data as bases for fire weather forecasting and fire suppression planning).		X	

	Substantial application	Limited application	Application unlikely
10. Detecting Wildfires			X
11. Mapping Wildfires (Charting spread of wildfires as aids to directing fire suppression. Includes measuring total environment around large fires).			X
12. Monitoring Air Pollution Caused by Wildfires and Prescribed Burning		X	
13. Monitoring Water Cycle, Pollution and Erosion (Includes detection and charting trends in water yield, erosion, turbidity, saturation of subsurface zones where flood peaks may originate, sources of avalanches, etc.; also delineation of flooded areas).		X	
14. Monitoring Snowfields (As bases for predicting water yield and avalanches. Partial overlap with application No. 13).	X		
15. Evaluating Damage to Forests and Ranges (Includes delineating and estimating amounts of timber and forage destroyed by insects, disease and fire; and of salvageable timber).		X[3/]	
16. Monitoring Livestock & Wildlife (Includes inventories and charting movements of domestic and wild animals and fish, and detection of diseased livestock).			X

Table 2. CRITERIA RATINGS TO JUDGE FEASIBILITY OF FOREST & RANGE APPLICATIONS OF SENSING FROM SPACECRAFT, CIRCA 1980

	Criteria[1]				
	(1)	(2)	(3)	(4)	(5)
Application or group of applications	Shortest frequency of application usually required	Registering space sensor responses judged feasible	Establishing signatures judged feasible	Required frequency of sensing judged feasible	Estimated more efficient than aerial or ground work
1. Major Land Classification	5 yr intervals	Yes	Yes	Yes	Yes, in combination
2. Detailed Land Classification	n.a.[2]	A few, mostly indirectly[3]		n.a.	Yes, in combination
3. Timber Inventory	5-10 yr intervals	A few, mostly indirectly[3]		Yes	Yes, in combination
4. Range Inventory	5-10 yr intervals	A few, mostly indirectly[3]		Yes	Yes, in combination
5. Inventory of Wildlife Habitat	1-10 yr intervals	A few, mostly indirectly[3]		Yes	Yes, in combination
6. Recreation Resource Inventory	n.a.	A few, mostly indirectly[3]		n.a.	Yes, in combination
7. Monitoring Large Management Units	Biweekly in growing season	A few	A few	No	--
8. Detecting Stresses on the Vegetation	At least semi-annually	A few	A few	Yes	Yes, in combination
9. Fire Weather Forecasting	Daily in fire season	Some	Some	Yes, for some	Yes, in combination
10. Detecting Wildfires	Daily to hourly in fire season	Some	Some	No	--
11. Mapping Wildfires	6 hr intervals on major wildfires	Some	Some	No	--

	(1)	(2)	(3)	(4)	(5)
12. Monitoring Air Pollution Caused by Wild-fires and Pre-scribed Burning	Every other day in season	Large concentrations only		Yes, for some	Yes, in combination
13. Monitoring Water cycle, Pollution and Erosion	At least biweekly in growing season, daily in flood season	Gross changes in turbidity and erosion		Yes, for some	Yes, in combination
14. Monitoring Snowfields	Weekly in ablation season, monthly in winter	Yes	Yes	Marginal part of season	Yes, in combination
15. Evaluating Damage to Forests and Ranges	n.a.	Extensive damages only 3/		Yes, for some	Yes, in combination
16. Monitoring Livestock & Wildlife	n.a.	No	--	--	--

1/ As explained in the text, a "no" for any criterion means that any criteria listed in a column to the right of that also are rated "no" or their rating is immaterial. Therefore, only where a "Yes" is listed under column 5 is an application judged to be economically feasible by substantial or limited space sensing by 1980. (Those applications in Table 1 indicated as having substantial or limited application from space).

2/ A "not applicable" (n.a.) designation indicates that need for an application has no standard time relation. The application is directed as needed. E.g. county assessors may require a detailed land classification only after a period of rapid economic development, and a forest-range damage survey is required only when fires or epidemic stresses are believed to have caused serious damage to the resources.

3/ These are judged to be applicable generally indirectly as they utilize space sensing data attributed to application No. 1, "Major Land Classification". (Those applications in Table 1 designated by footnote 3).

Table 3. ESTIMATED USEFULNESS OF SPACE SENSED DATA AND DATA COLLECTED BY AERIAL SENSING OR GROUND SURVEYS, BY APPLICATION AND CLASS OF USER, CIRCA 1980. 1/

Application or group of applications	Use for policy planning		Use for detailed planning, managing-protecting	
	Space data	Other data	Space data	Other data
1. Major Land Classification	L	L	na	na
2. Detailed Land Classification	na	na	s	L
3. Timber Inventory	M	L	s	L
4. Range Inventory	M	L	s	L
5. Inventory of Wildlife Habitat	s	na	s	L
6. Recreation Resource Inventory	s	L	s	L
7. Monitoring Large Management Units	na	na	--	L
8. Detecting Stresses on the Vegetation	na	na	s	L
9. Fire Weather Forecasting	na	na	M	L
10. Detecting Wildfires	na	na	--	L
11. Mapping Wildfires	na	na	--	L
12. Monitoring Air Pollution Caused by Wildfires & Prescribed Burning	s	L	s	L
13. Monitoring Water Cycle, Pollution & Erosion	s	L	s	L
14. Monitoring Snowfields	M	L	M	L
15. Evaluating Damage to Forests and Ranges	na	na	s	L

Table 3 (con'd)

16. Monitoring Livestock & Wildlife	na	na	--	L

1/ Estimated usefulness is indicated by symbols denoting relative amounts of useful data, as follows: L-large amounts, M-moderate amounts, s-small amounts. (See text for explanation of these terms.) A dash indicates that negligible amounts of data, if any, are estimated to be contributed by the particular collection media to the particular class of user. "na" indicates that the application is not generally of interest to the particular class of user.

Table 4. GROUND RESOLUTION REQUIREMENTS FOR IMPORTANT FOREST AND RANGE APPLICATIONS OF REMOTE SENSING

Application or Group of Applications	Approximate Ground Resolution Usually Required 1/
1. Major Land Classification & 2. Detailed Land Classification	Several hundred feet or less where interfaces are contrasting: bare soil-vegetation, forest-grass, etc. Ten feet or less where interfaces are noncontrasting, as for sub-classes of forest based on species composition.
3. Timber Inventory	Several feet or less for many items of data such as those on species and sizes of individual trees. 2/ Three-dimensional resolution is required on some of these items also.
4. Range Inventory & 5. Inventory of Wildlife Habitat	Several inches for many items of data such as those on species and condition of herbs. 2/
6. Recreation Resource Inventory	Ten feet or less for the most detailed items of data. 2/
7. Monitoring Large Management Units	Ten feet or poorer (even several hundred feet for some items) is satisfactory.
8. Detecting Stresses on the Vegetation	Several hundred feet for most stresses that are affecting significant geographic areas; several feet for stresses in incipient stages or affecting isolated trees or clumps of vegetation.
9. Fire Weather Forecasting	Several hundred feet or somewhat poorer for tracing synoptic patterns of thunder storms. Resolution not applicable for other general application which is based on use of satellites for communicating weather data gathered by ground stations.

Table 4 (con'd)

10. Detecting Wildfires	Twenty feet
11. Mapping Wildfires	Twenty feet for locating spot fires. Poorer resolution up to 100 feet or more satisfactory for mapping fire fronts.
12. Monitoring Air Pollution Caused by Wildfires and Prescribed Burning	Possibly several miles
13. Monitoring Water Cycle, Pollution and Erosion	Several hundred feet for significant extent of water pollution and floodings (as cuased by turbidity). Ten feet or somewhat poorer for erosion affecting significant portions of watersheds.
14. Monitoring Snowfields	Several hundred feet
15. Evaluating Damage to Forest and Ranges	Several hundred feet for damage that is extensive; several feet for damage that is localized or exhibits only minor physical effects.
16. Monitoring Livestock and Wildlife	No poorer than several feet

1/ Resolution of imagery tolerable for identification (as by spectral signature) of objects of features with normal feature-background contrast (see discussion of "Contrast" in Section IV). This also applies only when identification is not required for individual areas or units of interest smaller than resolutions cited. Thus for major land classification of forest, grass, bare fields, agricultural crops, etc. a resolution of several hundred feet is not satisfactory, obviously, if objectives of the survey call for identification of separate units of land use as small as 100 feet in diameter.

2/ Some other important items essential for this application are land classes, for which much poorer resolutions are satisfactory. See resolution requirements for applications no. 1 and 2.

B. Specific Applications.

1. Major Land Classification.

Through the years information on land uses has been beneficial to government agencies for planning purposes. As will be evident from subsequent discussions, accurate statistics on major land uses are essential bases for timber and range inventories and for some other applications.

An outstanding example of the value of land use data has been the widespread demand for the series of publications on major uses of land and water issued at five year intervals by the Economic Research Service of the USDA and its predecessor bureaus. The latest in this series (31) presents, as usual, current estimates of areas, by states, of such broad classes as croplands by major use, pasture and range, and forest land. It also discusses trends in land uses and some important relationships such as that of water to other uses. The preface of that publication contains some comments which imply both the increasing detailed demands for information on land uses and the difficulties of getting such information. Part of that preface is quoted here: "Although data from the various sources were classified with the objective of maintaining comparability with the estimates presented in previous reports...this objective was not always attained....It is believed...that estimates in this report and those of earlier reports are reasonably comparable at the national level and generally comparable at the regional level....State by state estimates are less reliable. The reader should also keep in mind that...data...do not fully convey the highly dispersed pattern of uses, the innumerable relationships between uses or the wide variation in land quality and intensity of use, particularly in relatively small areas...."

The basic reason for lack of comparability and inadequacy in details of data is that collection of really current data on land uses has been an expensive procedure--considering the rapidity with which uses of land are changing. Agencies interested in such data have used a variety of collecting methods--varying from mail canvasses and interviews to use of aerial photography. By and large they have obtained a reasonably good job for the money with available techniques. Some indications of how varied procedures have been is that to produce the study mentioned above, the Economic Research Service drew upon information provided by more than a dozen different agencies to put together a compilation. It is understandable that this compilation exhibits data with a variety of reliability and vintage. Errors have been unavoidable due to the wide range in vintage of data which normally must be integrated for estimates of land classes over large geographic areas. Even under the most favorable situations, as when aerial photo contracts have been let to cover whole regions or states, the range in age of data has usually been considerably greater than one year. And for the country as a whole the range in age has been a number of years. It may be noted that ASCS photography has been most used of any source in land-use surveys and related surveys and that coverage ranges up to eight years in age with an average age of three years (83).

Up to the present time there has not been a capability in aerial photography to insure that the whole Nation could be covered within a reasonably current period and the alternative of field work by crews working simultaneously throughout the country has been judged to be too expensive for nationwide surveys of land uses or similar surveys. Several government agencies and aerial photographic firms are now seriously considering possibilities for use of high altitude jet aircraft for photography and other sensing on a scope that was never really visualized until proposed by Katz (49) and by the Cornell study (13) about two years ago.

Yet space sensing should soon contribute a substantial part of the information needed to chart changes in major land uses in the country. Through sequential coverage (even at intervals no shorter than several weeks) and automatic classification using spectral signatures, the space sensors should collect most of the data needed for accurate readouts on the annual shifts in use between such broad classes as water bodies, developed areas (e.g., cities, towns, transportation networks), cropland, pasture and range, and forest land. There are a number of favorable indications for the prospects just discussed, including those from studies in interpretation of Apollo 9 photography (18) and interpretation of simulated space imagery (14). The results of several studies on automatic data analysis involving the utilization of spectral signatures for land classes also are encouraging (56, 51, 45, 22), even though automatic procedures must be refined before accurate operational results may be realized.

The data used for such reporting as that on annual changes in major land uses will no doubt be only a fraction of the total land-use data collected from space. Only part of the sequential coverages during the year may be used--perhaps only enough to take advantage of seasonal fluctuations in contrasts to favor interpretation. The readout of those coverages may also be on a representative sampling basis. The sampling rate would, of course, be dependent on the minimum size of reporting units. If reliable statistics were required only for the nation and for major subdivisions such as states and no estimates were required of land use by size class (those units of forest 1-10 acres, 10-100 acres, etc. in size), readout of a very small fraction of the land use identifications might suffice. Even if, as likely, estimates were required for smaller political or regional subdivisions and by size class classes of land use, it is hardly conceivable that an enumeration of every distinct unit of land use in the country would be merited, let alone complete annual mapping of land uses. This does not preclude a possible requirement for complete mapping at longer intervals (perhaps at the time of the decennial census) showing at least generalized land use. Note that the writer is careful to specify something "required", not "desired". The former implies that someone is willing to finance the cost of the survey to obtain information which is not only "interesting" but "valuable".

It may be assumed that considerably more data on land uses should be stored in the central bank of space data than would normally be required on a readout for any one survey of land uses. This bank would be an excellent source of data, not only for special localized surveys of land use (e.g., a special survey for a political subdivision such as a county on a directed basis) but as a historical record over the years which could be tapped for various purposes. As will be evident from subsequent discussions, accurate statistics on major land uses are essential bases for efficient timber inventories, range inventories and some other special purpose inventories. Indeed, through space sensing, for the first time the data base on which sampling data for various applications are expanded will be known with negligible sampling error and without the technique errors which have plagued technicians on resource surveys for years. Under such a procedure the sampling error can be reduced to such a small fraction of a percent that it may be ignored. Areas of land classes may be estimated with as much precision as if they were being determined by the conventional dot counting procedure which is frequently accepted as an accurate substitute for planimetering in estimating areas delineated on maps and aerial photographs (2, 71, 94). Precise estimates of areas would then depend merely upon registry of sensor signatures by major land class for each point in a pattern of sampling units over the landscape. Calculation of acreage for each class would be by simple proportion of sampling units in a class to total units sampled in the geographic area being surveyed and for which the total area is known. Although calculations might be made "on-line" for any geographic subdivisions desired, it would be preferable to store the sensed data by small geographic subdivisions for later retrieval and "off-line" computing to meet user requests.

Since space sensors would register a sample of contrasting land classes over huge geographic regions within a very short time period (within a few weeks or months at most) there would be no question that data were all truly current. This would minimize or eliminate some technique errors which have been inherent in regional and national surveys of land uses and which have been extremely difficult to evaluate and correct for.

In conclusion, land classification will be one of the first earth-resources applications to be exploited by sensing from space. By 1980 it is anticipated that data on broad land uses obtained by cameras and optical-mechanical scanners in ERTS vehicles and telemetered to the ground will be used by a variety of disciplines. As summarized in Tables 2 and 3, land classification data derived by space sensors should comprise a large part of that needed for broad policy planning in 1980. Since ground resolution of several hundred feet is satisfactory, register of responses from space sensors and identification of signatures for major land classes is estimated to be feasible; also the frequency needed for the application (minimum intervals of five years). Nevertheless a large part of the data needed for major land-use planning no doubt will continue to be derived from other sources. These data will include significant amounts derived by aerial sensors (especially for estimates over areas obscured by weather from space sensors) and the kind of data that sensors cannot collect--such as that on land ownership, on decisions between alternative uses and on intensity of use that land owners make.

2. Detailed Land Classification.

Under this application are grouped a range of uses for sensing data which the reader may prefer to identify separately as classification or surveys of "soils", "vegetation", "watersheds", or "land appraisals", etc. The writer admits to some merit in that alternative procedure. He would only suggest that under his choice much repetitive discussion may be eliminated since he proposes to talk to all procedures which are aimed primarily at classification, delineation and estimating acreages of various detailed classes of lands. This does not necessarily involve production of maps of land classes--though it may well do so.

Although the procedures presumably will provide information on both amounts and location of areas of the land classes which are essential components of such specific inventories as those of timber and forage resources, they do not produce all the estimates which are required on such inventories (i.e., estimates of volume of wood or forage by species and condition). The areas estimated under the "detailed land classification" application are, of course, the essential bases for expansion of details on volume, species composition, etc. to the geographic universe of interest--region, working circle, range allotment, etc.

A typical example of "detailed land classification" is the soil-vegetation survey of forest and range lands in California, financed by the state and conducted cooperatively with the U.S. Forest Service (74). This survey aims to classify and show on maps the physical characteristics that indicate the suitability of a unit of land for various possible land uses--such as for wood production, for grazing, and for watershed protection. Contrasting units of land are classified down to a minimum of about ten acres. On each unit the dominant vegetation species and soil type and phase are indicated. Thus much greater detail is obtained in this application than in application No. 1. Examples of main vegetation types that may be differentiated from basic data obtained by the California survey are chaparral, oak woodland, mixed conifers, redwood, sagebrush, and annual grasslands. Similar surveys in other parts of the Nation might indicate the amounts and occurrence of such types as the following: spruce-fir, pinyon-juniper, desert shrub and lodgepole pine in the Rocky Mountains and Southwest; oak-hickory, beech-birch-maple, and spruce-fir in the East; and longleaf-slash pine, shortleaf-loblolly pine and bottomland hardwoods in the South. It is apparent that current data on locations and amounts of such vegetation classes and associated soils are extremely useful bases for specific inventories to determine the worth and condition of the timber, forage, recreation and other resources of wildlands. One indication of the importance of soil-vegetation investigations is that the Forest Service spends about $800,000 each year on such projects on national forests.

An important use for detailed data on present and potential land use, or capability, is for tax assessment. For this purpose effective use has also been made of major land classification data which indicate where and how much cropland, timberland, grassland, pasture land, etc., there is in an ownership. The inference may be made that the present broad cover class is the index of suitability for the highest economic use of the land. Incidentally, the land capability classification developed by the Soil Conservation Service is one modification of land area classification. As competition for land becomes keener naturally there is more demand for more precise classification data on capabilities of both agricultural lands and other lands. In effect the tax assessors and local planning offices are interested in essentially the same breakdowns of lands as those agencies and individuals who are doing intensive land management.

Typical examples of detailed classification of lands are in the management planning surveys on national forests in California. A few years ago such surveys aimed primarily at inventories of the timber and range resources and recognized a number of area classes based largely on the vegetation types that occupied the land. Forested land, for example, was subdivided into approximately three dozen types based on predominant species composition (redwood, sugar pine, white fir, etc.) and into several stand-size, site and stocking classes (i.e., sawtimber, saplings, well-stocked, poorly stocked, nonstocked). Altogether there were not more than about two hundred possible separate classes, considering the various possible combinations of type-stocking, etc., which were recognized to be economically significant in management of timber and range resources. In recent years, as multiple-use management intensified, the managers became interested in far more area classes. Some of these are subdivisions of original timber and range classifications to indicate the health or condition of the resource; others are classes based on soil-vegetation and other physiographic aspects (approximating a natural ecological classification) which indicate capability of the land for production of various multiple-use benefits. There are now requirements for such classes as those showing relative stocking of desirable and undesirable trees in timber stands and of trends in land use, (e.g., areas formerly in cultivation or pasture during a previous survey but now restocking with timber, or potential timber, or forage producing areas being invaded by low-value brush) (87). The number of significant, separate classes (based on combinations of elements useful to California land managers) now runs into a four digit number--as compared to a small, three digit number a decade or two ago. An expansion of these possibilities to all fifty states gives some indication of the large number of spectral signatures that are conceivably of value within the forest-range universe. These are the possible signatures for <u>extensive areas only</u>: such as the signatures for types where sugar pine is a predominant species. It may be noted that forest managers in California have paid significant sums of money to determine where virtually all sugar pines of commercial size are located on their properties, even where that species is a minor ecological component of the type.

At this point a brief discussion is appropriate of the relative merits of mapping versus sampling for determining areas of natural vegetation. Maps of vegetation, per se, may have little value or much value. The value depends on the specific content. A map which merely portrays every item that may be collected by a sensing system will probably be difficult to use. Separately, each of those items may be "interesting", at least to a few people; but those items having economic significance may be obscured within the welter of merely "interesting" items. Furthermore, vegetation maps may soon become obsolete, as compared to contour maps or geologic maps, wherever man's activities are affecting the landscape. Before concluding that a vegetation map is the suitable answer to a data collecting problem the question is germane whether statistics on area classes derived from a sampling design won't provide a more suitable answer; particularly since statistics can be produced at far less cost than maps and are much less likely to saturate a data handling system than map production.

Moreover, when sensor signatures are developed for detailed land classes, such as vegetation associations, there are prospects for greatly minimizing one kind of technique errors inherent in land classification under today's type mapping procedures. These are errors due to the various subjective, human judgments that are made when areas of vegetation are classified and--quite often--delineated on maps. The minimum size of delineated units of land class may be as small as five or ten acres, but often much larger units are classified and delineated separately. In many instances the mapper must subjectively evaluate a variety of conditions over an area that must be designated as some specific class; pure conifer, pure hardwood, a mixture of conifer hardwood based on predominant species, etc. Yet often in nature there are no sharp boundaries between vegetation associations, only gradual transition zones. Thus it is well nigh impossible for a mapper to be consistent in his judgment. And it is sheer coincidence when two mappers delineate such variable associations identically.

It may be noted that consistency in area classification is much easier to achieve when rather small units of land are evaluated--1/4 acre field plots, for example--since the variability of vegetation is correlated directly with size of area. This suggests that the procedure recommended under the discussion of application no. 1, "Major Land Classification", should be advantageous in reducing the technique problem just mentioned: registering signatures centered on sample units scattered over the landscape. Since each signature may be from a small area with dimension approaching the minimum resolution of 100 feet assumed for space sensing in 1980, the effect is analogous to classification of 1/4-acre plots on the ground even when space sensing is applied. This has the advantage of simplifying development of sensor signatures, since some contrasts may be anticipated in average conditions of the respective areas surrounding any two points. Also machine registry of a signature is more objective than human judgment. Although this might argue for use of signatures for mapping average conditions, an automatic type mapping technique is more likely to saturate a data handling system than registering contrasting signatures between sample units is.

As indicated in Table 2, "detailed land classification" is not expected to be a straightforward space sensing technique in 1980. Many responses may well be registered by space sensors which theoretically could identify some significant classes of forests and range lands. But in the next decade there is little prospect that such responses will be sorted out and isolated from the heterogeneous "noise" that pervades when the gain of a sensor is turned up high enough to register "something". During that time period almost all responses will likely be unidentified. For example, similar responses might be obtained from such different land classes as a dry meadow, a fallow field, a forest plantation emerging from grassland --even a stand of coniferous poletimber killed by fire or temporarily defoliated by insects. It may exceed the capacity of well-funded researchers to sort out the signatures from such similar responses within the next decade, though by analysis of sequential coverages identifications of at least some may well be possible.

For determining many detailed land classes (including many subclasses of forest based on species composition), a ground resolution of ten feet or less may be required. Nevertheless there are reasonably good prospects that a few subdivisions of forest will be identifiable through space sensing by 1980. There is evidence from studies of Apollo 9 photography (18) that predominantly deciduous and predominantly evergreen classes of forest may be differentiated on the imagery anticipated operationally from space in another ten years. In the Apollo 9 photos the differentiation was over the southern United States where the hardwoods were in dormant aspect (March photography). Furthermore, anyone with some knowledge of the physiography of the area could deduce correctly that most of those areas of deciduous forest were bottomland hardwoods, as distinct from upland hardwoods such as oak-hickory.

This evidence and experience might be applied to another interpretation problem in an area outside the Apollo 9 coverage--to the Blue Mountains of eastern Oregon, for example. It might be an accurate inference that similar contrasts between evergreen and deciduous forests in that region and at that season would indicate predominantly Douglas-fir and predominantly larch stands, respectively. This shows the discretion with which somewhat equivalent signatures should be used. Furthermore, it demonstrates how important it is to integrate knowledge already available with data obtained by sensing. In this inference, effective use is made of common knowledge among Oregon foresters that there are no appreciable stands of hardwoods in the eastern part of the state, and that larch, a deciduous conifer, is abundant in some areas. A further reliable inference might be made, also, by a specialist in wildlife management. Since high proportions of larch are found on deep ash soils in the Blue Mountains, on northern aspects, he could deduce that in those situations vegetation valuable as game forage would occur also as an understory associate of the larch.

Before closing this discussion it is appropriate to emphasize how application no. 1, "major land classification", from space can contribute indirectly for "detailed land classification". A man charged with administering a soil-vegetation survey estimates that the gross information that could be contributed by space sensing should reduce his present costs of data collection; which by combined photo interpretation and field work may range from 25 to 40 cents per gross acre of coverage. Presently some photography is used for interpretation which is somewhat out of date since survey objectives don't justify photography of the regions of interest each year. He estimates that current data on gross shifts in land classes registered by the space sensors envisaged for 1980--large landslides, agricultural clearings in forest and major road construction developments--should reduce present costs of data collection by about ten percent.

In conclusion, the reader is referred to several points emphasized in the tables. Through the 1980 time period the bulk of the information for detailed classification of forest and range lands evidently must be collected by aerial and ground techniques. A limited but significant amount of the data needed by resource managers will be contributed, nevertheless, by space sensors, and most of that will be derived indirectly from that contributed to "Major Land Classification". During the time period envisaged in this study very few signatures of detailed land classes may be anticipated to be recognized by space sensors.

3. <u>Timber Inventory</u>.

Annual expenditures for timber inventories in the United States by public and private agencies are considerable. One agency, the Forest Service, spends about $2½ million each year on its Forest Survey project and another $2 million on management plans. Most of those expenditures are for collection of basic data and their analysis.

Kinds and details of data collected for a timber inventory vary, depending on the specific purpose of the survey--whether for purposes of (a) broad national or regional planning, (b) on-the-ground management planning or (c) sales of timber. These three kinds of inventories usually aim to provide estimates of areas, volumes, and growth and mortality of timber. These estimates may be broken down into classes of various kinds (based on species or quality or condition) and the information may be keyed to locality by in-place mapping of stands.

Despite their similarities, one of these kinds--inventory for timber sales--does not offer the opportunities for remote sensing that the others do. One reason is because so much is usually known about the timber when a sale is initiated that remote sensing can contribute little if anything to the job. The seller may have reasonably good information about areas of commercial timber by species types, stand conditions, etc. This is usually the situation enjoyed by large government and industrial forest owners if their timber management plans are reasonably current. And in the instances of timber sales between private parties the proposed sale areas are usually so small (perhaps only a few acres of forest) that remote sensing efforts, such as aerial photographic projects for individual sales are clearly uneconomic. Even in the instances where prints of current aerial photography may be available at insignificant expense, for example, such aids are unlikely to meet many of the data collecting requirements on small, individual sales. Most of the required data must necessarily be collected by field work on the ground: to determine precise boundaries between the sale area and other ownerships, to get details on quality of wood in merchantable trees and (when highly valuable timber is involved) to get accuracy of volume estimates which cannot be obtained by even the most efficient remote sensing techniques. These latter, of course, are the kinds of data collections which are required on individual annual sales from large forest holdings, also, and it may be emphasized that cruises for timber sales even on large holdings are on rather small blocks of forest land each year. (To avoid the implication that remote sensing can play no role in appraising timber conditions on small units of forest, cross-reference is made to application no. 7 where there are prospects for effective use of remote sensing to monitor even small tracts of timber that are parts of large holdings).

For the foregoing reasons, further discussion of the "timber inventory" application is confined to inventories needed for regional, statewide or national approaisals of the timber situation and for management planning. In other words, each inventory is concerned with a sizable geographic area. Seldom would a geographic area used for management planning be smaller than a hundred thousand acres, though this might be only partly forested. It could be a million acres--the approximate size of some working circles in the National Forest system.

In examining how remote sensing may contribute to timber inventories it is helpful to consider the following groups of required inventory data in turn: (a) areas of stands or forest conditions (including logged areas), (b) volumes, (c) growth and mortality, and (d) tree condition. Presently, and for the near future, remote sensing appears to be an effective tool for collection of data in the first two groups. It is becoming increasingly effective in the third group but is effective to only a limited degree in the fourth.

As background, it should be noted that although required data are substantially the same for management planning inventories as for regional or national surveys of the timber situation, the former must be in greater detail. Thus kinds of data collected on sample plots may be identical for both categories of inventories, but the required sampling intensities differ. For example, the same definitions, specifications, and field and office procedures are used by the Forest Service on its Nationwide Forest Survey, on inventories for timber management planning, and on a number of cooperative inventories with state organizations (87). At the same time, since estimates of timber volume on a working circle may be required to the same accuracy as that for a state-wide Forest Survey estimate, the distribution of samples within a national forest working circle may be much heavier than on other forest lands in the state. This is because timber may be essentially as variable over an area of only a hundred square miles as it is over an area of thousands of square miles in the same region. Another significant difference is that a detailed map of forest types and stand conditions is required within national forest working circles and only a generalized forest map is required for purposes of Forest Survey.

(a) Areas of Stands or Forest Conditions.

During the past several decades aerial photography has proven to be highly effective for collection of information on such significant timberland area classes as sawtimber, poletimber, seedlings and saplings, recent loggings and various area breakdowns of these classes based on species composition. The considerable literature on this subject, including the Forestry Chapter of the Manual of Photographic Interpretation (2), indicates that much better resolution of imagery has been preferred for interpretation of such classes than that assumed to be available from space by 1980. Nevertheless as sensor-signature research grows out of its infancy it appears inevitable that poorer resolution than was formerly deemed satisfactory will be accepted for purposes of interpretations of many area classes.

The first uses of sensor-signatures in operational surveys of timberlands may be expected to be along the lines indicated previously under discussion of applications no. 1 and no. 2 on land classification. The reader is referred to those discussions for prospects, limitations and suitable procedures which apply to the <u>area estimating phase</u> of timber inventories. Areas of classes of forest are not only important statistics in themselves; they also are the bases for all other statistics on the timberlands. They determine the expansion factor for sample plot data on volumes, growth and mortality. Thus any error in the measurement of area is invariably reflected in every other expanded statistic.

Too often under present inventory methods there is danger that errors in technique will obscure significant trends in the timber situation. This is in the not unusual circumstance where the volume of growing stock is gradually increasing or decreasing at a rate which may be less than one percent annually. It is evident that even such a gradual change--

if consistent in one direction over a decade or so--can have a significant effect on the timber economy. It is also evident that sequential inventories at intervals of five or ten years are desirable procedures to detect such changes. Obviously the aim should be to keep sampling errors very low on each sequential inventory (e.g., within one percent at 95% confidence limits). Assuming that growing stock volume might actually change more than five percent in ten years, presumably the sampling would be accurate enough to indicate the direction of change and its magnitude. This would not be true, necessarily, when a large geographic region (or state) is involved because in such circumstances large, unknown errors in technique may bias the estimate of the base on which the sampling data are expanded. This can occur under acceptable modern procedures when aerial photography provides an estimate of the forest area on which samples are expanded. Due to operational difficulties, including unsuitable photographic weather, it is not uncommon for photography over a region to range in vintage as much as two or three years. If the region is one exhibiting much timber cutting and activities by destructive agents such as fire and insects, adjustments should be made in area estimates revealed by photography to put all data in a common time frame. Since procedures for making meaningful adjustments are so costly (e.g., involving considerable additional ground sampling), there is a strong temptation to slight or ignore them. And in such an event, despite precision of survey implied by low sampling errors, the errors in technique--which may aggregate several percent or more for two sequential inventories--can obscure not only the magnitude of a trend but its direction as well. Thus the major purpose of the inventories may be defeated. The reader will appreciate that for policy planning it is far more important to determine trend in growing stock volume over time than particular amount of growing stock in any one year. Knowledge of trends, of course, is the essential basis for evaluating the usefulness of past forestry programs and the needs for future programs.

Sensing from space can make important contributions to the area estimating phase of timber inventory by reducing technique errors due to variability in imagery and by synoptic overviews providing current, comparable data for huge geographic regions. Those synoptic overviews will also simplify classification of data by using spectral signatures and other quantifiable criteria, thereby making the analysis of imagery less subjective. In effect, <u>sensing from space offers the first opportunity for making straightforward, accurate estimates of area parameters without the costs which have been considered prohibitive in the past.</u> Until operational tests are made there is no assurance that future costs will be less than those now expended on the most reliable present inventory methods (those still subject to significant technique errors). Judgments by several experienced inventory specialists, however, indicate that some cost savings may be made through surveys which combine data sensed from space with data collected by aerial and ground techniques--in the kind of survey that will insure reliable area statistics. These judgments show that savings can be made in present costs of data collection on large inventory projects--such as that of the Nationwide Forest Survey Project. The total costs of all phases of inventory (including reporting and administration) average about 4.5¢ per commercial forest acre covered. Approximately ten percent--about 0.5¢ per acre--is spent on area estimating. Perhaps twenty percent of that half a cent might be saved through use of space sensed data. Thus the potential saving by 1980 might be 0.1 cent per acre.

Now a tenth of a cent per commercial forest acre doesn't appear to be much, but it is more impressive when expanded over the average annual coverage by the Nationwide Forest Survey and management plan inventories. Presently the Survey is on a reinventory schedule averaging about ten years throughout the country, but there is considerable pressure to shorten that cycle to about 5 years in the most active timber producing areas and hold to a cycle of about 10 years in other areas. Assuming a more ideal average cycle of $7\frac{1}{2}$ years, the average annual coverage would be around 70 million commercial forest acres. Some management plan inventories are so closely coordinated with the Survey that they may be considered to be included in that figure. Other management planning inventories on federal, state and large industrial holdings cover an additional 25 or 30 million acres annually. A tenth of a cent an acre applied to an annual coverage of a hundred million acres indicates a possible annual saving of about $100,000 through use of space sensed data. Furthermore, regardless of cost savings, use of space sensed data should improve reliability of area estimates.

(b) Timber Volumes.

For some years photographic interpretation has been used for stratification of forest into timber stand classes which individually are less variable in volume than the universe for which they form collective parts. When field samples are stratified by these classes any desired accuracy of estimate may be achieved, of course, with fewer samples than if the sampling were unstratified within the same universe. Applications of the method have been described in a number of publications including the Manual of Photographic Interpretation (2) and the Forestry Handbook (71).

Applied judiciously, stratified sampling can significantly improve efficiency of surveys, but the techniques must be tailored to the particular survey objectives and to the universe scheduled for inventory. In regions where the forest is relatively homogeneous, only very limited stratification may be desirable, perhaps separation only into a couple or three classes. Even in regions where there is wide variability in timber stands care must be taken to avoid stratification in detail which exceeds the point of diminishing returns. There may be a temptation to overstratify for volume sampling merely because it is useful to identify many different stand classes for descriptive or other purposes. For example, in an inventory for management planning, it may be useful to recognize such different classes as pine sawtimber, pine poletimber, fir sawtimber, fir poletimber, etc., each by open, medium and dense stand densities. This does not mean that it is profitable to stratify field samples for determining average stand volumes in the working circle by each descriptive, detailed stand class. Stratification, of course, should be designed to separate the classes which exhibit significant differences in volume variability. Thus if the variances of growing stock volume are approximately the same for open pine sawtimber, medium dense fir sawtimber and dense poletimber regardless of species composition, all those classes might effectively be combined into one stratum when estimating total volume of growing stock. This might be defined as a "medium volume" stratum. It is possible that all other stands in the working circle might be grouped into two other strata based on similarities of volume variances: a "heavy" and "light" stratum, respectively. In this instance the total volume of growing stock in the working circle might efficiently be estimated by allocating field samples with the heaviest intensity, obviously, to the "heavy" volume stratum. The volume of growing stock on which allowable cut depends would simply be estimated by $Ah.\bar{v}h + Am.\bar{v}m + Al.\bar{v}l$, where Ah, Am, Al, represent total acreages of heavy, medium and light volume stands, respectively; and $\bar{v}h$, $\bar{v}m$, $\bar{v}l$, represent average volumes per acre in those respective strata. Although not used in calculating the total allowable cut, volume estimates might be required and calculated from field plot data for various breakdowns (e.g., major and minor species by stand-size class), just as acreage statistics might be required and compiled for the various detailed descriptive stand classes which might also be delineated on maps, for use in management planning and in resource management.

The writer has never heard of an efficient timber inventory where the sampling strata exceeded a dozen, and a number of effective inventories for regional or management plan surveys have used no more than half a dozen strata or have used multi-stage sampling which can be a very effective technique for reducing field work.

There is increasing interest in two-stage, or double sampling, and three-stage sampling for use in timber inventories (30, 46, 50, 72). These multi-stage sampling techniques can make the application of remote sensing very effective as has been demonstrated on a number of inventory projects including those of the Nationwide Forest Survey. That project has used aerial photography with double sampling on a number of regional inventories and with three-stage sampling to survey the vast interior forests of Alaska--a region containing one seventh of the forest land in the Nation (95).

A variation of multi-stage sampling was recently tested by the Pacific Southwest Forest and Range Experiment Station (52). This incorporated the theory of probability sampling for volume and used the Apollo 9 photography for the first sampling stage. The sampling was in five stages--using several scales of photography to orient the field samples into the timber stands with heaviest volumes. That test provided an indication of how useful even rather crude imagery from space will be. This is a pioneer example of five-stage sampling in timber inventories and the first test of sensing from space for this application. A follow-up benefit-cost study should provide indications of how many sampling stages may be used before the point of diminishing returns is reached. Just as stratified sampling requires some investment in every stratum, so does multi-stage sampling require an investment at every stage. The total investment must be less than with other methodologies; otherwise potential users will naturally prefer a less complicated method.

With respect to volume estimating, the contribution to consistent, current estimates on gross areas--such as area of the major land class of forest--is in effect the greatest single contribution that may be expected from space sensors in the near future. This will be along lines indicated previously. Most of the data for volume estimating will continue to be obtained (as now) from aerial and ground methods. Those data are details of timber which cannot be resolved by the space sensors of the '80's or details masked from any remote sensing.

(c) Growth and Mortality.

None of the standard books on forest photo interpretation or inventory (71, 72, 73, 5, 2) devotes any particular attention to techniques by which estimates may be made of growth of timber by photo interpretation. This reinforces an outlook for the near future that remote sensing will not contribute appreciably to data collection on timber growth. Significant benefits from sensing in estimation of mortality (particularly stands) are more appropriately discussed under other groups of applications. Under application no. 8, "Detecting stresses...", the prospects for sensing dying or sick stands of trees (where growth is curtailed)are analyzed. Under application no. 15, "Evaluating damage ...", use of sensing to estimate stand mortality by cause is discussed; and under application no. 7, the monitoring of gradual impacts on growth of timber are discussed. At this point the writer would merely observe that remote sensing (where the sensor is more than a few feet away from the object being sensed) does not appear to be an effective technique for evaluating growth and mortality of individual forest trees. To estimate rate of growth of sound wood and cull increment in individual trees and to determine specific time and cause of death of individual trees, work on the ground is the only practicable procedure.

(d) Tree Condition.

This phase of inventory is closely related to the preceding; for the growth rate and age of a tree are two aspects of its condition. More is involved, however. A tree may be healthy and putting on rapid growth, yet is may not necessarily be a desirable tree to the forest manager. Its wood may be of such inferior quality that it should be removed to provide growing space for a tree with better market prospects. To give the modern forest manager a useful inventory, an appreciable amount of time is spent by field men in appraising the various aspects of condition of an individual tree. And the tallies they make may identify whether a tree is "dominant" or "suppressed", is "desirable" or "undesirable", and also indicate the quality of wood in its stem. Since individual trees cannot be resolved on space imagery, such data are not amenable to collection by remote sensing from space. On aerial imagery which does resolve individual trees it may be possible to determine whether or not a tree is healthy, but the other aspects of tree condition mentioned above are almost never determinable except by direct on-the-ground observation. That is a good reason why there is no prospect for eliminating field plots on timber inventories. <u>This outlook should caution those who would design inventories exclusively to requirements for volume estimation, and perhaps skimp on field plots needed to get other important data besides those on stand volumes</u>.

As shown in Table 1, sensing from space should contribute substantially to the timber inventory application by 1980. The contribution will be primarily, yet indirectly, through application no. 1 on land classification. Information on land classes should permit an accurate estimate of the data base for inventories--the area of commercial forest land--whenever it is needed. Synoptic cover from space and matching of spectral signatures should provide that estimate with only minimum supplementing from other data collecting systems--on occasions where cloud cover precludes obtaining data from space sensors and to adjust questionable identification of commercial forest. Furthermore, use of sequential coverages from space and comparisons of signatures at sample locations for different years should provide rapid, accurate measures of trends in forest areas. These advantages in area estimating will accrue in the timber volume phase of inventories also to the degree that theyexpedite such sound statistical techniques as stratified and multi-stage sampling. The prospects are negligible that by 1980 remote sensing from space will be of assistance in another phase of inventories: that of evaluating tree conditions, although some evaluation of timber stand conditions by this means may be possible. In the other main phase--growth and mortality estimating--space sensing will contribute only in aspects which are more appropriately discussed under applications nos. 7, 8 and 15. To conclude, most data collected for timber inventory in 1980 will be by ground work and aerial photography, since many items of data amenable to sensing cannot be identified with resolutions poorer than several feet. Yet even the limited, gross information about forest areas that can be obtained by remote sensing from spacecraft should prove to be extremely valuable because of its accuracy and timeliness.

4. Range Inventory.

A primary aim of this application is to determine the long-term trends of amount, kind and condition of forage on public land grazing allotments.

An inventory of the range is the most time consuming and costly part of the range analysis and management planning scheduled on each grazing allotment at 5 to 10 year intervals (85). The rewards of exploiting sensing in this field may be substantial in two respects. In the first respect, the gross data on land classes anticipated from space may well provide the bases for the first reliable estimate of the overall acreage on which the grazing of range livestock and big game in the United States depends. The writer found no one who would venture to underwrite the reliability of any of several estimates that have been made of this acreage. The best approximation of a current figure appears to be that in USDA Ag. Econ. Report no. 149 (31) which showed the combined total in "grassland pasture and range" and "forest land pasture and range" to be 865 million acres in 1964. In the second respect, range inventories are costly, partly due to the isolated locations of many ranges. Some have been programmed at 5 cents or more per gross acre. Thus to get reliability of information never before deemed feasible and to aim at reducing costs of survey, there appears justification for increased application of sensing in range inventories.

Four main groups of data collected on a range inventory are that on (a) major vegetation associations, (b) suitability class (most productive and less productive), (c) vegetation condition, and (d) soil condition. The first two classes comprise data on gross features which might be classified and delineated by sensing even when ground resolution is no better than several hundred feet. Currently some of these data are obtained by photographic interpretation (2). The vegetation types in group "a" are, of course, the same land classes and main subclasses that are differentiated under application no. 1 and 2 on "land classification", grassland, forest, brush or sagebrush, for example. The data in group "b" on suitability class relate to the accessibility of an area, whether it contains forage and, if so, whether it may be grazed without hazard to other resource values such as those for watershed protection and recreation. Some of those items (e.g., on accessibility) may be effectively obtained by sensing techniques; others may not. For instance, some rather heavily timbered areas boast an understory of forage. This item probably will not be sensed except possibly indirectly if the sensor can identify a timber type that positively indicates forage in the understory.

Studies of the Apollo 9 photography and other recent investigations have indicated that some portion of the data required in range inventory groups "a" and "b" can probably be picked up by space sensors by 1980 (21, 18, 11, 12); essentially the data derived indirectly from the application of "Major Land Classification" as indicated in Table 1 and an accompanying footnote. Other needed data undoubtedly will be obtained at the same time period from airborne sensors--primarily in the form of photography, but possibly in the form of thermal imagery to define some significant boundaries between moisture regimes.

Since the data in group "c" are very detailed or minute, the prospect is that remote sensing will play only a limited role in their collection. A few items, such as amount of forage cover, are amenable to such collection.

But even here the range manager is concerned with the distribution, relative dominance and palatability of a wide variety of plants--many very small, requiring ground resolution no poorer than a few inches for identification. Much of these data can only be obtained on the ground through tallies of field samples. The data in group "d", on soil, are partly amenable to interpretation by aerial sensing; some of the obviously contrasting boundaries between very rocky soils and other soils, for example. But here, also, some details such as susceptibility to erosion and soil depth are marginal decisions, at best, for a remote sensor and are decisions easily made by the field man at the time he is tallying data in group "c". There is a challenge for further research to determine how far the role of sensing may be applied to collection of data on condition of range vegetation and soils. Perhaps the best opportunities for use of sensors in this field will be through techniques of multi-stage sampling where ground plots are integral parts of the procedure. Yet sampling by sensor can also contribute.

In conclusion, as indicated in Table 3, it is anticipated that a small amount of information will be collected from space sensors by 1980 in range inventory. However, most of the information for that application will continue to be collected by other methods. In viewing those prospects and in speculating further into the future it appears that obstacles to sensing from space are greater in this application than in many others, because much data required to be collected on range inventories are so detailed. Remote sensing can also play an important role in monitoring temporal changes in the range, as discussed under applications no. 7 and 8 ("Monitoring...management units" and Detecting... stresses....").

5. Inventory of Wildlife Habitat.

Data requirements for an inventory of big game habitat are similar to those for range inventory. Yet for many habitat studies, wildlife specialists (as compared to game managers) often focus on detailed features of the landscape: a particular stretch of stream a narrow stringer of brush, or a thicket. They tend to concentrate often on the interfaces between, rather than on the gross areas of, forest and grassland. These differences, and the fact that two distinctive classes of ultimate users are interested in domestic livestock and in game, respectively, are the reasons for discussing "range" and "wildlife" habitat applications separately.

One indication of the importance of inventories of wildlife habitat is that the Forest Service spends nearly a million dollars a year on such inventories and associated management planning. Most of this expense is for data collection. Nevertheless wildlife specialists say that present funding does not permit the frequency of surveys that is needed to determine trends soon enough for corrective measures--for all the land and waters within national forests where wildlife management is needed. An adequate survey of fish habitat, for example, costs about $10 per acre on lakes and about $50 per linear mile of stream. The estimated total of lakes and reservoirs within national forests is 2.1 million acres and there are estimated to be 83,000 miles of streams within national forests.

Assuming the maximum tolerable interval between surveys (10 years, as shown in Table 2), an inventory of fish habitats alone would require about two and a half times the current annual expenditures for surveys of all habitats on national forests.

Benefits from habitat inventories and the management measures dependent upon them are substantial, as indicated by one study of waterfowl habitat on a national forest in Minnesota (84). There the benefit-cost ratio was determined to be more than five to one. In other instances the benefit-cost ratios have been even higher, as in Alaska where certain fish habitat improvements gave a ratio of benefits to costs in the magnitude of 30 to 1.

Zones where wildlife is the major land resource are diminishing, in contrast to the zones for general outdoor recreation, and the broad environmental zones most suitable for management of some important wildlife, such as big game, are already well known. Although this suggests restricted opportunities for remote sensing, large amounts of data are needed for many variations of habitat inventory (see Table 3). Some of these data will no doubt be collected by ground methods, but a substantial amount can be collected by aerial sensing if the quality (including ground resolution of details no more than several inches in diameter) is good enough. Also the potential for increased use of remote sensors in this field is great if for no other reason than that they have been exploited relatively little in past inventories of wildlife habitat. The writer recognizes that excellent use has been made of aerial photography in some surveys of wildlife habitat, as has been pointed out in Chapter 8 of the Manual of Photographic Interpretation (2). The relative infrequency of such applications may be inferred, though, from that publication, since most of the chapter on wildlife management is devoted not to surveys of habitat but of wildlife itself. (That important use of sensing is discussed later under application 16, "Monitoring Livestock and Wildlife").

In some wildlife habitats aerially sensed data might be very useful on a sequential basis for problem solving. One problem example is the apparent decrease in aspen, an important browse for elk and deer, in Yellowstone Park and in other areas in the Rockies. Another problem, also in the Rockies, is the evident decrease in meadows due to invasion by conifers. Sequential sensing no doubt could contribute data on trend and rate of change in the vegetation and moisture stresses that would be helpful in evaluating these problems. Even sequential space imagery of rather poor resolution may be useful in appraising habitat of wildlife affected by large fluctuations in water levels--nesting and resting grounds of waterfowl, for example.

Another promising use for imagery from space was pointed out to the writer by R.S. Driscoll of the Rocky Mountain Forest and Range Experiment Station. By imaging the relative abundance of "desert bloom" in the Southwest, which is an index of quail population, space sensing could provide an annual forecast useful both to wildlife managers and to hunters.

In conclusion, for inventory of wildlife habitat in the near future, aerial sensing (with cameras to provide details on the vegetation and thermal sensors to provide information on the moisture regime) will be useful just as for range inventory. Resurveys will be needed at intervals of perhaps 1 to 10 years to measure trends. Just as in range inventory, a number of details--on vegetation condition, amount of browsing, etc. must be obtained through field work on the ground coordinated with aerial sensing in a multi-stage sampling mode or by stratified sampling.

As indicated in the tables, some contributions to wildlife habitat inventories are anticipated from space sensors by the 1980 time period. These contributions are not expected to be as great as those to range inventories for several reasons: (a) many features of particular interest in wildlife management that might be identified by space sensing are already charted--major water bodies, for example; (b) in many variations of wildlife habitat application there is focus on detailed landscape features (requiring resolutions no poorer than several feet); and (c) there evidently is much less need for inventory of wildlife habitat than for that of livestock habitat in foreign countries (see Section VI).

In closing this discussion, cross reference is made to another application (aside from no. 16 mentioned above) that can make a significant contribution to wildlife management. That is application no. 7, "Monitoring Large Management Units". As will be noted later, wherever application no. 7 is initiated on a management unit it should be an effective substitute for no. 5.

6. Recreation Resource Inventory.

Since recreation is the most rapidly expanding use for forests and range lands in the United States, it might be inferred that recreation resource inventory is a fruitful field for remote sensing. The relations of forests, meadows, rugged wastelands and main lakes and streams provided by synoptic views from space should be useful to the planners who are looking for undeveloped locations with good recreation potential. Yet in this country a great deal is already known about the broad zones most suitable for recreation developments. They have been highlighted over the years by reports from pioneering recreationists who explored them on foot and on horseback, by surveys which may have been aimed primarily at inventorying and developing other resources such as timber and forage, and by an extensive National Recreation Resource Review of about a decade ago (66). Furthermore, in the United States planners and developers of potential outdoor recreation sites may not be particularly interested in estimates of areas of various classes of land within a recreation zone. Who really cares, for example, how much of the Teton National Park or Yellowstone is in forest or grassland or barren rocks? It is enough to know that they comprise interesting patterns of landscape. And by the same token what is the intrinsic value of a vertical photograph from air or space that flattens into insignificance the spectacular visual resource of the Tetons? That is a scene captured far better on snapshots by tourists.

There is an intermediate stage of planning, however, when remote sensing may provide timely information obtainable in no other way. This is when decisions are being approached on choice of alternative zones and/or boundaries for new recreation developments. Since those decisions usually mean losses in other wildland values that may vary by alternative choices for recreation, the data on all land resources are useful. Recent examples of such situations occurred in the Cascades of the Pacific Northwest when withdrawals of large acreages of national forest timberland for recreation purposes were being considered. If current land classification data telemetered from space sensors had been available for rapid compilation into various geographic configurations, many feverish man days of compiling could have been eliminated. Another solution with considerable merit in such situations would be aerial sensing from high altitudes directed at large zones of interest. The answers might not be derived as quickly as from a bank of space sensed data but the sensing could be tailored to give more specific answers to meet objectives.

Use of sensors to obtain data for recreation planning is bound to increase as all phases of land planning increase. A recent co-operative study by the Pacific Southwest Forest and Range Exper. Sta. and the Department of Landscape Architecture of the Univ. of California suggests how useful photography can be in bringing out interrelationships in the landscape (57). One aspect of recreation planning emphasized in that study is recognition of the scenic resources as they will be viewed by most forest visitors. Ideally, analysis of these resources should be based on views from routes (such as highways) over which the forest visitors travel. In the planning stages, however, when one of the problems is to determine optimum locations for highways, trails and overlooks, it is obvious that aerial photography offers the most feasible medium for analysis of the scenery. Not only can aerial photography expeditiously and accurately portray the various scenic patterns of the landscape, it can by stereoscopic imagery indicate enfilades and defilades in views from any ground vantage points the planners desire. Stereoscopic imagery from space might serve this same purpose, but to a more limited degree, since three-dimensional resolution is less from space than from lower altitudes.

The main collecting requirements on recreation resource inventories are for detailed data on specific, local sites (where ground resolutions no poorer than ten feet are required). Collectively, these sites may constitute less than one percent of the recreation zone forming the visual backdrop for the outdoor visitors who recreate mainly at developed sites. A study made several years ago by the PSWF&RES of the U.S. Forest Service (3) emphasized how localized developments may be, even where recreation is fully exploited and favored over other forest uses. The study indicated that full recreation use of three national forests in California would divert less than a third of the land from timber production on one forest and would divert only slightly more than ten percent of such land on the other two forests.

The kinds of detailed inventories necessary to plan developments at these localized sites are not those where remote sensing provides much opportunity for cost saving. Many man hours of ground work apparently are required, regardless, to carefully appraise immediate sources of water and provide for its distribution; to survey the microrelief and soil; and determine specific locations of service roads, hardstands, buildings, tables, fireplaces, lavatories and other developments.

In conclusion, as indicated in Table 3, space sensing is expected to provide a small amount of information needed for recreation resource inventories by 1980. This will be essentially data on extent and relationships of major land uses (derived through application no. 1). Aerial sensing should provide more information. However ground surveys no doubt will provide most of the information needed for recreation plans, since the most effort in this application is devoted to collection of details at very localized sites. Remote sensing can play a role in locating these sites but hardly the primary one. One prime determinant for recreation sites, of course, pertains to the preferences of people--where they like to go and what they like to do. Recently recreation planners have been giving much attention to such sociological data. Presumably the collection of such data will be an important part of recreation resource inventories in the future: the kind of data which remote sensing has no capability for collecting.

Cross reference is appropriate here to application no. 5, "Inventory of Wildlife Habitat" and application no. 16, "Monitoring Livestock and Wildlife", where sensing applications of interest to hunters and fishermen are discussed; also to application no. 7, "Monitoring Large Management Units". An important phase of that application may well be the monitoring of use at developed recreation sites.

7. Monitoring Large Management Units.

From one viewpoint this monitoring application is a large group of applications, in that a variety of data are collected which span the breadth of the forestry and range disciplines. But since the data are used in every day, multiple-use management, often in integrated fashion, and there are common requirements for quality and frequency of sensing, it is desirable to treat this as one application. Its broad objective is to collect data indicating trends in conditions on a geographic management unit such as a working circle or national forest. The information derived from analysis of those data is used to evaluate how well management is being performed and to correct weaknesses in the resource situation through management action.

This application is analogous to the inspections that administrators and managers now make of their properties. This has a great advantage over current inspection procedures since it will insure continuity, frequency and scope of inspections that is not possible by overworked, specialized manpower alone. At the same time it brings to bear a combination of technology and human judgment in the analysis of problems that is not exhibited in any other sensing application in the forestry and range disciplines.

Optimum application is dependent on using sensor signatures as an integral part of data handling. Otherwise there is no consistent, efficient way to compare the resource situation at one time period with that at another and thus determine whether there have been significant changes in the resource over time.

More than any other, this application gets down to the everyday use of sensor outputs. To meet frequency and resolution requirements the cost will be high. Therefore the application should be considered only in regions where there is considerable forestry and range activity and where resource values are high. Furthermore, effective use cannot be made of the sensor output unless some agency or group of land owners controls management on the predominant part of the geographic universe being sensed. These considerations argue for exclusion of some large forest regions of the United States; such as interior Alaska where there is relatively little activity or immediate prospects for it and where forest values are low. In some regions as in the South, where forest values are high, there may be difficulties in application due to broken patterns of ownership. More logical, immediate regional choices are the Pacific Northwest, California and the Rocky Mountain states where federal agencies control large blocks of real estate. Hopefully, the application might be adopted over all the mountainous areas of the western continental United States in the not distant future. As a minimum the geographic area for initiating such an application should be thousands of square miles, to keep unit costs of sensing to a reasonable figure and to insure reasonable efficiency in analysis of management data.

As an example, consider the southern half of the Oregon Cascades, embracing an area of some 10,000 square miles or more. This includes lands administered mainly by federal agencies; primarily the national forests but some national park lands and lands managed by the Bureau of Land Management. All federal agencies in the region, with opportunity for coordinated management and protection actions, might choose to cooperate in a system of monitoring sensing for management. They might also make cooperative agreements with the owners of large forest industrial holdings in that region. As a beginning, the Forest Service might initiate the system on the group of national forests in southwestern Oregon. Regardless, here is a chunk of real estate managed essentially by one agency or a small group of cooperating agencies. On this geographic unit there is a lot of business every year. Loggers are cutting timber and trees are being planted in many locations; cattle and sheep are being grazed along with intermingled wildlife. The campgrounds are many and loaded with people in summer. There are many roads and trails and many more are being built each year. There are a number of lakes and reservoirs--large and small--and other impoundments for water are under construction or scheduled. Yet, there is still a lot of country untouched by those developments.

Obviously the demands on that area for management and protection are many, varied and unceasing. And those demands are on the increase, severely testing the staff of the organization. If remote sensing offers services of value to the forestry and range disciplines this may be the opportunity to capitalize on it. To take advantage of this opportunity, however, may be beyond the capacity of any commercial sensing organization in the world today. For what management needs is initial coverage by photography over the whole area within a matter of minutes to give imagery of uniform quality with ground resolution of objects ten feet or more in diameter where contrast is good (5:1 or better). Possibly some thermal imagery is needed also. If this initial goal is achieved the management may be reasonably assured that sequential coverage to the same specifications can be accomplished at whatever intervals are

X

preferred. (As indicated in Table 2 the required frequency of application is biweekly during the growing season. This is an approximate interval which is dictated by the rate of change on the most rapidly changing, major aspects of the resource. In southern Oregon in an average growing season approximately ten, sequential, biweekly coverages might be required).

Lest these appear to be unreasonable specifications, since no organizations may be prepared to meet them at this writing, it may be pointed out that almost inevitably at least one commercial survey organization will have this capability within the next few years, if for no other reason than to meet prospective requirements in the agriculture discipline. This kind of capability is the one discussed and proposed for development in the near future by a number of people and most explicitly was recommended in a study by Katz (49) and in the report in 1967 by the Cornell Center for Aerial Photographic Studies (13). This envisages using a jet aircraft flying at about 40,000 feet or higher, similar to the modified 707 now sensing for the Air Force. That is loaded with several kinds of sensors. Incidentally, a Lear jet, now in commercial use, might approach the desired capability, yet its range and capacity would be marginal. The imagery from such a sensing operation would have much better resolution than any anticipated from space in the near future but it would approximate the synoptic quality of space imagery in that there would be uniformity in tones not possible when coverage has significant temporal variation.

It may be emphasized that there must be some tradeoff between size of region covered by one sensing flight and the elapsed time for that flight. Recognizing that the matter merits more and better study than he can give it, the writer merely suggests that the elapsed time might be restricted to no more than an hour.

Looking ahead, assume that a sensing system for application no. 7 has been in operation over southwestern Oregon for several years. The resource managers are now familiar with the signatures which identify some main land classes and with the normal changes in signatures over time on those parts of the forest where change is relatively rapid. But they must still rely on their eyeballs to interpret most changes in sequential coverages. They do this on the console display system which rapidly produces images of correlated, multispectral views and comparative, sequential coverages. Some staff members, including the timber and range specialists, observe a series of sample areas that comprise representative samples of the forest and range lands. These "permanent" observation plots give them an unbiased cross-section of conditions. Hopefully, the signatures and imagery will record such changes as a plantation of seedlings emerging from the grassland into saplings, and a sapling stand thickening into poletimber, and--more strikingly--the sudden changes on a hillside when a stand is cut or the retreat of the snowline up the hillside with the advance of Spring. Highlights of the sensing through a season might be as follows.

The retreat of the snowline as recorded by the first sequential coverages of the year attracts the attention of every staff man in headquarters: the forest engineer, the specialists in timber management, range, hydrology and watershed management, and recreation planning. For as the snowline retreats their opportunities for seasonal field work expand. The specialist in hydrology naturally has a priority interest in the snow melt. Early in the season he virtually monopolizes the console displays, studying the imagery of snow patterns, even though he knows by heart the latest digital readings showing area estimates of the snow cover and rate of melt for several districts in southern Oregon. There isn't much question about the area parameter, which sensors could measure accurately, but there are other parameters not so easily measured. (Ed. note: For more on predictions of runoff, the reader is referred to application no. 14, "Monitoring Snowfields". It may be noted, though, that whereever there is a sensing system for the comprehensive monitoring of application no. 7, the requirements may be met for application no. 14. And eventually, if all geographic units in the western mountains are covered by no. 7 there may be no need for application no. 14.)

As the season advances the other specialists spend more time studying the sensing output. The range specialist watches the rate of phenological development of the vegetation to determine the optimum time for opening allotments to grazing and the man in charge of fire control also follows that development with a great deal of interest. He knows from basic statistics on land use (such as obtained in application no. 2) the relative importance of and distribution of the various vegetation associations and their ranking with respect to fire hazard. This is a situation that changes only slowly from year to year in the aggregate. And local changes in distribution of hazardous fuel types can be adjusted as appropriate, by comparing the last sequential coverage each season with that from the year before. Those are changes such as the increase or decrease in annual grasslands containing flash fuels and the changes in recent cutovers that might contribute to an increase or decrease in fire hazard due to logging slash. Early in the season the fire staff specialist is most interested in how rapidly the vegetation is developing to a stage of flammability, as an index for the date to man the seasonal fire organization. After that date, and up to the time in the fall when he uses the sensing data as an aid to judging when to discontinue that staffing, he will be more interested in the information on fire weather procured by application no. 9 and in the fire detection and mapping applications.

During the summer the recreation specialist and forest engineer go into frequent huddles as they watch the pattern of signatures change on some recreation areas. Sometimes they will take prompt action after those huddles to divert the traffic of forest visitors away from sites where the monitor reveals the vegetation is suffering and into areas where the monitor confirms that there is lots of healthy greenery.

The timber management specialist probably spends more time than any other staff man in studying the sensing output during the summer, beginning shortly after the roads are opened for logging. He looks particularly for any differences in the normal sequence of signatures in localities where current logging is underway. Whenever there is something different, he confers with another staff man--the engineer or watershed specialist, perhaps--anticipating that there might be some deviation from good practice in road construction or in slash disposal. And a field trip may be scheduled to the location in question. Sometimes the trip will reveal that the difference is due merely to a random variation of the normal pattern. Possibly an unusual topographic situation or variation in ground cover has caused a deviation from a "typical" signature, but he doesn't begrudge the time he takes for that field check as he recalls the countless hours he has spent on the ground trying to find the problem localities before the sensor was available to narrow down the zones for checking. On some field trips, though, he finds something that calls for management action. It may be an unforeseen development calling for an improvement in management policy; it may be a noncompliance with timber sale regulations which he brings to the attention of the logging operator.

Near the end of the growing season the range specialist again takes particular note of the readout and imagery on phenological development preparatory to closing the grazing allotments. The staff men charged with pest control also spend considerable time studying the data. Not only are they interested in the sequential data for the current season but often they come to the console requesting data on previous seasons, trying to pinpoint areas where the sequence of signatures doesn't fit the pattern expected in healthy stands. This requires the most sophisticated interpretation effort of any, considering the large number of variables in the forest population in terms of species composition, stand ages, and topographic situations and site. And even when there is a strong indication of an unhealthy situation it is by no means clearly evident whether the stress is serious. It may be temporary due to moisture stress in an abnormal season or to some disease or insect not permanently crippling. But it could also be an indication of a developing, killing epidemic or insidious air pollution. Therefore some problem localities are earmarked by pest specialists and scheduled for field checks. In some instances there have been field reports that an endemic forest pest is increasing, and the sensing gives a better measure of the magnitude of the threat.

Naturally the timber management specialist coordinates closely with the experts in forest pests and much of that coordination is to appraise progress of plantations. For example, it is probable that one day they question the condition of the plantation of pine on Bear Mountain, a relatively inaccesible area, and together they study all the digital readout for that locality that has been obtained during the past several years. In so doing, they select sequential pictures as well. They also put the pictures of another locality on the console for comparison-- that of the plantation on Brushy Knob of the same species and age. That one the timber management specialist knows is healthy. He visited it only last week and that comparison reassures them about the plantings on Bear Mountain.

There must be some careful preparations before the foregoing projection can become an effective reality. The application requires a good data base with geodetic positioning of detailed land classes equivalent to those discussed under application no. 2. These classes must be identified by locality through a reference system such as geographic coordinates or the standard state reference grid printed on USGS maps. The application also requires an efficient data handling system. If the application were to be initiated by the time a commercial concern offers an aerial platform capable of delivering the required sensing, that might be no more than two or three years away. Provided the geographic locality were similar to that used in the example discussed previously and the agency were the Forest Service, it is not unlikely that a data handling capability could be developed in the same time span. There is some encouraging research aimed at automating the handling of data sensed over forest and range lands--such as the work by Langley at the PSWF&RES on his Wildland Resources Information System (86) and the work by Lent (56) and others at the Forestry Remote Sensing Laboratory, University of California.

One phase of that kind of research is to establish sensor signatures, and much more effort is needed on that phase. As long as the overwhelming bulk of data interpretation is done by humans any system for handling masses of data is greatly handicapped. It is evident that until a considerable number of sensor signatures are developed--subject to rapid identification by humans, if not necessarily by machines--the monitoring of large management units is economically questionable.

Annual costs of photography alone for the 10,000 square mile Oregon example may be no less than $200,000 (at $20 per square mile). That is based on efficient jet operation at about 40,000 feet above the terrain where there is no great air traffic problem. Also it assumes complete coverage but with small-scale imagery (1:80,000 or smaller) which could be obtained in a very few passes, and that there would be about ten, complete, sequential coverages per year. It may be assumed added costs for data handling would be at least double those for sensing.

A minimum investment of forty dollars per square mile or about 60¢ per acre each year is not to be made without some prospect of substantial continuing benefits of monitoring in multiple-use management. That prospect cannot be visualized by looking at only one or two functions of management. Timber sale administration, for example, should not be charged with more than a fraction of that 60¢ per acre. Even though remote sensing offers an opportunity for less costly administration of sales, the total expenditure by the Forest Service for all phases of timber sales, when prorated against all commercial acreage in the national forests, is only 50¢ per acre. There must be a number of prospective benefits aside from those anticipated in sales administration before application no. 7 can be a reality.

If the hypothetical example given previously suggests the many important problems that management might solve with the aid of sensing, it may also suggest that data from space sensing will not be too helpful for this application in the near future. Only insignificant amounts of space data are anticipated to be useful for this application by 1980, because imagery from telemetry is anticipated to be too poor in quality and coverage too infrequent. Regarding quality of imagery, an exception is that the telemetered snowline will probably be contrasting enough and in enough detail to permit reasonably good estimates of extent of snow cover, as recognized in tabulation and discussion of application no. 14. The frequency of coverage will not be ideal for monitoring the snowline, however.

One prospect for very substantial benefits to multiple-use management is in detection of stresses on the vegetation, discussed under application no. 8. Incidentally, this suggests caution to those who are estimating values of possible benefits from sensing against a possible duplication, under some other applications, of benefits that will be contributed by application no. 7. Some possibly duplicating applications are: numbers 1-6, 8, 13-15. The writer emphasizes, however, that the part of total forest-range universe in the United States on which such duplication may be expected in the near future, is a relatively small proportion. For example, with respect to application no. 3, "timber inventory", most of the timberlands in the United States are in small individual holdings under variable management policies. Thus application no. 7 is not a realistic prospect on small holdings except through unusually close cooperation in management by groups of land owners.

8. <u>Detecting Stresses on the Vegetation.</u>

This is one of the most challenging sensing applications in the forestry-range disciplines, because prospective benefits are so great and so are the technical obstacles. On the one hand there are prospective savings through reduction of the tremendous annual losses in productivity of forests and ranges due to impacts of insects, diseases, drought, overgrazing, air pollution and other damaging agents. The value of only part of those losses--that in volume and growth of wood on U.S. timberlands due to insects and disease--is estimated to be about $140 million annually (79). And more than $6 million is spent annually just to control two specific forest pests alone: bark beetles and blister rust disease. On the other hand the road of research may be long and difficult.

The magnitude of needed research is pointed up by a recent report by a panel of outstanding forest entomologists which indicated that adequate control of forest pests is one of the greatest problems forest managers face (32). Apparently there is opportunity for remote sensing to contribute significantly to the solution of that problem. At the same time this possible contribution depends upon research to establish sensor signatures for both healthy and sick stands of vegetation. To illustrate the complexity of signature research, some investigations on range vegetation are cited. The research was in a test area where ground truth was available on 18 specific associations dominated by big sagebrush, low sagebrush, silver sagebrush, western juniper and crested wheatgrass (67). Preliminary examination of the training samples indicated that 4 of the 18 associations might be correctly classified by multispectral scanning techniques even though all of the sagebrush communities were similar. There were, however, strong similarities in responses from the universe of 18 associations. This suggests that either the initial selection of training samples did not accurately represent pure subjects or the reliability of automatic recognition from this single set of growing-season imagery might be less than has been achieved for some agricultural crops.

By no means do those preliminary results indicate that the foregoing research will be unprofitable. On the contrary research at greater depth into these subjects may pay excellent dividends. Nevertheless it must be recognized that considerable trials beyond the test area are needed to prove whether even 4 of the 18 associations can be consistently identified by four signatures represent "normal" stands. Then there is still the task of determining "normal" signatures for the other 14 associations and various "unhealthy" signatures to indicate specific sicknesses that the various associations in this one range environment are susceptible to.

The reader will not be surprised at the amount of research it may take to establish spectral signatures if he recalls the close similarity in visual appearance of a variety of stands that are significantly different in at least one respect. It is a logical inference that sensors may have the same difficulty in recognizing those differences regardless of the capability of machines to sense things the eye cannot. The problem is confounded by the difficulty of maintaining fidelity of sensing on sequential coverages--a difficulty that concerns more than one researcher in this field.

A few, very useful signatures of harmful stresses on the vegetation may be established, apparently, without the tremendous task of research implied for those just discussed. These are the signatures of damage that forecast more inevitable damage to come unless prompt management action is taken. As an example the writer recalls a survey he participated in nearly two decades ago (39). The prime objective was to estimate the volume of timber killed by combined impacts of blowdown and bark beetles throughout the Douglas-fir region of the Pacific Northwest and to chart the locations of concentrated damage where timber might be salvaged. That considerable effort, described under application no. 15, "Evaluating Damage...", contributed in part to another objective: detection of centers of incidence from which further damage might spread through an expanding epidemic of bark beetles.

The damage began with two serious winter storms resulting in widespread blowdown and breakage of timber by wind and freezing rain. Local foresters suspected there had been severe damage to timberlands immediately after the storms had passed but they could not guess these marked a catastrophe that would kill ten billion feet of the most valuable timber species in the Nation. They could not know either the magnitude or locations of the damage by blowdown until the concentrations were mapped systematically from the air. Nor, even knowing how windthrow favors insects, could they visualize the magnitude of subsequent kill of standing timber by beetles--from the broods that expanded for two seasons in windthrow--until after the usual delayed fading of foliage marked it. Thus, before marshalling for salvage began, the beetles had greatly increased the mortality. Many of the areas of blowdown were five acres or more in size--the kind of features that would contrast with adjoining standing timber--even on telemetered imagery. Obviously sensing could not help minimize the destruction by wind and ice. However, it could, in such a circumstance, greatly reduce the potential destruction by insects. Men could not get to all the concentrations of windthrow in such a vast forest region before the insects did; but men would know where those concentrations were, virtually as soon as the beetles did. Without doubt the first cloud-free pass of a vidicon sensor after an ice storm would pick up the signatures of damage: either the blazing white line painted by the "silver thaw" across miles of timber or the persistent scar underneath where the trees were broken or windthrown.

Further examination of that Douglas-fir example indicates other variations of signatures that forecast damage. Naturally, there are always beetles in Douglas-fir forests, and that endemic population is not distributed uniformly. There are also "flags" to mark where the populations are heaviest--clumps of recently killed trees, perhaps only single dead trees. These flags, of course, are what aerial observers look for in their annual pest detection flights. These flags or markers might also form sensor signatures to identify zones (perhaps several hundred acres in size) where endemic beetle populations are concentrated; yet where beetles have attacked far less than one percent of the stand. Zones where flags are more abundant--yet still representing a very low proportion of the stand--together with signatures for zones where blowdown is concentrated would no doubt indicate localities where insect control could be most effective--since attacks of catastrophic proportions might be expected unless expansion of beetle populations were checked. Still another signature--recognizable as the foregoing through distinctive pattern in the forest--would be significant. This is the one for zones where recently killed trees form substantial proportions of the stand. That signature would be, perhaps, of no value in planning for control of beetles since the abundance of flags would be prima facie evidence that much of the stand is killed (even many trees still exhibiting green foliage) and the remainder probably foredoomed to early death. It would be a useful signature, however, to indicate areas where timber salvage should be given priority before the wood deteriorates.

This conclusion that signatures may be registered by space sensors for timber containing so few dead trees that they may comprise considerably less than one percent of the stand is based largely on indirect evidence. The reader will be familiar with the phenomenon that the eye may be impressed with some contrasts at a distance that are not so impressive on closer view, due to the concentration of a great amount of detail into a narrow angle of view. For example, a bloom of flowers over a broad hillside tends to be more striking at medium distance than in a closer view. There also is more direct evidence: an example involving visual observation and space photography that was called to the writer's attention by Dr. Poulton of Oregon State University. He said he was flying a few thousand feet above the ground across the southwestern United States at the same time that some of the photographs were being taken from Apollo 9. Since this was in March, he knew that some major associations in that region were showing spring growth activity. Yet by visual observation he did not note any particular contrast in the usual grays of the landscape. After telling me that, he pointed to some differences in tones on the color infrared photographs taken by the Apollo flight on the same date. There was no doubt that there were contrasts (not striking, but recognizable) in the tones between areas of some major associations such as the mesquite desert grassland, the short-grass steppes and the oak woodland. One reason for the contrast was that some associations were exhibiting new growth, others were only beginning to put on new growth or were dormant.

The foregoing suggests how a specialist can use sequential coverages to great advantage in phenological monitoring phases of application no. 7. It also tends to confirm how signatures based on average contrast over sizable areas of terrain may be distinct enough for use in the automated sensing systems of the future. This also indicates why resolutions of specific details and tedious "eyeballing" by humans will no longer be necessary for some data analysis. Evidence of this kind, no doubt has influenced a recent change in viewpoints by interpreters in that they now are willing to accept poorer resolutions than previously for identification of certain phenomena or objects; the change in viewpoints noted by Katz in his paper on the NRC summer study (49).

There are other examples of productive research into visual symptoms of damage or threats of damage to vegetation that can be exploited by sensors. For example, recent research at the PSWF&RES indicates that visual symptoms (yellowing and mottling of vegetation) may be reliable indicators of air pollution stresses on vegetation. Since these symptoms may be detected long before the tree succumbs--perhaps as long as 10 years before its death--presumably there is time enough for action against air pollution.

But there is another large area for sensing of vegetation stresses, and potentially the most profitable one--if it can be exploited.

That is in detection of previsual symptoms of stresses on the vegetation, so that damage or threats of damage may be identified much earlier than when reliance is only on detection of visual symptoms. Progress on research into this area has been slow. As yet there are no operational techniques for previsual detection of stresses.

This slow progress is partly due to the more laborious search for earlier symptoms than for the later, visible symptoms of attacks by some pests. It is due partly to the difficulty in searching for symptoms of insidious pests which (like cancer) may not exhibit conspicuous warning symptoms until much of the stand is condemned to death. An example of research progress will be given in each category. In the first category, there is some progress to establish previsual symptoms for bark beetle attacks on ponderosa pine. The objective was to establish some easier means, other than the arduous and costly ground examinations of the tree trunks, of detecting which trees still exhibiting green foliage had been infested and weakened by beetles. Research to date shows that "old" and "recent" mortality can be differentiated from live trees by using an airborne multipsectral scanner. There are also indications that consistent signatures may be established whereby thermal sensors can discriminate "hot" trees that are infected from "cold" trees that are healthy, in pure stands of ponderosa pine where bark beetles are primary pests (40). Progress is not so encouraging in trying to establish thermal sensor signatures for Douglas-fir trees infested with root rot (90). This research is complicated not only by a wide range in site, topographic and stand conditions for this species, but also by the insidious nature of the disease itself, which experts tell us is often difficult to identify even by close examination on the ground. One encouraging preliminary result of this study is that holes occurring in the forest canopy as groups of trees succumb to root rot may contribute to a sensor signature for stands where centers of infection are heavy. Provided this feature yields a valid spectral signature the prospect of detecting major stresses on stands due to root rot is good. In effect this would be a signature of damage that forecasts damage to come, just as with the signature for increasing beetle populations that forecasts an epidemic of insects. Similarly, it would also be a signature that could be picked up by space sensors.

One complication in the operational use of thermal sensing to detect changes in health of vegetation is that there are stresses in the ground moisture regime. Thus an otherwise healthy stand of vegetation under temporary stress of drought may be expected to register differently than when ground moisture is abundant. Careful correlation of hydrologic information with sequential sensor outputs will be required in such situations to determine whether there is any other stress than temporary drought.

The foregoing pertains to harmful stresses. There is also an important role for sensors in evaluating effects of cultural treatments on forests and ranges. Aerial sensors, particularly, should provide imagery of suitable resolution to monitor the reactions of forest plantations and range seedings to treatment by fertilizers and irrigation, thus providing excellent management tools. Where the treatment is over a large section of terrain, there is naturally an opportunity for space sensors to also play a role, since signatures indicating changes in plantings or seedings due to treatment should be evident in magnitudes similar to those due to phenology mentioned previously. It may be noted that on large management units this application may be preempted by application no. 7. Considering the extent of forests and related wildlands in this country, this is not a likely preemption over a large proportion of those lands in the foreseeable future.

In conclusion, as the tables indicate, a small but significant amount of information about harmful stresses on the vegetation is anticipated to be contributed by imagery from spacecraft by 1980. Considerable additional useful information on stresses should be contributed by that date from high-level aerial photography. Both photographic and thermal sensors in low-flying aircraft are expected to contribute substantially to this application in the near future. In the long term, the prospect for increasing the use of sensors from high altitudes for detecting stresses on the vegetation depends to a large degree upon success in several fields of research and development. One example is spectral signatures research and refinements in instruments to give better ground resolution. Although resolutions no better than hundreds of feet apparent on telemetry from space will suffice to indicate stresses which extend over wide stretches of terrain, much better resolutions (on the order of a few feet or less) will be needed to detect some economically significant stresses.

9. Fire Weather Forecasting.

Since fires are periodic threats to forest and range resources a considerable effort has gone into research on methods for effectively planning for preventing, detecting and controlling wildfires. This has involved aggressive, continuing research into phases of remote sensing that are strongly supported by several agencies including the military.

An important part of fire planning--forecasting fire weather--depends, of course, upon timely reports of humidity, wind and temperature from representative portions of the forest-range universe. Over substantial sections of some regions ideal reporting stations are at inaccessible locations. Thus current, reliable forecasts have not been possible--or have been very costly at best. To solve this problem, fire fighting organizations foresee widespread use of remote controlled ground weather stations in the near future. In one large region containing many inaccessible areas--the Columbia River Basin--there is already a fair network of weather stations (about 2,000 stations). The network is used by the Bonneville Power Administration and U.S. Corps of Engineers for forecasting water runoff and streamflow. This network of microwave and teletype would be very useful as a nucleus for fire weather forecasting in the Pacific Northwest, though probably more readings would be required, such as those on humidity, in addition to those now taken.

For a few years the fire weather data might be picked up and relayed by ground stations. But by 1980 it is reasonable to expect that, on request, a communications satellite will be capable of querying the ground weather stations in a particular region and transmitting the readings (by relay from some central ground station) to regional fire control headquarters such as those in regional offices of the U.S. Forest Service. This technique would take advantage of the continuous surveillance of a communications satellite at about 22,300 statute mile altitude apparently in fixed geosynchronous position over the equator (47). For transmittal of fire weather data, the satellite system would replace most of the telephonic facilities which often are overloaded. To minimize conflict with other traffic via satellites, fire weather reporting should, of course, be limited to those seasons when such a service is urgently needed. During the 1980 time period it is assumed that satellite service for fire weather communications will be limited to regions where risk from forest and range fires is great and to those periods when fire danger is the most critical: when combinations of high temperature and low humidity (and sometimes strong wind) bring flash fuels close to the ignition point and favor rapid spread of flames. The communications traffic on fire weather in other situations is presumed to be handled by ground facilities. This assumes that the same remote-controlled ground stations comprise a large part of the basic network used in both satellite and ground systems.

In discussing potentials of remote sensing, one aspect of fire weather forecasting merits particular emphasis. That is the tracking of thunderstorms and monitoring of cloud-to-ground lightning strikes. These strikes are, of course, very hazardous to wildlands. Each year about 7500 lightning-caused fires occur in the United States. In some regions lightning is the most frequent cause of forest and range fires. In the Rocky Mountain States, for example, lightning causes some 70 percent of the fires in wildlands (33). That this is a continuing, important hazard to forest and range lands is indicated by estimates by ESSA that at any given moment there are 1800 thunderstorms in progress over the surface of the earth and that lightning strikes the earth 100 times each second (89). Assuming that these discharges are randomly distributed so that forested lands receive them in proportion to the amount of surface forested, there would be more than half a million discharges over forest land during every 24 hour period.

Research in remote sensing of thunderstorms by the Northern Forest Fire Laboratory is encouraging. Much of the research has been aimed at detecting lightning strikes by some detector (radar and others) located on a mountain top. One detector recording luminosity can detect strikes up to 50 miles away in broad daylight. In such a situation the eye could not detect strikes further than 25 miles away. Incidentally, fire lookouts are believed to see only half the lightning strikes that occur, and in severe thunderstorms, when visibility is severely restricted, only about 25 percent (33). Sensors have been developed to look at the electrostatic field to discriminate between cloud to cloud discharges and the dangerous cloud to ground discharges and to determine which of the latter are the fire-causing, continuous types of lightning (35). Luminosity sensors are now being satisfactorily used for the purpose because they are simple and their signals are easy to evaluate. In Alaska tests currently are underway with airborne sensors aimed at developing a monitoring system to detect fire-causing, cloud-to-ground strikes.

There is no immediate prospect of using sensors from space to locate dangerous cloud-to-ground lightning strikes, due primarily to the limited range of the sensors now in development. Nevertheless, there are foreseeable prospects that space platforms will be used to trace thunderstorms that are potentially dangerous as fire hazards to forest and range lands. The Forest Service is now planning cooperation with ESSA in meteorological studies to follow synoptic patterns of thunderstorms. Yet improved coverage by meteorological satellites is needed. Thunderstorms have durations of a few hours at best and are often measured in minutes. One research study showed that about two thirds of all storms last no more than an hour and a half (33). Neither the Tiros nor the Nimbus series of satellites has given the frequency of coverage needed to monitor thunderstorms effectively, despite good jobs of monitoring storms of longer duration, i.e., cyclones and hurricanes (77).

By 1980, meteorological satellites similar to those in the proposed Aeros series (77) should be in orbit. These satellites in a geosynchronous, equatorial orbit should have the capability for virtually continuous surveillance of weather. Resolution of cloud detail should be somewhat better than under former systems--a fraction of a mile (60). Those capabilities should permit tracing the synoptic patterns of thunderstorms and, hopefully, detecting which ones offer the greatest fire threats to vegetation resources, i.e., with potentials for cloud to ground strikes of a continuing nature. In the near future it is likely that the potential for lightning-caused fires will be predicted by numerical models based on data supplied, via satellite, from the network of remote-controlled, ground, weather stations.

In the foreseeable future, when space sensors are monitoring the synoptic patterns of thunderstorms and there is coordinated aerial and ground sensing to trace which storms have the damage potential of cloud to ground strikes, the fire control job should be greatly simplified. Then the fire control organization not only can be readied for efforts against the most likely localities where lightning-caused fires may originate; it can also act prior to strikes, possibly through such means as cloud seeding (34) to neutralize the most threatening storms.

In conclusion, it may be noted that for fire weather forecasting the sensing must be on a daily basis and in some respects on a continuous basis; just as in the next two fire applications to be considered. Fire weather forecasting is the only one of the three applications directly concerned with wildfires where any significant contribution from space sensing is anticipated by 1980. In trying to objectively appraise the prospects that are painted in such bright colors by some researchers and fire control men and in more neutral colors by others, the writer estimates that the contribution from space sensing in fire weather forecasting will be limited, as shown in Table 1. As shown in Table 3, that contribution is rated "moderate" in amount. Relative contributions from space, as compared to data collected by other media, are estimated to be greater to fire weather forecasting than to any of the other forest-range applications except no's. 1 and 14. This is not dependent on use of data from ERTS vehicles as such. The contributions are anticipated to be from communications and meteorological satellites.

10. <u>Detecting Wildfires</u>.

It has been estimated that costs of forest fire detection in the United States now exceed $10 million annually (43). At the same time fire control organizations are continually trying to improve detection techniques as one means of reducing costs for fire control which now approach $350 million a year and to reduce the destruction of natural resources by the more than 100,000 fires that occur in this country each year. An indication of the toll taken by fires is that the value of unsalvaged timber and the timber growth loss destroyed each year is estimated to be more than $20 million (79).

A significant amount of research is in progress to improve detection. Most of this involves remote sensing techniques to give more reliable, timely detection. The combinations of visual air observation, ground patrols and fire lookouts in current use do not insure rapid detection when visibility is poor.

There are indications that integration of remote sensing into the fire protection system will insure consistently rapid detection, and some authorities believe that detection costs will also be reduced. Current research is concentrated on developing thermal sensing and operational tests have been made of the most promising thermal techniques. These include use of sensing windows in the 3-6 and 8-14 micron wavelength ranges to achieve ground resolution on hot targets as small as 20 feet in diameter. With presently available equipment this means use of aircraft flying at about 15,000 feet above the ground. While results of these tests have been encouraging they do not forecast that thermal sensing is a panacea for all fire detection problems. As Hirsch, a leading researcher in this field, has pointed out: "...targets...in forest fire applications are at least 500 degrees F. hotter than their surroundings. This has led many...to assume that temperature and... resolution requirements for forest fire surveillance are much less stringent than for...other...(thermal) applications. This assumption is not valid. We must know the locations of fires with respect to topography...and imagery must be good enough not only to pinpoint hot targets but also to resolve fine details of terrain." (42).

A prototype fire detection system now being refined was given its first thorough testing in the 1967 fire season and the results were reported in "Fire Control Notes" in 1969 (58). This test covered a study area of 41 national forests in the western United States. The system, installed in a Convair T-29B aircraft, included three items not found in other infrared systems: (a) a rapid film processor, (b) a target discrimination module (TDM) which automatically marks hot targets on the film, and (c) a Doppler radar navigation system which provides accurate, instant information on an aircraft's position.

More than 1400 target marks were recorded on the film during this test. Of these only about 600 were interpreted as hot targets; the remainder were interpreted as false alarms: road, snow, water body, etc. (Since the test, the TDM system was redesigned to reduce if not eliminate that discrimination problem.) Of the 601 hot targets, 35 percent were interpreted as wildfires; though some later proved to be campfires, slash fires, unknown and unconfirmed, etc. The other 65 percent of the hot targets were incorrectly identified because of incomplete ground intelligence. This merely confirms, of course, that regardless of detection method there must be good intelligence on location of camping areas, hot springs, scheduled slash burnings, etc. so that wildfires may be screened out.

Actually 134 wildfires in various stages of control were scanned. Only 40 Of those were unmanned fires when scanned--the kind the system is aimed to detect. The TDM detected 58 percent of those, whereas the conventional methods had detected only 35 percent. Several of the 14 fires that were detected by the IR system and not by conventional methods could have become serious if they'd remained undetected for long. This apparent substantial advantage of the thermal sensing system over the conventional methods must be weighed against a disadvantage. The scanner picked up 55 unconfirmed targets that were within the universe interpreted as wildfires. Despite a considerable amount of time spent in searching by suppression crews, none of those targets could be found or identified. Some could have been small fires that went out naturally; others false alarms. Lookouts later reported flareups at two of the unconfirmed locations. Regardless, this matter of unconfirmed reports of fires poses a problem for further research. This also underlines the importance of the patrolman on the ground. He will be needed in any event to contact the public on other matters along with compliance with fire regulations. Only he can surely verify whether the hot spots in heavily used parts of the forest are due to controlled heat sources such as barbecues, cars, motorcycles, clusters of rollicking teenagers, or many other nondangerous threats to the forest. And he, of course, is a first phase attack unit on any heat source that may threaten the wildlands. He is not only a priority unit in the detection phase of fire control, he is also a key unit in the suppression phase. In effect, he is a more efficiently designed unit for detection and suppression of many forest fires in their incipient stages than the most sophisticated combinations of machines that man is likely to devise.

The foregoing indicates why most men in fire control are definitely interested in the use of sensing to supplement other means of fire detection yet why none of those interviewed by the writer would estimate probable cost savings by this technique.

One experienced fire control man visualized the incorporation of two phases of sensing into the fire detection system along the following lines in the near future. As one phase there would be fast jet flights at 15-20,000 feet above the terrain giving thermal readouts on film. These flights might be every few hours across main danger zones at the peak of the fire season, designed to give readings on suspected wildfires. Flights, of course, would not be halted by darkness, but readouts would not be possible through clouds. Ground headquarters would monitor these readings, screen out those fires known to be under control such as in campgrounds and would schedule checks of suspect locations either by low flying aircraft scheduled in the next phase or by suppression crews.

In another phase, flights would be made by slow-moving planes at low level only a few thousand feet above the terrain. Most of these flights would be in daylight and would take advantage of both visual and thermal sensing. Part of the coverage would be systematic, but at longer intervals than the high level flights (possibly only once a day). That coverage would be scheduled only over zones where fire danger was most critical, where flash fuels were abundant, or where terrain was so inaccessible that there would be a much greater logistical problem in fire control than normal. The other flights would be on a directed basis--to check on suspect locations revealed by the high level flights, to cover areas obscured to high level flights by clouds, and to monitor areas after lightning storms.

In both phases, interpretation of imagery might best be done in the aircraft, and fire locations referenced to a geographic grid, then radioed to fire control headquarters. Telemetry of imagery to headquarters apparently would be a less preferable alternative due to loss in resolution of targets which may be barely detected on the original imagery.

It is possible that with such a system there would no longer be need for lookouts. Yet ground patrols presumably would still be required. Also if fixed lookouts (humans or TV stationed on the ground) were to be eliminated they would take with them the virtually continual surveillance for one of the surest indicators of a fire--its plume of smoke. Prime reliance for detection, then, would be on visual observation of smoke plumes by the observer in an aircraft (perhaps only a daily pass) and the capability of the sensor to detect the flames. If main dependence were to be placed on the latter, aircraft flights must be close enough to insure that tree trunks do not obstruct the line of sight between sensor and a fire. Research indicates that tree trunks may completely obscure line of sight to a fire when the aspect angle exceeds 60 degrees from the vertical in moderately stocked timber stands and when it exceeds 48 degrees in heavily stocked stands (93). Thus to effectively sense fires in dense stands of timber may require halving the distance between flights over those required to effectively sense fires in moderately dense stands.

Looking further into the future, the highest level flights might be made from spacecraft. That might be no realistic probability until thermal sensors were replaced with microwave sensors; and as indicated under an earlier section there are some technological obstacles in using microwaves that are not likely to be solved within the next decade or two.

In conclusion, as noted in the tables there is little prospect of a contribution from space sensing in the application of fire detection by 1980, because of inadequate resolution and not enough frequency of coverage. For the near future that application should depend upon close coordination between thermal sensing and visual observation from aerial platforms, lookouts and ground patrols.

As a footnote it may be mentioned that even the crude space imagery expected by 1980 will reveal the locations of some forest fires. Space imagery, with resolutions no better than 100 feet, should certainly pinpoint smoke plumes from fires that are well underway. Also, if a protection organization is functioning, virtually all of those fires (recognizable on the infrequent and poorly resolved imagery from space) would already be the focus of suppression efforts; therefore such imagery might be "interesting" but hardly "important" to fire detection organizations.

11. Mapping Wildfires.

Much of what has been said about fire detection applies to the fire mapping application as well, with one main exception. Fire mapping is always needed on a directed basis. There is no general limitation on frequency of coverage, except as that applies after sensing has been committed to monitor a wildfire. Once monitoring begins, coverage is desirable about four times within every 24 hour period. Several investigators recommend the following flight times for thermal sensing: 0400, 1000, 1400-1600 and 2000-2200 hours (41). This coverage, they advise, should be most useful to the fire boss in deployment of suppression forces. It also avoids the hours immediately before and after sunrise and sunset when, as they report "...thermal washout, low sun angle, and rapidly changing conditions make...difficult...good terrain detail on IR imagery." One of these investigators also advises in another publication that "Sorties made at night yield the best imagery." (8). It is noteworthy that this is time when fire behavior tends to be quiescent.

Lower level flights are recommended for fire mapping than when thermal sensing for fire detection. Flights between 4,000 and 6,000 feet above the terrain are recommended with present equipment for effective mapping of fire perimeters. (For an excellent discussion of the present state of the art the reader is referred to "Project Fire Scan, Fire Mapping Final Report" (41). Fire control men have made good use of thermal sensing flights on several large uncontrolled fires; the kind where blankets of smoke may obscure observation of a fire front by any other method--the kind of situation exemplified by the Sundance Fire in Idaho during the disastrous 1967 fire season (4).

One investigator has estimated that in a few seasons of application infrared mappers have reduced fire suppression costs by more than a million dollars and have saved more than ten million dollars in resources that would otherwise have been consumed (8). Apparently few fire bosses care to subscribe to such a specific estimate, though most appear to welcome infrared sensing as an aid to fire control. They may be thinking of delays in the drop of the imagery to the fire camp caused by palls of smoke and turbulent air or of situations when cloud cover precludes use of thermal sensing--situations not too uncommon when wildfires are raging out of control. They may also be thinking, as one seasoned fire control chief was when the writer interrogated him, that on really destructive fire the critical aspect concerned neither detecting nor mapping the fire. The main problem confronting the fire boss was a logistical one of marshalling enough forces and committing them soon enough at the right point on the fireline to suppress the flames--when there was no question where that commitment should be made.

In conclusion, as shown by the tables, there is no expectation that sensing from space will contribute significantly to the fire mapping application by the year 1980. Just as with fire detection, sensing from space may reveal where large fires are raging and may even trace some main perimeters during the moment when the space sensor passes. But the resolution will be so poor and the intervals between observations so great that no particular contribution may be expected. In the further future, when microwave techniques are perfected and space sensing is virtually continous with good resolution, there are prospects that sensing from spacecraft can make a substantial contribution. For the near future, the fire boss must continue to rely on observers in fixed wing aircraft or helicopters, supplemented by thermal sensing from aerial platforms--and by reports from firefighters returning to the camp from the fireline for his decisions on committing suppression forces.

12. <u>Monitoring Air Pollution Caused by Wildfires and Prescribed Burning</u>.

Recently there has been considerable concern over the amount of air pollution that may be caused by wildfires and slash burning. Forestry authorities are giving increasing attention to this problem. In the West, particularly, this includes investigation into various other methods of slash disposal as alternatives to burning. In the South the concern is oriented on the large acreages of forest land where burning is prescribed (on some 2-2½ million acres, annually) to reduce fuels and increase forage. Foresters are also discussing the possibilities of tracing movement and amount of smoke over forested areas by remote sensing under the assumption that fires are serious threats to air pollution. To the best of the writer's knowledge no specific investigations have been made or are underway into the use of sensing to evaluate this problem; therefore any conclusions are speculative. Nevertheless, photography could certainly be useful for monitoring smoke concentrations. Also sensing in the thermal infrared and microwave regions appears promising.

Research apparently is needed to answer such pertinent questions as the following: How much wood smoke (aerial extent in square miles and density) is a significant contributor to air pollution? Does the tolerable amount of smoke vary appreciably by locality? That is, may a large quantity of smoke over a relatively undeveloped forest region ordinarily dissipate over that region without constituting a pollution problem? Does this depend greatly on the local topographic situation? Is a few square miles of smoke concentrated over a small inversion zone more serious than how many square miles over other zones? How frequent must monitoring of smoke concentrations be? Should frequency of monitoring vary significantly by topography or other situations which cause inversion zones or otherwise affect air movements?

Until research is done, only very tentative conclusions may be reached on how sensing may contribute in solving the problem and what kind of sensing may be required. Some argue, of course, that sensing on a moderate scale can help in furthering investigations of the problem. Presently the assumption is made that smoke from fires in forest and range lands constitutes an air pollutant, although whether it has toxic effects approaching that of industrial smog, for example, is not known. It is assumed that any smoke concentration of several square miles which prevails for more than a day or so is a pollution threat. Therefore monitoring presumably should be at intervals no longer than two days in regions and during seasons when fires are occurring. It is also assumed that any concentration exceeding several square miles in area should be recognized. Presumably the main concern is with much larger concentrations such as occur during the fire season for days on end over whole drainages of a hundred or more square miles in area. These are the smoke palls that would appear to have not only a significant detrimental effect on air quality but also on its clarity. Certainly obscuration of scenery by smoke is not welcomed by forest recreationists. When these combined effects are considered it is evident that pollution by smoke even in undeveloped areas may be an appreciable problem. At this speculative stage it would appear better to exaggerate the problem rather than to underestimate it; hence the assumption that a concentration of smoke only several square miles in extent might be significant.

With the foregoing in mind the conclusion may be reached that aerial photography from high altitudes, at intervals of two or three days, should be useful in appraising the amount and movement of smoke concentrations. Until more is known about the importance of this potential pollution problem, flights just to serve this one application may be economically questionable. This caution leads to a consideration of opportunities for data collection in conjunction with some other sensing application. Obviously, here the objective is to collect information on something that obscures the detail required for most sensing applications in the forestry and range disciplines. Thus the best opportunities for combining this application with another is with a monitoring application such as no. 7. Unfortunately the frequency of coverage in no. 7 does not appear to be often enough for monitoring smoke. Nevertheless even approximately biweekly coverages should give some information on the distribution and movement of smoke palls. Indeed this probable benefit to application no. 12 should reinforce the justification for initiating application no. 7 at an early date in some important forest region.

Still in pursuit of available data that might be useful in monitoring smoke, it is profitable to anticipate what will be collected in the near future by space sensors. In line with the study assumption on state of the art by 1980, sequential coverage is anticipated by ERTS vehicles at intervals of about 18 days to give resolution of 100 feet. Thus the resolution should be adequate. Both Gemini and Apollo 9 photography produced imagery of smog patterns. Sequential coverage at 18-day intervals should give some useful information on movement and persistence of concentrations of smoke. If, perchance, the monitoring application no. 7 were producing aerial coverage in some forest region and that coverage was not coincident with the coverage from space, there might be some sequences in the combined coverages only a week apart.

Pursuing the possibilities of using data from space still further, it is profitable to look at the prospective coverage from meteorological satellites. There the prospective sequential coverages are in terms of hours. Certainly coverage on a daily basis will be available. Furthermore the resolution of imagery from those weather satellites should be adequate to resolve smoke concentrations of several miles in extent--provided the density of smoke is great enough and provided smoke is differentiated from clouds. It is evident that clouds must be differentiated from smoke for weather forecasting. Presumably the multichannel measurements by cameras and radiometers in weather satellites (75) will help solve that problem. Thus there should be an opportunity for remote sensing from space to contribute to monitoring of air pollution by smoke from fires in forest regions. As indicated in Table 2 this contribution from space is rated as only "small" for the near future, due to the many unresolved questions about the problem including the one as to what density of smoke may be both toxic and easily detected by sensing.

13. Monitoring Water Cycle, Pollution & Erosion.

This application is one of the broadest in scope. The major phase, the evaluation of the moisture regime or hydrologic cycle, extends far beyond the forestry and range disciplines. Yet to a large degree the establishment of a water balance in many regions (whereby precipitation less losses equals water yield) is determined on upstream, forested watersheds. And the quantity of water and the rate of its movement from upstream watersheds naturally have a strong impact upon what happens downstream in developed areas where flooding and silting with their effects on pollution are most damaging. Data on the moisture regime, of course, are directly useful in forest and range management and protection; in fire control planning, tree planting programs, range reseeding, and other activities. The data may indicate not only severe moisture stresses on the vegetation but also susceptibility to stresses by various forest pests such as insects and diseases. Obviously there is an overlap from this application into others; an overlap that is probably greatest with the comprehensive monitoring application no. 7 and also evident in no. 14, "Monitoring Snowfields". In the latter instance, however, a clear distinction may be drawn between applications.

Some indication of the effort expended on forested watersheds to obtain and evaluate hydrologic data is that on national forests each year something approaching half a million dollars is spent for water quality surveillance, another $1 million for water yield improvement and about $1 million for hydrologic surveys and planning hydrologic restorations. About 15 percent of all the foregoing is for data collection, primarily by ground methods.

Unquestionably remote sensing can play an important role in this application. A good documentation of the uses of aerial photography in hydrology is presented in Chapter 10 of the Manual of Photographic Interpretation (2) and much of that concerns applications on upstream watersheds. The reader is referred to that publication for good explanations of how photography may be effectively used to determine for a watershed such items as total precipitation, water loss (by interception, transpiration and deep seepage) and yield of water. Photography, of course, is a good recorder of the scars left by water erosion, of the extent of flooding (and its progress and abatement by sequential coverage), and of the extent of flood plains and of depositions of sediments. These features usually exhibit strong contrasts with adjacent features on photography. Thus, even on rather low resolution photographs from space, those features should be among the most recognizable.

One aspect of water pollution is amenable to photographic sensing: the degree of turbidity caused by sediments in suspension. Provided photographic factors are constant, in any given body of water the lighter the tone of the water the greater the turbidity. Since shallow water is registered in lighter tones than deep water, sequential photography is the reliable way to evaluate change in turbidity of a stream or lake.

Though turbidity affects water quality in several respects, (e.g., making it difficult to treat), there are, of course, other important quality considerations including that of temperature. This suggests the use of thermal infrared sensing. Low level airborne thermal sensing appears to be an excellent tool for evaluating the small differences in water temperature of only several degrees that are so important to appraisal of water quality for fishlife and other purposes. Since a thermal sensor also responds to differences in moisture content of soils, there appears to be a good prospect for using this tool to appraise moisture levels at both surface and subsurface that have significant effects on runoff and floodings. This might be particularly useful in determining the subsurface zones where the soil has been saturated and where there are possible sources of destructive floods. Further research is needed to establish the limitations of thermal sensing for appraising moisture levels; but prospects are encouraging that this technique may not only reduce ground work in trying to make flood forecasts, but also provide much better information on this problem than is possible by present methods.

Increased use of aerial sensing appears in the offing, at least through visual and thermal infrared windows, for monitoring the water cycle and erosion, and evaluating water pollution. The needs are for sequential coverages but the required frequency varies. Obviously some sequential coverages would be desirable at intervals no longer than daily--perhaps even hourly--during periods when flooding might be expected or is underway. Coverage to evaluate the moisture regime throughout the growing season might well be accommodated within a biweekly cycle such as that suggested for application no. 7. Coverage to evaluate changes in turbidity might also be biweekly--at least monthly. Coverage to appraise erosion effects, on the other hand, might be on a directed basis to get current appraisals after severe storms in critical areas. It might be accommodated within an annual cycle in other circumstances and in noncritical areas. An annual cycle should be often enough to reveal any gradual erosion and at the same time provide a measure of progress in revegetation and other improvements designed to correct erosion.

In conclusion, for many of these applications, aerial sensor platforms would seem to be needed, as for applying thermal sensing under the prospective state of the art in the near future. At the same time data from space should be useful in any variations of the application where resolution and frequency of coverage are satisfactory. Specifically, it would appear that the vidicon coverage visualized from ERTS vehicles by 1980 would provide useful information on soil erosion. The sequential coverages should indicate the increase or decrease in larger eroded areas (a hundred or more feet across). Signatures might also be developed to identify zones where small fingers of eroded ground are interspersed between patches of vegetation. Any substantial amount of pollution due to increased turbidity should also be recognized by space sensors. The Gemini and Apollo photography of the Colorado River mouth provided evidence that both turbidity and water depths may be registered from space. As shown in Tables 1 and 3, a significant amount of information from space is anticipated for this application by 1980.

As a footnote it should be mentioned that there can also be a contribution from communication satellites to this application by 1980, similar to that anticipated in fire weather forecasting. There should be an opportunity for specialists in hydrology and watershed management to tap via satellite the same ground weather stations that fire control men rely on for fire weather forecasting. Depending on the communications traffic, this might be limited only to periods of critical flood danger. If the competition for communication service does not preclude use on a more regular basis, this source of data could be one of the best for managing the water regime on forest watersheds.

14. Monitoring Snowfields.

An important part of the required data for estimating water yield in many forest regions is obtained by snow surveys. The importance of estimation of snowpacks in forecasting water runoff is indicated by the following quotes from an appraisal of the huge Columbia River Basin (78). "The Columbia...and its tributaries are being developed rapidly for power, flood control, irrigation and navigation...In order that reservoirs may be operated to best advantage...(it is) important to have reliable forecasts of runoff, both seasonal and short term...data on snow coverage were required particularly for short term forecasting... during the ablation season...as long as at least 40 percent of the basin above Columbia Falls is snow-covered there is...high flood potential..."

In the mountainous West, as the reader may know, snow surveying is a special function of the Soil Conservation Service, although in some areas other organizations may be charged with responsibilities for this job. In California, for instance, snow surveys are under the direction of the State Department of Water Resources. On western national forests there is, of course, participation by Forest Service personnel. While it is true that this is an application which is not confined to the forestry-range disciplines and that hydrologists are the scientists primarily concerned with the application, most of the snowfields in the United States are situated within extensive forest areas or in close proximity to them. Therefore, "monitoring snowfields" cannot be ignored when evaluating possibilities for remote sensing over forests and ranges.

Present methods for snow surveys rely mainly upon courses which transect the mountains and which are traversed on foot. Three parameters must be measured at periodic intervals: area, depth and density (water content) of the snow pack. No reliable technique has been devised to obtain data on snow density except by ground sampling. Aerial photography is used in some regions to good advantage to estimate area; and, provided periodic coverages can be made, photography appears to be the most effective way to obtain reliable data on areas. Aerial photography can be used also in measuring snow depth. A photogrammetric method has proved successful using large-scale photos where good ground control is available (70). However a simpler, accurate method is to establish depth markers on the ground in inaccessible country and photograph them periodically to provide depth readings (2). In effect a multi-stage sampling scheme, integrating photography and ground work, may be used to get reliable estimates of volume and density of snow pack periodically. Vertical photography, either complete or in sampling coverages, provides estimates of area; more limited oblique photography at low levels provides readings on snow depth; and ground samples at more limited locations provide data on snow density.

There have been limited investigations into sensing techniques to estimate snow density and eventually some technique may be perfected for use at least at low level. Regardless, hydrologists apparently feel that some work must be done on the ground. Therefore the prospects for significant reduction in costs of operation of snow surveys through sensing density of snow are not good, particularly when it appears that relatively few ground samples of density need be taken. This is because density apparently is relatively constant over large areas within a given altitudinal zone. One investigator reports that "... Samples of new snow showed largest variability....After snow melt began, density samples were less variable..." (36).

The reader will recall that wherever application no. 7 is applied the monitoring of snowfields might be accomplished with the biweekly cycles scheduled during the growing season for that broader monitoring application no. 7. Actually, though, biweekly coverages are not fully satisfactory for monitoring snow fields during the season of rapid snow-melt. As noted in Table 2, weekly coverages are recommended during the ablation season. Also, approximately monthly coverage of snowfields is desirable during the winter. Thus the normal frequency for application no. 7 is not in itself all that is needed for application no. 14. The reason the monitoring of snowfields was presumed to be marginally possible under application no. 7 is that at the same time supplemental coverages were presumed to be available by 1980 from space sensing. Presumably the coverages from space would be available year long, clouds permitting, at perhaps 3 week intervals and might well be staggered between the regular biweekly coverages of application no. 7 during the growing season.

The good contrast between snow and other features on space imagery has been reported by several observers (1, 76). Even imagery from meteorological satellites, with considerably poorer resolution than expected from ERTS vehicles, can be better than normal aerial coverages since--cloud cover permitting--they would insure complete synoptic views.

In conclusion, ignoring the probability of an overlap and preemption of monitoring snowfields by the comprehensive monitoring of application no. 7 in some areas, it appears that both aerial and space imagery soon will be making useful contributions to application no. 14. Space sensing should be making a substantial contribution in the estimation of one of the three parameters needed to evaluate snowfields--that of area. This explains the moderate amount of space data credited to this application by 1980. Aerial photography may be considered as supplementing space sensing primarily to provide additional cycles of coverage during the ablation season to estimate areas of snow packs. Aerial photography should also continue to contribute along with ground work to the periodic estimation of snow depth. Ground surveys, alone, may continue to contribute the data needed on snow density. As indicated earlier, this integration of data collecting methods may be considered to be a useful variation of multi-stage sampling.

15. Evaluating Damage to Forests and Ranges.

This application is directed to an area after there is reason to believe that serious damage to forests or ranges has resulted from attacks by destructive agents such as fire, disease, weather or insects. This application may follow closely behind an application aimed to detect and prevent spread of fire or harmful stresses on the vegetation but its two-fold objectives are different since it always comes after considerable damage has occurred. Primarily it aims to determine (a) what parts of the resource are salvable after partial destruction and (b) what measures should be taken to restore productivity of the land (implied by conditions indicating significant reduction in productive capacity such as soil erosion and destruction of growing stock).

The value of losses due to destructive agents on forests and ranges of the country run into millions of dollars each year. These losses in sawtimber, alone, have averaged a quarter of a million dollars annually in the past decade, according to an estimate by the U.S.D.A. (79). Much of the damage of this kind was appraised through aerial surveys (visual and photographic) and ground work. But more prompt application of remote sensing to all areas where severe damage was believed to have occurred no doubt could have considerably reduced these losses by focusing attention on all areas containing salvable timber. Furthermore, prompt sensing would also have drawn attention to critically damaged areas where remedial measures were needed to restore productivity of the land for yields of timber and other resource values.

There are occasions when application no. 15 can help prevent subsequent losses to resources. The reader will recall, in the discussion of application no. 8, reference to a survey to appraise damage to timber after catastrophic blowdowns and beetle attacks in the Pacific Northwest (39). To some degree that survey helped prevent further damage by focusing attention on insect attacks which had already reached epidemic proportions. The prime purpose of that survey in the '50's, nevertheless, was to determine amounts and locations of dead, salvable timber before deterioration set in.

That survey of catastrophic damage in the Douglas-fir region illustrates the kind of special damage surveys needed in the near future when the monitoring application no. 7, at best, will cover no more than a small proportion of the universe of forests. When compared to the methodology discussed in application no. 7, that survey used primitive techniques. The deadline for beginning of salvage precluded the flying of aerial photography over this vast area (much of Western Oregon and Washington), therefore the job of mapping and estimating was done by coordinated visual observation from low-flying aircraft and crews taking samples on the ground. With respect to salvage opportunities, the survey provided in-place estimates in two categories--heavy and moderate--of both blowdown and beetle-killed trees. In heavy blowdowns, more than 25 percent of the stand was estimated to have been windthrown; in moderate blowdowns, 10-25 percent of the stand. In heavy beetle kills, groups of more than 30 individual trees were estimated to have died; in moderate kills, groups of only 6-30 trees. For blowdown, the relative size of area was also mapped to show two classes: more than 10 acres and 5-10 acres in size. The foregoing kind of information could be obtained by aerial sensing. Under the state of the art assumed by 1980 most of that information would be very useful in planning by regional organizations. In particular it would show increases in fire hazard by localities, due to concentrations of dead timber. That information alone, however, was not enough as the basis for a comprehensive salvage program. Ground sampling surveys were necessary to indicate what portions of the blowdown timber were unbroken and sound material, suitable for marketing. Also other information not obtainable by remote sensing was needed: locations of damaged timber by individual ownerships (even though proportional distribution of the total within major ownership classes--public and private was known); and which locations were contiguous to or within the areas scheduled for cutting under a current plan and what part must be scheduled as emergency logging operations.

The foregoing example illustrates one of the best opportunities for capitalizing on remote sensing. The areas of damage were extensive throughout a large region where the level of forest management was reasonably high but not intensive.

Some generalizations may be appropriate at this point. One generalization is that remote sensing usually cannot play a primary role in regions where forest management is quite intensive, as in western Europe or in some parts of the deep south of the United States. In those situations the owner-manager already knows the species, the age, the size class and condition of each individual stand of trees on his property. He has probably carefully supervised their planting after the latest harvest cuts. And when a catastrophe comes along he will, no doubt, take a proprietary interest in examining his property expeditiously on the ground--on foot or by car--within hours after the catastrophe strikes.

In that quick appraisal he may learn as much as an expensive reconnaissance by remote sensing can tell him. Another generalization is that in regions where little or nothing is known about the character of forest, there is prima facie evidence that no one really cares very much what condition it is in. Thus the efforts of remote sensing--if someone undertakes them--may be largely wasted. They may not be entirely wasted, however; and for more on that the reader is referred to Section VI on the foreign potential.

Extrapolating from damage by blowdown and beetles to damage by fire or disease does not change the perspective greatly. There are some important items to be obtained accurately by remote sensing; others to be obtained by ground work. For more on the procedures and on how aerial photography can contribute in evaluating damage to forests, the reader is referred to Chapter 7 of the Manual of Photographic Interpretation (2).

There are serious damages to ranges that remote sensing has a good potential for evaluating, now that large areas of western U.S. ranges are being reseeded artificially. Damages by defoliators, such as crickets and grasshoppers, and by abusive grazing of animals are becoming so extensive that even telemetered imagery from space may well indicate the affected areas. Weeds are also becoming a serious problem on range reseedings. For example, medusahead is invading the cheat-grass ranges of southern Idaho and eastern Oregon. Since this weed remains green after the cheatgrass is cured it appears that a valid spectral signature may be developed to indicate where the weed occupies any significant part of the range. A signature of damage such as this is, in effect, also a signature of harmful stress on more desirable vegetation. Just as clumps of beetle-killed trees may indicate the beginning of an epidemic threatening timber production, so large clumps of weeds may indicate an epidemic threatening forage production.

In conclusion, as shown in the tables, there are small but significant contributions anticipated from space sensing by 1980 in evaluating forest and range damage. These contributions, mainly indirectly through application no. 1, should indicate where damages to forests and ranges are concentrated, rather promptly after major attacks by such damaging agents as wind, fire, insects and disease. These indications from space should greatly simplify planning and executing surveys by air and on the ground needed to appraise details of damage, since they would immediately narrow down the areas of interest to zones of damage. Here again, as in other applications, multi-stage sampling that integrates space sensing, aerial sensing and ground work (to give ground resolution of several feet) may well be the economical method of survey to reveal damage that is localized or where there are only minor, outward manifestations of damage.

16. Monitoring Livestock and Wildlife.

For several decades aerial surveys have been used for enumeration of big game and waterfowl. Most of these have been by visual observations from low-flying planes. Some effective surveys have also been made using large-scale aerial photography. Chapter 8 of the Manual of Photographic Interpretation (2) discusses and illustrates a number of successful censuses of big game and waterfowl made by photography from low altitudes. Invariably these indicate situations where the background was relatively uniform and where there was no cover such as trees or shrubbery to hide the wildlife: caribou and muskox on muskegs; antelope and deer on prairies; ducks and geese on open water; spawning salmon in clear, shallow streams, etc. Understandably there are no illustrations of sensing where wildlife takes to natural cover: elk in lodgepole thickets; deer sheltered in chaparral; trout lying under rocks; or bass under lily pads.

Until recently, when research and testing began at the Forestry Remote Sensing Laboratory in cooperation with federal and state agricultural agencies, few attempts had been made to use aerial photography for census of domestic livestock. The results of those studies (44), even though preliminary, are encouraging, for application of photographic sensing over the agricultural lands which comprise a large part of the universe covered on such periodic surveys as those by the Statistical Reporting Service of the USDA for the annual agricultural outlook. Incidentally a related variation of this application is to check number of animals by ownerships for tax assessment purposes. A double sampling system with ground data taken on sample areas coincident with photography should provide a means of adjusting the count upward for animals hidden from aerial observation by trees or man-made shelters. The surveys might not only indicate numbers of animals by type: horses, cattle, sheep; they might also indicate probabilities of diseased stock. Naturally, where cattle and horses (in particular) are lying down there is a possibility of sickness, especially if animals are on their sides.

The same studies indicated greater problems in using photographic surveys on wildlands, primarily because of the greater abundance of cover. Where cover is as considerable as it is on typical forested ranges many animals would be hidden from aerial view at almost all times of day. Thus the ground work that might be necessary for accurate adjustment of photographic counts might approach that required for an independent ground survey.

There has been considerable interest in using thermal sensing to enumerate both wildlife and domestic stock. One successful test of this technique was reported in 1968. This was over a deer enclosure in Michigan (20). Infrared imagery in the 8-14 micron range was flown at midday on a January day at a thousand feet above the snow-covered terrain. There was approximately a seven degree differential between the deer and background. This aerial census was in very close agreement with the known deer population. In such situations, where one species of game predominates and terrain is not obscured by foliage of conifers or by deciduous forest in leaf, the method offers good results.

Theoretically, thermal sensing at night could reveal big game grazing in forest openings in contrast to domestic animals bedded down (not always in cover, however). The hours near dawn and at twilight might offer good opportunities to register gig game were it not for the thermal washout and rapidly changing thermal conditions at those times (refer to application no. 11 for a discussion of this limitation). The possibilities of thermal sensing for inventories of livestock and wildlife are intriguing, but there are complicating problems of successful application due to numerous heat sources in forests and ranges: smouldering campfires, roads, cars, motorcycles, fishermen and hunters and many other outdoor recreationists, variations in water--the ponds, the small streams--cattle, elk, deer, the still-warm beds they may just have left. True, the locations of some of those heat sources are fixed and their identity may be known. But those made by man and by animals are not, and for the foreseeable future it appears that under most situations the best prospects for census of livestock and wildlife are the same as they have been: aerial photography where the background is uniform and unobscured, and visual observation where there is considerable cover and variety of background.

The visual procedure has the advantage that it can be used in weather which is unsuitable for photography; so that technique may be used in the future more than photography. Canvasses of big game and livestock are usually aimed at rather specific and limited times regardless of whether the weather favors sensing. For big game the time may be when the animals are congregating preparatory to migration or are migrating; for livestock the time may be in early summer when forecasts of fall market prospects are wanted. Another prime advantage of visual, low level observation is that not only species but type of animal may be determined: whether male or female, adult or young, and the breed. These items are extremely difficult if not impossible to determine by any instrumented sensing. Furthermore, visual observation may pinpoint quite accurately whether animals are indeed sick or merely resting. A buzz at low level may confirm, whether an animal is really sick--perhaps dying or dead. Also, as required, on-ground surveys may be used to confirm or adjust visual aerial counts.

Incidentally, one useful variation of directed sensing under this application is to check compliance of permittees with agreement to graze specific numbers of animals on public grazing allotments. To verify compliance with grazing permits this check, by aerial photography, may be required twice each year, at the times the herds are moved on and off the ranges.

It will probably be evident from the foregoing that there is no prospective application from space in the near future for monitoring livestock and wildlife. The resolution requirements are not achievable by space sensing either for specific details or for useful spectral signatures. Tables 1-3 indicate that for the foreseeable future the data needed in this monitoring application must be obtained from aerial surveys or work on the ground.

VI. THE FOREIGN POTENTIAL.

Through arrangements with the United States any country in the world may become a user of data collected by ERTS vehicles. Presumably there will be a considerable difference between benefits of sensing over forests and ranges in a highly developed, industrialized country and those in a relatively undeveloped, or developing country. Hopefully the material in Section V will be useful to readers attempting to appraise potentials in countries with developed economies, bearing in mind that the discussion in that section was aimed at the domestic situation and may not specifically apply to a country with an economy dissimilar to that in the United States. Subsequent discussion in this section outlines some rationale and prospects in what are often termed "developing" nations. Although no line may be drawn around a distinct group of developing nations, it seems useful to accept (as much current writing does) that most of the nations in Latin America, Africa and Asia fall within this group.

At this point it appears useful to make some generalizations about developing nations. Their economies are not well industrialized, although some segments of the economy in a particular country may be well advanced. The resources of the forest lands are not well utilized or are overutilized, even approaching exhaustion. Obviously, this means that there is little or no management of those resources, except in some regions in some nations. Per capita income in those countries averages not more than ten percent of that in North America, and in none of them does income of the average individual appraoch that in the United States. Two thirds of the world's people now live in the developing nations and--more significant--the rate of population increase there is twice the rate in the industrialized nations. According to a provisional United Nation's report made in 1963, more than three quarters of the world's population will be living in the developing countries by the end of this century.

In considering the needs of the people in the developing nations and their prospective demands, and, in turn, the prospects for application of remote sensing in the next decade or so, there is one fact that overshadows any other. In the foreseeable future the demands of those people will be focused on human subsistence, in producing necessities for existence--food, water, and minimum fuel and shelter. With this fact clearly overshadowing all others it is appropriate to consider the specific demands upon the forests and ranges that are likely as part of the much needed economic development programs in these nations. Demands for the conventional five, multiple uses of forest and ranges--for wood, water forage, recreation and wildlife--will first be considered. Then the prospective use of remote sensing to help meet those demands will be appraised.

Demands for Wood.

Since wood exports can provide valuable credits for international exchange, foreign as well as domestic requirements for wood products merit consideration. World-wide consumption of industrial wood (which excludes that used for fuel) is increasing at about three percent per year according to a study published by the FAO in 1967 (27). By far the largest part of the increased use estimated up to 1975 will be in developed countries--about 70 percent of the total. During the near future per capita use of wood in developing countries is estimated to remain at its relatively low level--only one seventh of that in North America.

When total prospective demands are compared to total supplies it is evident that there is an abundance of timber in developing regions. Those regions embrace more than half the forest land on earth, and, according to the FAO forest inventory (26), the rate of timber removals for all purposes in the developing nations aggregates less than one percent of the growing stock. Furthermore, since no estimates have been made of timber volumes in many undeveloped regions, there is an unknown, unreported volume of growing stock available which may equal or exceed that reported (inferred from estimated area of forest in regions for which no volumes were reported). Thus the ratio of growing stock to timber removals in developing nations may be on the order of 200 to 1. In the United States (essentially self sufficient in supplying needs for wood), for example, the ratio is only about 60 to 1.

Utilization of the timber resource may require considerable expansion of transportation systems in some developing regions to meet domestic demands for wood. Otherwise no particular forest management measures may be necessary, particularly since a large part of those demands will be for fuel, and for that use even low grade materials will suffice. Increased exports of higher quality timbers may be anticipated from some of the developing nations to help meet increasing world-wide needs. A few favorably situated developing nations are expected to profit substantially from exports to wood-hungry countries with advanced economies. The Philippines and some adjacent southeast Asian nations on accessible trade routes to the United States and Japan are examples. But in most developing nations the exports of timber will probably be limited, at best, to rather small quantities of very high grade materials. The FAO report on world timber trends underlines this (27). So does the latest report on timber trends in the United States (88) which indicates that the lion's share of U.S. demands for wood imports in the foreseeable future can easily be met by another advanced nation--Canada.

Only to meet a few requirements for high grade hardwoods for veneer and other specialty use, will the United States and other industrialized countries be looking to the less accessible regions in developing nations. Regardless, although by the end of the century the use of hardwood for veneers and plywood in the U.S. is expected to be approximately double that today, about half of those requirements are expected to be met by local supplies. The actual amount of imports will depend largely on whether the prices for foreign timbers remain at reasonable levels. The current estimate is that by the year 2000 the volume of those prospective hardwood imports will be less than five percent of the total wood use in the United States and will comprise less than 20 percent of the total volume of wood imports into this country. The other 80 percent will be soft-wood sawlogs and pulpwood presumably from Canada. It appears, generally, that developing nations have no better prospects for exports of wood to other industrialized nations than is indicated by this U.S. example.

The foregoing indicates that world trade in timber products will have some stimulating effect upon forestry and forest industries of some developing nations, but that the stimulus will probably be localized to comparatively accessible regions. In the foreseeable future the main impact on timber resources of developing nations is bound to be from domestic demands for wood. Since generally low quality timber will meet domestic needs (much of the demand will be for fuelwood), it is unlikely that there will be any universal pressures for forest management merely to meet foreseeable objectives of timber production. Even most developing nations that now are net importers of forest products--such as typical countries of Latin America--should not require much emphasis on forest management to become self sufficient. Some development of transportation and local forest industry, either locally or in neighboring regions, should eliminate any deficits in manufactured items such as pulp and plywood that are now imported from industrialized countries.

Demands for Water.

With increasing population and industrial expansion, the demands for water for domestic and industrial purposes may be expected to grow; thus the forest and ranges will be increasingly important as watershed cover in developing nations. Although water quality standards might not necessarily be raised (to approximate those in presently developed countries), there will inevitably be emphasis upon regulation of stream flow to insure the continuing quantity required for human subsistence. And, along with more dams and other engineering structures to insure delivery of water supplies to population centers, more watershed management may be expected in the upland forests and ranges. The managers of those watersheds may tolerate turbid water yield as normal but they cannot afford to tolerate extremes of drought and flooding or disturbances to the vegetation cover that will seriously disrupt the water regime. Large-scale removals of forests may be tolerated in those tropical and subtropical regions where slopes are gentle and individual clearings are small and not concentrated within short time periods. Natural revegetation or prompt plantings of food crops could minimize effects of runoff and erosion on such sites. On the other hand large-scale disturbances to ranges are more likely threats to watersheds. Although rainfall may be scant in many regions where ranges are extensive, the precipitation may come, of course, in cloudbursts. And since revegetation--either artificial or natural--may be slow, serious damages by alternate flooding and drying of streamflow can result. This suggests that more management may be directed to range than to forest lands in developing regions to insure continuing quantities of water.

Demands for Forage.

Meat and milk rank first and second, respectively, in value among farm products worldwide, according to the FAO of the United Nations (25). Probably half the value of the world's meat and milk products is derived from grains and crop residues. Nevertheless, their production is dependent on ranges in many developing regions, such as the vast grasslands of South America and East Africa. The FAO estimates that permanent meadows and pastures occupy nearly one-fifth of the land on the globe--next to forest, the most extensive land use on earth. Apparently forage will continue to be the basis for life of people in many developing regions in the foreseeable future.

Although some of these ranges no doubt will be converted to more intensive agricultural use as pressure for food increases, by far the largest proportion seem destined for production of range forage indefinitely, since they are beyond reach of any foreseeable, economical system of irrigation. Some of the savannas in more humid climates also offer possibilities for good yields of forage indefinitely, with corresponding justification for range management. Notable examples are the vast grasslands of Argentina which provide not only meat for domestic markets but for export credits.

Demands for Outdoor Recreation and Wildlife.

The demands for these products of forest and ranges in developing nations may be discussed concurrently since in large measure demands for outdoor recreation and wildlife probably be generated by the same group: foreign tourists. The great majority of local inhabitants will probably be too preoccupied with a struggle for existence to be concerned with recreation and wildlife developments--except as those might induce cash from tourists. Exploitation of outdoor recreation will apparently be focused primarily on a few resorts to attract tourism from high-income countries. Such resorts as those in the Kashmir of India and the high lake district of Chile and the nearby Nahuel Huapi National Park of Argentina will no doubt continue to prosper and expand. Establishment of recreation facilities in similar areas may be anticipated, but altogether such developments should fall far short of the booming business in outdoor recreation in the developed group of nations.

That phase of outdoor recreation focused on wildlife is unlikely to expand in developing countries. As the reader knows, the great big-game hunting grounds of East Africa, Southeast Asia and Central America are shrinking toward oblivion, with more and more of the habitat being diverted to grazing by domestic stock and other purposes. That trend will evidently continue so rapidly that within a few years the only reminders of the habitats that attracted the famous safaris of yesterday will be such showcases for nearly extinct animals and birds as the Malaysia National Park, The Kruger Game Reserve of South Africa and the Serengeti National Park in Tanzania. With this in prospect, land management for recreation and wildlife purposes in the developing nations must obviously be relegated to very limited parts of the forest and range universe.

Demands for Land Clearings for Food Crops.

Gains in productivity through fertilization and other intensive management on existing fields, imports from countries with agricultural surpluses, and increased range forage will undoubtedly help developing nations meet their needs for food. Nevertheless, conversion of large amounts of forest and range lands apparently will be needed also to prevent growth of population from outstripping food supplies. According to a FAO report (25), "...if 20 percent of the unused tropical soils were used for cultivation, the...arable area in the world would increase by about 40 percent". Evidently, then, extensive areas of forest and range are destined for conversion into intensive agricultural uses in tropical regions.

Prospective Sensing Applications.

At this point there is no need to go into general usefulness and techniques of the major kinds of applications discussed in Section V, but it is appropriate to briefly review those applications in the light of the prospective environment of developing nations just discussed. The writer suggests that nine of those sixteen applications will be relatively unimportant at least through the 1980 time period. The opportunities for applications number 5 and 6 (inventory of recreation and wildlife habitat) will be in very limited areas; and numbers 9, 10 and 11 (the applications on detection and control of fires) will hardly be of critical concern in economics not dissimilar to those during the period of settlement of North America--where fire was looked upon as a tool for land clearing, not as a threat to forests. There will be exceptions, of course, where fire control organizations will operate, as on critical watersheds. Application number 12, "Monitoring Air Pollution..." is unlikely to be called for until the developing nations achieve a much higher degree of industrialization with associated atmospheric poisons which would seem to be far more serious threats to populated areas than smoke from forest and range fires. Application 14, "Monitoring Snowfields", is hardly relevant in the mild or tropical climates of most developing nations. Applications number 7 and 15 (monitoring large management units and evaluating damages) cannot be especially important until resource management is applied more intensively. Where ranges are extensive, however, application number 15 offers a promising technique for appraising actions to restore full production after damage to forage.

The seven applications with best immediate prospects in developing areas, are numbers 1-4, 8, 13 and 16. Among those applications, numbers 1 and 2 on land classification stand out. Partly this is because of indirect contributions made by establishing main area parameters for estimating various subclasses of forest and range lands--the kind of contributions indicated by footnote 3 in Table 1. But the main contribution of applications numbers 1 and 2 should be by indicating extent and location of some areas most suitable for agricultural clearings. Although the criteria for classification of some lands suitable for agriculture may only be recognized by examination on the ground (perhaps through soil sampling), other criteria may be recognized by remote sensing--gross physiographic features of cover, drainage, slope characteristics, etc. Some of those physiographic features should be apparent even on the telemetered space imagery anticipated by 1980. As illustrations, land classes are cited for two localities in developing regions--the first in the tropical lowlands of Petén in Guatemala with which the writer is familiar, the second in northeastern Argentina described to the writer by Prof. Merle Meyer of the University of Minnesota and which is a region he is familiar with.

In the Petén of Guatemala and adjacent parts of the Yucatan in Mexico, at least four significant land classes may be recognized on telemeted imagery because of their extent and anticipated differences in spectral signatures (due to characteristic patterns): (a) dense forest on rocky limestone hills; (b) open scrub forest in poorly drained bajos; (d) dense forest on well-drained lowlands; and (e) savannas. The first two classes have low potential for either food or wood production. In "a" slopes are so steep and rocky that logging is economically questionable; if cleared for agriculture they could be subject to serious erosion and rapid decreases in fertility. In "b" obviously wood production is poor and, since drainage doesn't appear feasible, prospects for agricultural production are very limited. The third land class contains the most productive forest lands and presumably those most suitable for production of food crops. It may require both aerial sensing and ground examinations to subdivide this broad class into areas more suitable for agriculture than for timber production. The fourth land class might also be cultivated, although economic studies could reveal that it is more valuable as natural pasture since it is a good forage producer.

In northeastern Argentina there are also four significant land classes which should be evident on telemetered space imagery: (a) upland, open, scrub forests (monte); (b) upland grasslands; (c) poorly drained lowlands (bañados); and (d) esteros--extensive, even, lower areas with standing water. To some degree all these classes produce forage. The first class might best be retained for extensive grazing and fuelwood production. The second class is suitable for producing various food crops. Since there are no economical prospects of drainage of the last two classes, the best possibilities for conversion to agriculture may be through cultivation of rice.

Sensing from space should contribute to applications numbers 3 and 4, "timber inventory" and "range inventory", in developing nations in the near future mainly through furnishing area parameters relating to the land classification applications. In many developing regions it is possible that the detailed inventory of timber volumes by various categories, so useful in more advanced nations, will not be particularly useful. Thus essentially the only likely contribution by remote sensing will be confined to gross land classification. There is no point, of course, in a detailed inventory for timber management purposes if the natural forest is to be cleared and replaced by either food crops or by plantations of exotic trees (e.g. the common, economical, silvicultural method in the tropics of replacing native rain-forest mixtures with pure stands of teak). And even where high-grade timbers are selected and marketed as the native stands are liquidated, this selection need not require an inventory--only salvage of the most valuable trees as the land clearing proceeds. Also even where a detailed inventory appears justified so that logging may be oriented to selection logging of the most valuable timbers, remote sensing faces obstacles in tropical forests much greater than those in most temperate forests. Aside from weather which may preclude photographic sensing over long periods, the forest is so complicated that the prospects are not good of developing useful spectral signatures for stands containing the premium trees demanded by the export market. Readers acquainted with tropical rain forests will appreciate how complicated the species composition may be. There may be several dozen species on each acre, no two acres identical in composition for miles on each side, with perhaps 500 species found within a fifty mile radius, and yet with transitions so gradual that the acres on the extremes of that radius may have several species in common. Furthermore some of the most valuable species may be nearly obscured from overhead view by the luxuriant foliage of other less valuable trees:

Spanish-cedars or mahogany in Central America almost hidden or intertwined by wild-figs or other much less valuable trees, for example.

Because forage may well be more valuable than timber in many developing countries, there may be considerably more use of aerially sensed data to complement that sensed from space for range surveys than for timber inventories.

Aside from sensing for land classification purposes the next most important application of sensing over forests and ranges of developing countries may be to detect stresses--provided the needed spectral signatures are developed. The good prospects for this application over range lands relate, of course, to the general value of forage. But for timber lands also, during the developmental period of the foreseeable future, it will be important to give a measure of protection even though exploitation and inventories of them may not be scheduled for decades. Lest this view seem to contradict one expressed earlier--that fire protection applications of sensing will not be important--the significant difference might be underlined between the impact of fire and those of insects and disease upon vegetation resources. There can be no doubt when fires are occurring, and when they begin to reach intensities and frequencies that threaten serious damage the only question is whether the observers care enough and have the capability to control them. On the other hand attacks by insects and disease usually come without any spectacular warnings to draw the attention of even concerned observers. And without some continual surveillance to detect stresses, such as that from a rather sophisticated system of sensing, wide-spread and serious damages can occur before resource managers are aware that control is appropriate--even when they have both interest in and capabilities for control.

What is needed in many regions that are developing or awaiting development is the kind of sensing application that could have prevented such a catastrophe as the one that moved across the forests of Honduras between April 1963 and April 1964. Before anyone was really aware of the immensity of the damage and before control could be taken, beetles had destroyed 20 percent of the pine growing stock in the nation--some of the choicest sawtimber in the western hemisphere. It has been estimated that if the exportable portion of that lost timber has been marketed it would have brought an equivalent value of more than 75 percent of the GNP for Honduras in 1964 (28). Undoubtedly had there been some overall sensing surveillance in operation in Honduras during the sixties, similar to that discussed under application number 8, with frequency of approximately semi-annually, a large proportion of those losses could have been prevented. There was some local interest in and capabilities for pest control in Honduras, and through support by outside agencies--AID and FAO--there should have been opportunity for control measures to blunt the main force of the insect attack--had there been prompt warning of an epidemic of beetles.

Another potentially important application in developing countries is number 13, "Monitoring Water Cycle, Pollution and Erosion". Whether any comprehensive monitoring in developing countries is foreseeable similar to the idealized application in developed nations discussed in Section V is questionable. Nevertheless, over watersheds in those parts of developing nations where population is concentrated there are prospects that data derived from both space and aerial sensors will prove very useful in appraising flood threats. By the same token, that phase of application number 15, "Evaluating Damages..." pertaining to damage by flooding may also be applied usefully. To that extent the rather poor prospect which was projected earlier for application number 15 may be upgraded.

Application number 16, "Monitoring Livestock and Wildlife" should also be a useful one in regions where grazing is a primary activity. Although this application should be a useful one in the same regions where application number 4, "Range Inventory" is used, it is unlikely that these two applications may be performed concurrently. The reader will recall that resolution requirements are different for these applications. Also application number 16 is required on a directed basis whereas the other application lends itself to periodic, sequential coverages.

In conclusion it may be emphasized that while there are prospects for exploitation of some sensing applications to great advantage in developing nations, these prospects may not be realized in as early a time frame as those projected in more advanced nations. This is because, regardless of whether the state of the art in sensing and data handling advances at the rate assumed in this study, resource managers in developing nations may not be in a position to take advantage of sensing techniques. Whether they can take advantage of the state of the art in the 80's as early as the 1980's will depend largely upon two limitations: (a) the progress in collecting and coordinating ground truth in developing nations with sensor responses and (b) the degree of acceptance of remote sensing potentials by the authorities who determine budget expenditures for resource management in developing nations. Both of these limitations are reflected in the recommendations for research and development outlined in Section VII. Evidently it will take a great deal of effort to overcome these limitations, or minimize them.

With respect to ground truth in developing nations, the reader will appreciate that very little research has been done (compared to that in advanced nations) on the native vegetation and only meager beginnings have been made in attempting to tie the plant physiology, ecology and microclimate of forest and range associations to spectral responses that sensors might pick up. Even some of the best of these small beginnings have been overlooked, apparently, in the cooperation on the two initial foreign test sites for earth resources survey sponsored by NASA (59). The writer understands that in neither Brazil nor Mexico were official arrangements made for local forest or range specialists to participate when U.S. representatives of earth resources disciplines visited those countries to arrange for sensing test sites. Only through happenstance and initiative on the spot by U.S. foresters were arrangements made for some forest coverage by a NASA sensing vehicle. In Brazil, fortunately, arrangements were made to cover some plantations of an exotic species--Eucalyptus--in conjunction with coverage of terrain that was primarily agricultural. Unfortunately, that forestry test site is far removed from the vast, tropical forests of the Amazon Basin where one of the most challenging opportunities for remote sensing of forests on the globe is located. In Mexico, fortunately, arrangements were made for a test site in some of the valuable pine forests in the highlands. At the same time, unfortunately, there are yet no arrangements for a test site in the extensive and relatively unknown, but valuable, tropical forests of the Yucatan Peninsula. This oversight is more unfortunate in view of the fact that Mexican foresters (generally well trained and competent) are among those who have taken considerable interest in tropical forestry. This is evidenced, in part, by some good publications on the subject issued by the Instituto Mexicano de Recursos Naturales Renovables. It is evidenced, also, by experimental work in the forests of Yucatan during the mid 1960's by the staff of the cooperative forest inventory project financed by the Mexican Government and FAO. In the Yucatan area detailed field information was being gathered on timber species and composition; also aerial photographic flights were projected using several film-filter combinations aimed at determining the most suitable one for evaluating the timber resources.

The foregoing not only indicates opportunities that might be capitalized on in the future, it also emphasizes that high government officials must be sold on the value of remote sensing and the scope of its potentials; otherwise profitable cooperation on a technical level is not possible.

In closing this section it may be noted that one of the important, intangible benefits of any applications of remote sensing in developing countries can be the education of people in the need to conserve and manage natural resources. And it is quite possible that some investments in remote sensing--possibly by outside interests such as the United Nations Development Program--will pay good dividends in advertising the magnitude and condition of the forest and range resources of developing countries and dangers which threaten them. Remote sensing may be an effective vehicle for the education so sorely needed to overcome apathy toward management of resources. Only after that apathy is overcome may some appreciable share of the national effort be allocated to resource management. And then sensing may begin to play a continuing role even in those nations where, for the foreseeable future, allocation of funds will be primarily to prevent starvation.

VII. RECOMMENDED RESEARCH, DEVELOPMENT & TESTING

Two logical frames of reference for this section are the NASA "Earth Surveys Program Documentation (60) and the USDA "...Program of Research for Remote Sensing" (80). The first document is largely devoted to plans and proposed schedules for launching, orbiting and maintaining data gathering capabilities for earth-orbiting satellites. It also discusses some aspects of sensing systems which are primary concerns of data using agencies in earth sciences. The following is a pertinent quotation from that document which suggests how research by user agencies might be directed to capitalize on space sensing in the near future: "in all of the Earth Resources Disciplines, effort must be devoted to: (1) The development of rapid means of reducing raw sensor data to multispectral signatures of significant phenomena and features; (2) The establishment of statistical measures of the significance of such signatures; (3) The conduct of pattern recognition and feature extraction research on multispectral signatures; and (4) The establishment and maintenance of a comprehensive library of selected flight data and multidisciplinary ground truth data collected over test sites."

Implicit in the foregoing is the same viewpoint which evidently influenced the decision on the three top priority areas for research outlined in the USDA program document; namely (a) Laboratory Research, (b) Application and Information Systems Analysis and (c) Airplane Measurement Research. The emphasis in "a" is on research in the basic theory and empirical approaches to a better understanding of spectral responses of both reflected and emitted radiant energy from plants. In "b" the emphasis is on data acquisition and data handling and analysis.

In "c" the emphasis is on more research and testing of spectral signatures from high enough in the atmosphere so that operational application from space is simulated.

Research and development in the areas recommended in those documents should favor exploitation of the forestry and range applications believed to be most feasible from space. And unless such research is given priority,financing of the proposed series of ERTS vehicles does not appear to be justified. In the remainder of this section some suggestions are given on how research and development might be oriented to serve the forestry and range disciplines in the near future.

Signature Research

Disproportionate amounts of effort have been put into instruments for sensing and into collecting sensor responses. Relatively little effort has been put into research to determine what the data collected by the sensors mean. And the only way in which those responses can be translated into meaningful signatures is through many tedious man hours in the ground environment.

Research on spectral signatures should be pressed with a real sense of urgency. Very few tentative "signatures" have been researched, and there have been no replicative tests aimed to establish the "normal" signature for even one of the important forest-range associations in the country. Furthermore, efforts to establish sensor signatures for specific stresses on forests due to their greatest enemies--disease and insects--are apparently limited to only a handful of investigations, including those on three root rots (90, 64, 65) and the Black Hills Beetle (40).

Hopefully, prospects expressed by the NRC panel on forestry-agriculture-geography (61) may be realized in the near future and that "...sensor--signature research...has the potential of yielding disproportionately great returns for a relatively modest inventment..." This may be a realistic statement of prospects insofar as sensing of agricultural crops is concerned; but the writer is not optimistic about "great" returns that are in prospect for a "modest" investment in sensor-signature research in the forest and range disciplines.

The approach to multi-spectral research at the Laboratory for Agricultural Remote Sensing (51) will contribute undoubtedly, to the forestry and range disciplines by providing automatic signature identification by optical-mechanical scanners for some major land classes. However, the brunt of research to develop useful signatures on significant breakdowns within the universe of forests and native ranges must necessarily be carried by organizations and institutions concerned with forest and range disciplines. Regardless of whether the LARS approach to signature identification (by means of a multi-spectral scanner in flight) proves to be the most feasible for sensing of forest and range lands, the basic LARS takeoff from a well established base of ground truth appears to be the realistic course for research.

Assuming the LARS approach is sound, the most stable sites on which to conduct any research investigations in the forestry and range disciplines would be established experimental or demonstration forests and ranges. In such areas there are large reservoirs of ground truth. According to the observation of this writer not every so-called research study in remote sensing has been based in such a favorable situation.

He would, however, cite several examples of what appear to be good bases for studies. The University of California made good use of its water tower at Davis on a number of preliminary studies to develop research and testing procedures, even though the tower and its surroundings had no resemblance to anything in the real world of forests and ranges. Also the University of California group made effective use of the large background of survey and observation data available at its summer forestry camp in the Bucks Lake and Meadow Valley vicinities. That was a better crossection of Sierra conditions than anything else under U.C. surveillance and for those reasons was chosen as a NASA test site. The Forest Service made use of ground truth at several of its experimental areas, including, for example, the Challenge Experimental Forest which is used by Langley and his co-workers (53) and the Wind River Experimental Forest used by Wear in his research into sensing forest diseases (90).

If the writer were to emphasize any element in this study that overshadows any other it would be the importance of ground truth. Without reliable ground information there is virtually no prospect of effective sensing from space. Furthermore, to determine ground truth and to key it appropriately to data obtained from aircraft or spacecraft will probably require more effort and expense than any other phase of research and development of sensing for forestry and range purposes. It is expensive enough for LARS to obtain the ground truth for crop identifications. First there must be laboratory analyses to indicate the basic spectral responses for healthy and unhealthy vegetation of various categories. Then there must be responses and tentative signatures developed by sensing from cherry pickers only a few feet above the cultivated crops on the Purdue experimental farm. Then that information must be related to what happens when the sensors are thousands of feet or many miles away from the crops being sensed. Those agricultural situations are simple compared to those encountered in the universe of forests and native ranges. Since agricultural crops are in man-made fields, they have regular patterns and boundaries. Also there are relatively few important crops: wheat, oats, rye, cotton, etc., compared to the many variations in types of natural vegetation. Agricultural fields are also accessible. Furthermore a cherry picker technique is not practicable when close surveillance of forest is wanted for research purposes. As a minimum, forest researchers must probably think of hovering with helicopters or tethered balloons at low altitudes.

Research in sensing techniques to identify food crops is obviously far more important than research to identify forest types. The amounts of Douglas-fir and Lodgepole pine and shortleaf pine in the growing stock may consume the interest of a forester; but those estimates don't begin to approach the significance of whether wheat, or rice, or corn may be plentiful enough for purchase by the man in the street Since fiber is outranked by food in the priorities naturally there are fewer dollars to allocate to research in forestry than in agricultural applications of sensing, regardless of the complexity of identification problems in the forest universe. Thus it is imperative to concentrate research in the forestry and range disciplines on those signatures which are both relatively easy to establish and which are also most significant. At the same time note might be made of the suggestion in the study on potential benefits of remote sensing by the Cornell group (13) and in the summary report on remote sensing by the Economic Research Service (82) that remote sensing might contribute more to range than forestry applications since "there is so much room for improvement and because the management of range land is so dependent upon timely information". Also, of course, forage contributes rather promptly to the supply of human food.

Some questions which sensor-signature research should aim to resolve are suggested by the pioneering research on natural vegetation recently done by Lent and co-workers at the Forestry Remote Sensing Laboratory (56). In that study "signatures" were noted for several classes of lands: timber, brush, grassland, roads, etc.; also for three different kinds of brush which, by ground examination, proved to be based on differences in species composition. The term "signatures" is enclosed within quotation marks advisedly. As yet there has been no opportunity through testing to replicate results and so to verify whether separate, distinctive signatures have been established for the broad land classes or for the types of brush.

Assuming that a distinctive signature is established for each type of brush, the use of each signature in a sensing system should not be automatic. Its use should first be justified as economically important, bearing in mind that only significant data should be incorporated within the system when there is always a danger that a flood of data may saturate the system. The economic justification may rest on empirical judgments. For example, if one of the types of brush is known to grow only on sites where timber-growing is judged to be a more valuable land use, it may not be difficult to get support by resource managers to underwrite reasonable costs of survey charged to sensing for the amount of that potential timberland occupied by brush. If one of the types of brush represents a valuable forage for big game or is a volative source of fuel it may not be difficult to get support by resource managers to underwrite cost of collecting information on its distribution as a basis for wildlife management or fire protection planning. If--on the other hand--the several types of brush are judged to be of similar economic importance --regardless of interest to people who are not prepared to invest money for data collection in some particular type--all types might best be treated as one composite universe in data handling.

Considerations on whether a signature is both distinctive and economically important might best be made concurrently, rather than sequentially as might be implied by the foregoing discussion. For example, with respect to the brush types, if initial considerations showed that a specific kind of brush had no particular economic significance, there should be no reason for pressing expensive investigations to establish a distinctive signature for that kind of brush.

A somewhat similar situation is posed by the group of five,well-known southern pines. Aside from the resin derived from two of these species, the products of these trees may be grouped within one common category in the marketplace. It may be argued that research aimed at establishing separate, distinctive signatures for loblolly and shortleaf pines would be questionable (to cite two species which have no economically significant resin contents). On the other hand it may be argued by range and wildlife managers that stands of these different species of pines indicate significantly different habitats for livestock or wildlife. The understory in a stand of longleaf pine, for example, may be an optimum habitat for certain game birds and animals as well as domestic livestock. These several considerations indicate how important it is to weigh priorities for signature research even in situations where offhand judgment suggests that search for specific signatures within a rather broad universe is not justified.

In the same context, but focusing on the Pacific side of the country, research to establish distinctive signatures for both Ponderosa and Jeffrey pines should be seriously questioned even though stands of each species are abundant on the Pacific Coast. As with southern pines, it may be presumed that such research faces what looks like an extremely difficult problem, if all stands of each species regardless of vigor and age or size are to be differentiated. And, as with southern pines, the wood of Ponderosa and Jeffrey pines is sold as one product.

To emphasize problems even within what might be considered as an uncomplicated universe, reference is made to pages 25-37 of the LARS bulletin (51). That illustrates the difficulty in establishing distinctive signatures for such important cultivated crops as alfalfa, oats, wheat, and clover. On one occasion, for example, there was no explanation for identical "signatures" for oats and alfalfa. On another occasion red clover and weeds exhibited identical "signatures", and on still another occasion the presumed "signature" for red clover was recorded from a field containing "areas of pasture, alfalfa and...soybeans." Incidentally, the foregoing illustrates why it is hardly appropriate to claim a "unique" signature for a sensor response to anything. The best that may be anticipated is a high probability that a "signature" will be "distinctive" throughout the universe to be surveyed.

It is hoped that the past years of investigations on experimental forests and ranges will provide a substantial basis for the spectral signature research referred to in the first of the three priority areas of research mentioned in the USDA program document. Some researchers believe, however, that there are many large gaps in research in plant physiology, ecology and microclimate which must yet be filled, since very little past work was keyed to energy reflected and emitted from plants under various stages and conditions of growth. One of the few exceptions to this has been the research in plant anatomy related to reflectance characteristics by Olson, Weber and co-workers at the University of Michigan, described in several progress reports to NASA (91, 64, 65). The magnitude of the gaps in research will not be known until a concerted effort is made to determine the applicability of past research to remote sensing. And even if there are large gaps to be filled, the future research task should be least when applied to experimental forests and ranges since advantage may be taken of detailed inventories of vegetation and records of growth which are not available in other areas. Without such an advantage the task is staggering. It is appalling, regardless, considering how insignificant a proportion of the domestic forest and range universe is now represented within NASA test sites and within those very few other experimental areas where remote sensing investigations are now oriented.

It is appropriate here to quote from the report of one researcher who has faced the problem of trying to establish recognition features, if not signatures, for forest associations which are mixtures of species (quite common associations, of course). Lauer reports (54) that "...in mixed stands...there tends to be...variability of tree tone or color _within_ a...species...greater than the tone or color difference _between_ different species. Consequently tree morphology...must be the primary means of identification; image tone or color is of secondary importance..." Lauer goes on to point out that "multi-stage sampling can help in obtaining tree inventory data for heterogeneous mixed forest stands". Yet with respect to specific use of multi-stage sampling (which includes the use of large-scale photography) he goes on to say that the number of trees by species may be seriously underestimated. Furthermore, he asserts it is "...nearly impossible to distinguish between incense cedar and ponderosa pine on both large and small scale photos..."

It should be noted that Lauer was trying to develop clues to interpretation which an experienced interpretor might recognize. Those are not exactly comparable to signatures which might be used in data analysis by machines. The writer's experience substantiates the conclusions by Lauer. He would add, only, that there is a strong probability that establishing meaningful signatures for forest and range associations will be much more difficult than establishing recognition features which a good interpreter may intuitively use without formalizing the reasons for interpretation decisions.

One important aspect of signature research must be to determine whether more than one signature (and how many) is needed for each feature to correspond with several sensing variations of an application. For example, with respect to photographic sensing, assume that coverage is planned (perhaps on a sampling basis) from three different altitudes: perhaps from space platforms, from high-flying jets, and from low level aircraft. To perfect an application, at least one set of signatures might be needed for each of the following: for rather even tones as registered from space, for contrasting patterns of tones registered from high altitude flights, and for contrasting, detailed patterns of light and shadow registered from low-level flights. To complicate this research further, signatures might be needed for each altitudinal level of sensing to represent significantly different illuminations of features. The reader will recall from the assumptions for this study that details imaged from ERTS vehicles are scheduled to be illuminated with sun angles giving informative shadowing of details. Inevitably the sun angles will vary significantly by season; thus so will the shadowing of details with consequent effects on signatures. Whether one signature or a few may suffice for identification of a particular feature, there must be investigation of the possible sources of variation. And when the possibilities just mentioned are added to the possible variations due to geographic variability in each forest association (such as the Douglas-fir) with all its component age and site classes, signature research cannot be done except by a formidable, well-organized effort.

It is suggested that whenever it becomes evident that the prospect of obtaining the signature for a forest association is bleak it would be desirable to orient the research to another objective. For example, to take a hypothetical but not unrealistic situation, suppose the spectral responses were similar from typical stands of lodgepole pine and over-stocked, stagnated stands of ponderosa pine. The researcher might be advised to move on to a more likely prospect, assuming that the differentiation between those stands with quite similar or identical sensor responses must needs be resolved by field work (as a phase of multi-stage sampling, perhaps) unless an experienced interpreter could discern the differences. Presumably spectral signatures will be developed in the not distant future which will allow identification of a number of cultivated crops with good reliability (perhaps 95% of the time), especially if sequential coverages and "crop calendars" are fully exploited. Within the same time period it is likely that valid signatures will be established for only a small proportion of the thousands of important forest and range associations. For the foreseeable future this suggests that a large proportion of the actual data analysis in forest-range disciplines must be done by humans.

The writer does not presume to recommend specific priorities for research on spectral signatures since those are decisions which must be made by the administrators of research funds. Nevertheless if the reader accepts the rationale outlined in this study and the prospects for applications that are indicated in Tables 1-3, he will probably agree that research should be pushed to establish spectral signatures for all major land classes (forest and grasslands, etc.) and for major subclasses of natural vegetation such as the Douglas-fir, pinyon-juniper and sagebrush associations. Hopefully, he will also agree that priority should be given to developing signatures for serious damage to or stress on the vegetation caused by such destructive agents as fire, insects, weather and disease. These might exclude signatures for those agents for which no effective control measures have been devised--e.g., Dutch Elm disease--except as those may be necessary for identifications to prevent confusion between "significant" and "nonsignificant" signatures. Presumably the reader will also agree that signatures to indicate significant effects on vegetation due to man's activities--e.g., logging, land clearing--will be very useful also. Incidentally, the effort required to establish signatures for some of these activities may be less than to establish signatures to differentiate many significantly different vegetation associations. Indeed not only might recently logged stands be differentiated from uncut stands but several classes of cutover areas significant in fire control planning might also be differentiated, for example. These classes are: where no slash disposal has been amde, where slash has been piled but not burned, and where slash has been disposed by prescribed burning. This presumes that over sizable areas--such as clearcuts of 40 acres or larger--there will be distinctive patterns for each class, due to differences in shadow details, which will be reflected in distinctive signatures. It may be pointed out that clearcuts of 40 acres or larger should be distinctive even on the telemetered imagery from space expected by 1980.

Still with no intention to indicate rigid priorities, but keeping in mind the desirability of establishing signatures which are now economically important, the writer suggests an approach to priorities for signature research which should be useful in the forestry discipline. Insofar as possible, research to establish signatures for the broad vegetation associations listed below would appear to be justified from the standpoint of timber management in the United States, if for no other reason. Signatures for both healthy and "sick" stands are needed, of course. Two criteria, only, were used as guides for this listing: the estimated area extent (percent of the U.S. forest universe occupied) of an association, and the estimated proportion of the Nation's growing stock represented by the key species for an association. These criteria were derived from the latest comprehensive report on the Nation's timber resources (88). The writer rates those associations at the top of the list more important than those at the bottom from a judgment evaluation of the combined criteria just cited. Even if the reader accepts that judgment, it is probable that he can think of other criteria (based on other forest values) which may well change the relative ratings of those priorities. Furthermore, obviously there are other associations (such as those from primary range vegetation) that also merit priority for signature research.

Major vegetation association	Percent of forest area in U.S.	Percent of timber growing stock in U.S.
Oak-hickory & oak-pine	28	6
Loblolly-Shortleaf pines	12	7
Douglas-fir	7	17
Ponderosa-Jeffrey pines	7	7
Bottomland Hardwoods	11	3 plus
Longleaf-Slash pines	5	2
Northern Hardwoods (Beech, birch, maple)	7	Less than 1
Aspen-birch	5	Neglig.
Lodgepole pine	3	3 plus
Eastern spruce-fir	4	Neglig.
Western spruce-fir	3	1 plus
Hemlock-Sitka spruce	2	10
White-Red-Jack pines	2	Neglig.
Sugar, Western white pines	1	1 plus

Testing for Validity of Signatures

Another effort which will require many thousands of man hours on the ground as well as considerable expenditures in aerial sensing is in testing to establish validity of tentative signatures. Virtually nothing has been done on this phase. Furthermore, there is a real danger that this phase may be slighted so much that automated analysis of sensed data may be discredited by attempts at operational applications which produce intolerably erroneous results. The basis for this concern is twofold. First is the traditional difficulty in getting photo interpreters to subject their judgments to statistical evaluation. The technical meetings and literature on photo interpretation are cluttered with so-called "research results" which were based on one man's judgment under one set of photographic and field conditions. This difficulty is compounded by the problem of organizing enough manpower on a research study so that there can be a valid statistical evaluation of differences in results due to interpreters. Second is the reluctance to replicate tests. In this connection it may be noted that only two of the twelve latest annual reports of progress during 1968 on NASA-financed sensing studies in the forest and range disciplines mentioned plans for replicated testing. No doubt, most of the work plans contained at least general schedules for such testing. Nevertheless, unfortunately, both the importance and amount of work required for adequate testing evidently were discounted.

The results of human interpretations not substantiated by tests may well be questioned, and <u>results of any machine interpretations will hardly be worth reading unless the signatures used in the procedure have been adequately tested</u>. At least an experienced interpreter can temper his decisions with solid judgments, knowing, for example, that the images of many dissimilar stands may be so similar that the eye cannot discriminate them. Except on extremely large scales of photography, for instance, who can determine where true fir is the predominant and not the minor species in the transition zone with Douglas-fir in the Pacific Northwest?

An experienced interpreter may make this determination, perhaps, not because of differences in images of the two species, but because he knows the detailed topographic situations most favorable to each species which may not easily be incorporated as parameters for machine analysis. Users should be wary of any results of analysis by an "idiot machine" which has been programmed for signature readouts unless the signatures have been carefully tested using replicating samples by sensors coordinated with field checks.

The reader will appreciate that the coordinated check of sensor and field samples will be a difficult enough job in an experimental forest where a detailed map showing subtle but significant difference in the forest cover is usually available. He will also appreciate that the man hours required for each check will be much greater when the test (as it should be) is in a forest situation where there is much less ground control. For, regardless of whether some advantage is taken of such aids as helicopters to reduce travel time, there must usually need to be work on the ground if only to determine whether the test sample is in a healthy stand or one under stress.

Developing Data Handling and Analysis Techniques

As compared to the signature problem, the effort to solve the data handling and analysis problem begins with several advantages. There is a wealth of highly developed hardware, and suitable software techniques and knowhow--all of which can be geared to the problem. Nevertheless, the task in that area is tremendous, and the feeling of those who are seriously considering the problem is that much more money must be spent on data handling and data analysis than on data collection. As the recent NASA program document emphasized when describing the ERTS system, "...it's most awesome potential aspect (is) the ground data handling and interpretation..By comparison the space segment...will be cheap and simple by today's technology" (60).

Without presuming what form the data handling structure for earth resources space and related data will take, the writer assumes that there will be a large central data handling facility, such as described in the NASA program document, to index and store earth resource data obtained by space sensors. It seems quite unlikely that ultimate major users, such as the Forest Service and Bureau of Land Management, would want to record all data in real time transmitted from space. Regardless of whether major users in forestry and range disciplines prefer to duplicate all material of interest from that central data bank and handle all their own analysis, it would seem important that they spell out the specific kinds and forms in which they want to retrieve data. This means specifying what items of data they want from every sequential coverage in off-line readout and in what format; and what data they will require only on request. The important requirement for identification of data by geographic locality is not unique to forestry and range disciplines. Presumably there will be some standard method for such identification for each cell of data. Yet users of data on forests and ranges must decide what their minimum needs are for geographic referencing long before the central data facility operates or they may find the reference system inadequate.

Some important questions of particular concern to major agencies using forest and range data are how to efficiently handle dissemination and analysis of data internally. In the Forest Service, for example, at what level, or what levels, should the storages be maintained for all data required for an application: that from space, from aerial collecting and from ground surveys? Should there be one master repository, or several, in the Forest Service for the sensor signatures? Or should all those data be stored at the NASA central facility, for example? The answers to these questions should be determined at the same time that the main (NASA) depository for space data is organized. And the answers, obviously, can be satisfactorily obtained only through a systems design study made for each major using agency (public and private). Apparently there is need for a data handling and analysis subsystem for the agency which takes maximum advantage of the government-wide system tied to the central data facility.

Since data handling and analysis capabilities do not come cheap, it may well be that there cannot be a direct pipeline to transmit sensed data to every major field station, such as the headquarters for a ranger district in the Forest Service, for example. Perhaps the lowest levels to which data from the central facilities should be forwarded and where the consoles for automated analysis should be located are the headquarters for administrative and experiment station regions. It appears that the sensing applications with best potentials might be effectively performed on regional bases. These headquarters would be relatively close to both field problems and to the managers and technicians acquainted with local conditions. Such headquarters might well be the main depositories for spectral signatures and other information which would facilitate interpretation. By the same token, regional control of signatures and analysis should facilitate the frequent changes and improvements that are inevitable as signature research and knowledge of the regional environment increase. Most of all, if analyses are done on regional bases those most concerned with day-to-day management of resources would be in close proximity to current analyses and the analysts.

As compared to analysis of data on cultivated lands, analysis of forest and range data will no doubt require much more effort by humans. Only at some indeterminate future date may machines take over the same proportion of analysis in the forestry and range disciplines as the LARS report (51) visualizes in the agricultural discipline. This means that in analysis of forest and range data there will be more need for instruments which can display actual images from several spectral bands and from sequential coverages than there will be for the automatic readouts of multispectral scanners as advocated for agriculture in the LARS investigations. Image enhancement may also be used to advantage in graphics to facilitate human interpretation, and presumably automatic equipment will be used to help screen out irrelevant data. Hopefully, no great investment will be required to develop such analytical equipment. Apparently there are on-shelf items of hardware which might be adapted or modified to meet forest and range requirements. There are several instrument makers who would be pleased, apparently, to fulfil such requests within a relatively short time if the requirements were known. It may be noted that such development might be most effectively done by commercial agencies--in contrast to the great amount of research and development of signatures, which apparently can best be done by cooperative research efforts of the Forest Service and universities.

Testing of Applications

Operational, full-scale tests of the applications cited earlier in this study cannot be made until components of a complete data collecting and handling system have been put together. The timing for the first full-scale test of an application depends in large part upon judgment--as to the geographic area for the test, whether enough signatures have been validated to make the test worthwhile, whether enough ground truth is available (or can be expeditiously collected) to check unforeseen problems that may occur, etc. Hopefully, well in advance of the decision for a full-scale test, considerable thought will have been given to prospects aside from the investigations on spectral signatures and on details of data handling and analysis. The kinds of related efforts that are necessary are explicit or implied in the enumeration of the eleven forestry areas recommended for forestry research in the USDA program document (80). All but one of those areas correspond to applications or groups of applications emphasized in this current study. That one area (site quality) appears to be intangible and difficult to attack by sensing since there seems to be no consensus amoung foresters as to what site really is. Therefore it is submerged in the present study under "detailed land classification". Only one of the eleven forestry areas identified in the USDA document (detection and mapping of forest fires) is not deemed to be amenable to sensing from space in the near future, for reasons given in the present study.

Research-development of Sensors

The development of photographic equipment and processing would seem to be ahead of effective use of the equipment in the forest and range disciplines. There is evidently need for more research and development of other sensors that could contribute to forest and range disciplines. Better spatial resolutions are needed in thermal sensing than can be obtained by present equipment. Improved thermal sensing could contribute greatly not only in fire detection and mapping applications; it might also lead to a breakthrough in detection of stresses on the forest vegetation. Yet even greater results might be achieved by research and development in microwave sensing with the aim of providing an all-weather capability useful in several forest and range applications, and not presently filled by radar. How much support land-managing agencies are justified in giving to development of better sensors depends upon success in establishing signatures for important phenomena and objects. It is futile to keep on developing sensors that provide finer resolution and discrimination between "noises" and "responses" unless those "responses" can be identified as signatures of things that are significant.

Benefit-Cost Studies

Under the stimulation induced by the recent, widespread promotion of remote sensing there has been some tendency to ignore economic benefits of sensing as immaterial provided an argument can be made for intangible benefits. Without downgrading the intrinsic values of benefits which are so intangible they appear not to be measurable in dollars, the writer suggests that those who argue solely on the basis of benefits not valued in dollars must shoulder the full burden of proof for their arguments. As a straightforward, logical procedure after technical feasibility of a technique of sensing has been established, there should be prompt investigations to determine whether the technique is economically feasible of operational application. The ideal determination of whether such a new technique is prospectively useful should be based on study of the benefit-cost ratio anticipated through operational application of the technique and comparisons to show whether that ratio is more or less favorable than the ratio anticipated by any alternative (usually current) method of data collection. The ratios should be expressed in monetary terms even if those are not precisely determinable. A less than ideal approach to comparisons of alternative techniques is to ignore estimation of benefits and assume that benefits must exceed costs for any technique used for a data collecting purpose in the past; then to assume that any less costly technique of collecting the same data is even more acceptable.

This economic phase of research, needed as a basis for any changes recommended in general methods of data collection, obviously cannot be made without realistic experience data. Thus it should follow closely behind the final stages of developing and testing the technical feasibility of a technique.

Education

Without a strong, continuing program of education, of course, much effort to develop useful techniques may be wasted. Since this point applies to any field of research endeavor, the reader may question why the writer ends his report on this note. Partly this is because education was touched on several times (and not only by educators) during interviews. Partly it is that the writer finishes this study with some of the same apprehension that he had when he started it: that there has been a lot of misinformation, along with information, about remote sensing. He hopes, along with many others, that future emphasis will be on information and education. Unless this is so there is a strong probability that remote sensing may remain a fascinating topic of conversation--for a time--and will not be used in the foreseeable future nearly to its capabilities.

Propaganda (in its derogatory sense) contrasted with education in remote sensing is a subject that need not be taken up here. It is pertinent to emphasize that the present cooperative partnership between land-managing agencies like the U.S. Forest Service, the U.S. Bureau of Land Management and the Oregon State Land Board on the one hand and universities on the other is a healthy one to insure that proven research and development in remote sensing is used. Not necessarily will this be insured without continuing close cooperation between those agencies. The university graduates who are recruited by the land-managing agencies should have more technical knowhow than those who preceded them. But it will do neither them nor the agency they work for any good unless they can demonstrate knowhow resting on theory soundly supported by research and development. One of the ways to insure this, naturally, is for the universities to participate in research and development of techniques to simplify or solve problems that are faced by resource managers. Another coincident way, naturally, is for resource managers to participate through seminars or as invited speakers in the classrooms of their potential recruits.

VIII. APPENDIX - A

A. List of persons who furnished pertinent information (See preface for several others).

Aldred. A.H.	Grad. student,Univ. of Calif. on leave from Canadian Dept. of Forestry, Ottawa, Ontario, Canada.
Aldrich, R.	Principal Research Forester, Remote Sensing Project, PSWF&RES, Berkeley, Calif.
Aufenthie, Thomas	Timber Inventories, USBLM, Portland, Oregon.
Barrows, Jack	Director, Div. of Forest Fire and Atmospheric Science Research, USFS, Washington, D.C.
Baughman, Robert G.	Principal Research Meteorologist, Lightning Research Project, Northern Forest Fire Lab., Missoula, Mont.
Bedell, Thomas	Prof. of Range Improvement & Utilization, Dept. of Range Management, Oregon State University, Corvallis, Oregon.
Bongberg, J.W.	Director, Div. Forest Pest Control, USFS, Washington D.C.
Boring, Wm. R.	Chief, Water Management Branch, USFS, Portland, Ore.
Brackebush, Arthur P.	Chief, Northern Forest Fire Lab., USFS, Missoula Montana.
Bradley, Richard	In charge Photographic Contracting, USFS, Wash., D.C.
Carneggie, David	Forestry Remote Sensing Laboratory, Berkeley, Calif.
Castles, John R.	Chief, Timber Sales Admin. Branch, USFS, Wash., D.C.
Chandler, Craig C.	Div. of Forest Fire & Atmospheric Science Research, USFS, Washington, D.C.
Clifton, Joseph	Director, Photographic Division, ASCS, USDA. Washington, D.C.
Colwell, Wm.	Proj. Leader Soil-Veg. Survey, PSWF&RES, Berkeley, Calif.
Dickerman, M.B.	Associate Deputy Chief for Research, USFS, Wash., D.C.
Dill, Henry W.	Land Resources Branch, ERS, Washington, D.C.
Dilworth, J.R.	Head, Dept. of Forest Management, School of Forestry, Oregon State Univ., Corvallis, Oregon.

Dunford, E.G.	Chief, Branch of Watershed Management Research, USFS, Washington, D.C.
Draeger, Wm.	Forestry Remote Sensing Laboratory, Berkeley, Calif.
Driscoll, Richard S.	Principal Plant Ecologist, Rocky Mtn. For. & Range Exper. Sta., Fort Collins, Colo.
Fahnestock, Geo. R.	Leader, Fuel Appraisal Research Project, PNWF&RES, Seattle, Washington.
Farrell, Norman J.	Chief of Fire Control, USFS, San Francisco, Calif.
Fuquay, Donald M.	Leader, Lightning Research Project, Northern Forest Fire Laboratory, USFS, Missoula, Mont.
Furniss, Robert L.	Consultant in Forest Entomology & Forest Pest Control, Portland, Oregon.
Gillmore, Lloyd	Chief, Div. of Watershed Management, USFS, Portland, Ore.
Graham, Howard E.	Meteorological Services, Div. of Fire Control, USFS, Portland, Oregon.
Halverson, Howard G.	Water Yield Improvement, PSWF&RES, Berkeley, Calif.
Harman, Wm. E.	Washington, D.C. Representative, Mark Hurd Aerial Surveys.
Hartong, Allan L.	Research Forester, Forest Fire Science Project, Northern Forest Fire Lab., USFS, Missoula, Mont.
Hirsch, S.N.	Leader, Fire Scan Research Project, Northern Forest Fire Lab., USFS, Missoula, Montana.
Hixon, Homer	Director, Div. of Timber Management, USFS, Wash., D.C.
Hoglind, Herbert	In charge, Forest Management, U.S. Bureau of Land Management, Portland, Oregon.
Holscher, Clark E.	Director, Div. of International Forestry, USFS, Wash., D.C.
Hopkins, Walter	Chief, Branch of Forest Recreation Research, USFS, Washington, D.C.
Howlett, M.R.	In charge Photogrammetric Center, USFS, Wash., D.C.
Iverson, John	Specialist, Remote Sensing, Photographic Div., ASCS, USDA, Washington, D.C.
Johnson, Edward A.	Chief, Branch Environmental Management, Div. of Watershed Management, Washington, D.C.
Johnson, Floyd A.	In charge, Biometrics, PNWF&RES, Portland, Oregon.

Josephson, H.R.	Director, Forest Economics & Marketing Research, USFS, Washington, D.C.
Kampmann, T.S.	In charge, Management Plans & Inventories, USFS, Portland, Oregon.
Langley, Philip G.	Project Leader, Forest Measurements Research, PSWF&RES, Berkeley, California.
Lent, Jerry D.	Forestry Remote Sensing Lab., Berkeley, Calif.
Lowden, Merle E.	Director, Div. of Fire Control, USFS, Washington, D.C.
Luney, Percy B.	Economist, Land Resources Branch, Economic Research Service, USDA, Washington, D.C.
McArdle, Richard	Land Resources Branch, ERS, Washington, D.C.
Meyer, Merle	Professor, School of Forestry, Univ. of Minnesota, St. Paul, Minn.
Miller, Robert	Office of the Administrator, USDA, ARS, Washington, D.C.
Newport, Carl	Mason, Bruce & Girard Consulting Foresters, Portland, Ore. and member Panel on Forestry-Agriculture-Geography, Summer Study on Space Applications, Nat'l Research Council.
Norick, Nancy	Forestry Remote Sensing Project, PSWF&RES, Berkeley, Calif.
Olson, Charles E.,Jr.	Instructor, Dept. of Forestry, Univ. of Michigan, Ann Arbor, Mich.
Olson, Olaf C.	Soils & Geology Resources, Div. Watershed Management USFS, Washington, D.C.
Ostrom, Carl	Director, Timber Management Research, USFS, Washington, D.C.
Otte, Robert	Chief, Land Resources Branch, Economic Research Service, Washington, D.C.
Paine, D.P.	Dept. of Forest Management, School of Forestry, Oregon State Univ., Corvallis, Oregon.
Paulson, Harold A.	Chief, Branch of Range & Wildlife Habitat Research, USFS, Washington, D.C.
Pierce, Monte K.	Ass't Director, Div. of Fire Control, USFS, Wash., D.C.
Pope, Robert	Leader, Survey Techniques Project, PNWF&RES, Portland, Oregon.

Rummel, Robert	Chief, Range Analysis/Planning Branch, Div. of Range Management, USFS, Washington, D.C.
Sandau, Warren	In charge, Range & Watershed Management, USBLM, Portland, Oregon.
Sankela, Wm.	In charge, Timber Inventories, USBLM, Portland, Oreg.
Schmid, C.W., Jr.	Research Physicist, Lightning Research Proj., Northern Forest Fire Lab., USFS, Missoula, Montana.
Schwarzbart, Gideon	Management Sciences Staff, PSWF&RES, Berkeley, Calif.
Shea, Keith R.	Project Leader, Forest Diseases Research, Forestry Sciences Lab., PNWF&RES, Corvallis, Ore.
Smith, James L.	Project Leader, Water Yield Improvement, PSWF&RES, Berkeley, Calif.
Storey, Herbert C.	Director, Div. of Watershed, Recreation & Range Research, USFS, Washington, D.C.
Strode, D.	Ass't Director, Wildlife Management, USFS, Washington, D.C.
Taylor, Alan R.	Research Forester, Lightning Research Project, Northern Forest Fire Lab., Missoula, Montana.
Valfer, Ernst	Management Sciences Staff, PSWF&RES, Berkeley, Calif.
Wear, John	Remote Sensing Research, USFS, Portland, Oregon.
Weber, F.P.	Remote Sensing Project, PSWF&RES, Berkeley, Calif.
Wert, Stephen	Remote Sensing Project, PSWF&RES, Berkeley, Calif.
Weyermann, Geo. F.	Chief, Plans & Silviculture Branch, USFS, Portland, Oregon.
Wilson, Kenneth O.	Chief, Div. of Fire Control, USFS, Portland, Oregon.
Wright, Kenneth	Ass't Director, Forest Protection Research, PNWF&RES, Portland, Oregon.
Zumwalt, E.V.	Ass't Director for Forest and Range Resources, U.S. Bureau of Land Management, Washington, D.C.

VIII. APPENDIX - B

B. List of pertinent references.

1. Aldred, A.H. "Potential of Satellite Photography in Forestry", Forest Manag. Institute, Ottawa, Ontario, Information Report FMR-X-11. Sept., '68.

2. American Society of Photogrammetry. "Manual of Photographic Interpretation". Washington D.C. 1960.

3. Amidon, Elliot and Gould, Ernest M., Jr. "The Possible Impact of Recreation Development on Timber Production in Three California National Forests". Tech. Paper No. 68, PSWF&RES, USFS, Berkeley, Calif. 1962.

4. Anderson, Hal. E. "Sundance Fire: An Analysis of Fire Phenomena". U.S.D.A., Forest Service Research Paper INT-56, Ogden, Utah. 1968.

5. Avery, T. Eugene. "Interpretation of Aerial Photographs". Burgess Pub. Co., Minneapolis, Minn. 1962.

6. Baker, Simon. "An Evaluation of Crop and Land Use Data in a World Sample of Countries". USDA, Economic Research Service, Washington, D.C., Nov.,1968.

7. Bickford, C.A. "The Sampling Design Used in the Forest Survey of The Northeast". Journal of Forestry 50:290-292. 1952.

8. Bjornsen, Robert L. "Infrared Mapping of Large Fires". Fifth Symp. on Remote Sensing of Environment Proc. pp. 459-464, Univ. of Mich., Ann Arbor. 1968.

9. Brock, G.C. et. al. "Photographic Considerations for Aerospace". Itek Corp., Lexington, Mass. 1965.

10. Carman, P.D. and Carruthers, R.A.F. "Brightness of Fine Detail in Air Photography". J. Opt. Soc. Am. 41:305-310. 1951.

11. Carneggie, David M. "The Evaluation of Rangeland Resources by Means of Multispectral Imagery." Annual Prog. Rep. for Earth Res. Survey Program,Office of Space Sciences and Applications, NASA. 30 Sept.,'67.

12. Carneggie David M. "Analysis of Remote Sensing Data for Range Resource Management". Annual Prog. Rep. for Earth Res. Survey Program, Office of Space Sciences & Applications, NASA. School of Forestry & Conservation, Berkeley, Calif. 30 Sept. '68.

13. Center for Aerial Photographic Studies, Cornell Univ. "Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest, and Range Resources". Ithaca, N.Y. Dec., 1967.

14. Center for Aerial Photographic Studies, Cornell Univ. "Development of a Land Use Classification System Based on Interpretation of Imagery from the Earth Resources Technology Satellite". Interim Rep. on Contract Project for the Economic Research Service, USDA. Feb., 1969.

15. Colwell, R.N.,et. al. "Basic Matter & Energy Relationships Involved in Remote Reconnaissance: Report of Subcommittee I, Photo Interpretation Committee". Photogrammetric Engineering. Sept., 1963.

16. Colwell, R.N. "Determining the Usefulness of Space Photography for Natural Resource Inventory". pp. 249--, Proc. 5th Symposium on Remote Sensing of the Environment. Univ. of Mich. Ann Arbor, Mich., Apr., 1968.

17. Colwell R.N. "The Usefulness of Sequential Space Photography for Earth Resource Inventory". 19th Congress of the International Astronautical Federation. New York, N.Y. Oct. 1968.

18. Colwell, R.N., et. al. "A Survey of Earth Resources on Apollo 9 Photography". Spec. rep. of research performed under NASA contract no. NAS 9-9348 for the Earth Res. Survey Program, office of Space Sciences & Applic. NASA. April,'69.

19. Committee on Science and Astronautics, USHR, 90th Congress. "Earth Resources Satellite System, Report for the Subcommittee on NASA Oversight". Washington, D.C. 1968.

20. Croon, Gale W., et.al. "Infrared Scanning Techniques for Big Game Censusing". Jour. of Wildlife Management 32 (4): 751-759. Oct. 1968.

21. Culver, Roger N. and Poulton, Charles E. "Application of Ecology and Remote Sensing in the Analysis of Range Watersheds". Prog. Report on Contract for U.S. Bur. of Land Management by the Ag. Exper. Sta., Oreg. State Univ., Corvallis, Oreg. June, 1968.

22. Dalke, Geo. W., et. al. "Multi-Image Correlations Study for MGI, Final Report (U)". Prepared by the Center for Research, Inc. Univ. of Kansas,to report on a contract for the USA Topographic Laboratories. Laurence, Kansas. Dec.,1968.

23. Dill, Henry W., Jr. "Worldwide Use of Airphotos in Agriculture". Ag. Handbook No. 344, USDA, Economic Research Service. Wash. D.C. Sept.,1967.

24. Fahnestock, George R. "Impacts of Forest Residues and Their Disposal on Forest Land Management and Environment in the Pacific Northwest". USDA, Forest Service, PNW For & Range Exper. Sta. Seattle, Wash., June, 1968.

25. Food and Agric. Organiz. of the United Nations. "Agriculture in the World Economy". Second Edition, Rome, Italy, 1962.

26. Food and Agric. Organ. of the United Nations. 'World Forest Inventory". FAO, Rome. 1963.

27. Food and Agric. Organiz. of United Nations. 'Wood: World Trends and Prospects". Basic Study No. 16. Rome, Italy, 1967.

28. Food and Agric. Organiz. of United Nations. "Survey of Pine Forests, Honduras". FAO/SF: 26-Hon 50. Rome, Italy, 1968.

29. Forestry Remote Sensing Laboratory, School of Forestry & Conservation, Univ. of Calif. "Remote Sensing Applications in Forestry". Quarterly Progress Rep. for NASA Contract No. R-09-038-002 for the period Apr. 1 to June 30, 1969.

30. Freese, Frank. "Elementary Forest Sampling". Ag. Handbook no. 232, USDA, Forest Service, U.S. Gov't Printing Office. Dec., 1962.

31. Frey, H. Thomas, et. al. "Major Uses of Land & Water in the United States with Special Reference to Agriculture, 1964". Ag. Econ. Rep. No. 149, USDA, Economic Research Service, Wash. D.C. Nov., 1968.

32. Furniss, Robert L., et. al. "Forest Pest Losses and the Forestry Profession". Journal of Forestry 65 (5): 284-287. May, 1969.

33. Fuquay, Donald M., "Project Skyfire Progress Report, 1958-1960". Research Paper 71, Int. Forest & Range Exper. Station. USDA Ogden, Utah .1962.

34. Fuquay, Donald M. 'Weather Modification and Forest Fires". Ground Level Climatology. Amer. Assoc. for the Advancement of Sci. pp. 309-325, 1967.

35. Fuquay, Donald M. et. al. "Characteristics of Seven Lightning Discharges that Caused Forest Fires". Jour. of Geophysical Research, Vol. 72, No. 24. Dec. 15, 1967.

36. Gary, Howard L. "Density Variation in a Snowpack of Northern New Mexico". Proc. of 35th Annual Meeting, Western Snow Conference. April, 1967.

37. General Electric Corporation. "Percheron Suitability Applications and Payloads". Study performed by GE-SMSP for NASA-OSSA. Apr., 1967.

38. General Electric Corporation. "Proposal for an Earth Resources Satellite". Study performed for NASA-OSSA May, 1967.

39. Greeley, A.W., et. al. "Final Report...Blowdown and Bark Beetle Survey in...Oregon and Washington". PNWF&RES & BEPQ, USDA, Portland, Oregon. July, 1953.

40. Heller, Robert C., et. al. "The Use of Multispectral Techniques to Detect Ponderosa Pine Trees Under Stress From Insect or Pathogenic Organisms". Quarterly Progress Report for Earth Resources Survey Program, Office of Space Sciences & Applications, NASA, For. Remote Sensing Lab., Berkeley, California, 31 March, 1969.

41. Hirsch, Stanley N., et. al. "Project Fire Scan, Fire Mapping Final Report". USDA, Forest Service Research Paper INT-49, 1968.

42. Hirsch, Stanley N. "Project Fire Scan--Summary of 5 Years' Progress in Airborne Infrared Fire Detection". Fifth Symposium on Remote Sensing of Environment, Proc. pp. 447-457. Univ. of Mich., Ann Arbor, 1968.

43. Hirsch, Stanley N. and Madden, Forrest H. "Airborne Infrared Line Scanners for Forest Fire Surveillance". Annual Technical Symposium, Society of Photo-Optical Instrumentation Engineers, San Francisco, Calif., Aug., 1969.

44. Huddleston, H.F. and Roberts, E.H. "use of Remote Sensing for Livestock Inventories". Proc. Fifth Symposium on Remote Sensing of Environment. pp. 307-327. Univ. of Mich. Ann Arbor, 1968.

45. Hycon. "Multispectral Image Processor and Display Study". Proposal to NASA by the Hycon Co. Apr. 10, 1968. Monrovia, Calif.

46. International Union of Forest Research Organizations. "Aerial Photographs in Forest Inventories, Applications and Research Studies". 96 pp. Munich. 1963.

47. Jaffe, Leonard. "NASA Communications Satellite Program". Second National Conference of Peaceful Uses of Space, NASA SP-8, pp. 103-114. U.S. Gov't Print. Off. Wash., D.C. May, 1962.

48. Katz, A.H. "Observation Satellites: Problems and Prospects". Astronautics. April, 1960.

49. Katz, A.H. "Reflections on Satellites for Earth Resources Surveys: Personal Contributions to a Summer Study". Report P-3753 Published by the Rand Corporation. Santa Monica, Calif. Dec., 1967.

50. Kinashi, Kenchi, et. al. "New Development of Sampling Designs in Forest Inventories". Bulletin of the Kyushu Univ. Forests, No. 35, Apr., 1962.

51. Laboratory for Agricultural Remote Sensing. "Remote Multispectral Sensing in Agriculture". Research Bull. No. 844, Agric, Exper. Station, Purdue Univ. Lafayette, Ind., Sept., 1968.

52. Langley, Philip G., et. al., "Multi-Stage Sampling of the Forest Resource Using Space Photography, An Apollo 9 Case Study". Advance copy furnished by Pac. SWF&RES. Berkeley, Calif. 1969.

53. Langley, P.G. and Sharpnack, D.A. "The Development of An Earth Resources Information System Using Aerial Photographs and Digital Computers". Annual Progress Report, Forestry Remote Sensing Laboratory, For Earth Resource Survey Program, Office of Space Sciences and Applications NASA. Sept., 1968.

54. Lauer, Donald T. "Forest Species Identification and Timber Type Delineation on Multispectral Photography". Quart. Prog. Rep., For. Rem. Sensing Lab. for Earth Resources Survey Program, Office of Space Sci. & Applic. NASA. 30 Sept., 1968.

55. Lent. J.D. "Cloud Cover Interference with Remote Sensing of Forested Areas from Earth-Orbital and Lower Altitudes". Ann Progr. Report, Forestry Remote Sensing Lab. for Earth Resources Survey Program, office of Space Sci. & Applic. NASA. Berkeley, Calif. Sept., 1966.

56. Lent, J.D. "The Feasibility of Identifying Wildland Resources Through the Analysis of Digitally Recorded Remote Sensing Data". Thesis submitted in partial satisfaction of the requirements for the degree of MS in Forestry, Univ. of Calif., Berkeley. 1968.

57. Litton, R. Burton, Jr. "Forest Landscape Description and Inventories". Forest Service Res. Paper PSW-49, PSWF&RES, Berkeley, Calif. 1968.

58. Losensky, John B. "An Operational Test of an Infrared Fire Detection System". Fire Control Notes, USDA, Forest Service. Vol. 30:2 pp. 8-11. 1969.

59. NASA. "International Programs". Prepared by the Office of International Affairs. GPO 870-0-39. Wash., D.C. Jan., 1969.

60. NASA "Earth Surveys Program Documentation". Prepared by Earth Surveys Planning Panel. Apr. 22, 1969.

61. National Research Council. "Useful Applications of Earth-Oriented Satellites. Forestry-Agriculture-Geography". Report of Panel 1 of Summer Study on Space Applications for NASA. National Academy of Sciences, Washington D.C. 1969.

62. National Research Council. "Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee". Summer Study on Space Applications for NASA. National Academy of Sciences, Washington D.C. 1969.

63. National Research Council."Useful Applications of Earth-Oriented Satellites, Summaries of Panel Reports". Summer Study on Space Applications for NASA. National Academy of Sciences, Washington D.C. 1969.

64. Olson, C.E., Jr. and Ward, J.M. "Remote Sensing of Changes in Morphology and Physiology of Trees Under Stress". Ann. Prog. Report, Forestry Remote Sensing Laboratory for Natural Resource Survey Program. NASA. 1968.

65. Olson, Charles E. Jr., et. al., "Remote Sensing Implications of Physiologic and Morphologic Changes in Forest Trees". Quarterly Prog. Rep., Forestry Remote Sensing Lab. for Earth Resources Survey Program, Of. of Space Sci. & Applications, NASA, Berkeley, Calif. 31 Mar., 1969.

66. Outdoor Recreation Resources Review Comm. "Outdoor Recreation for America". A report to the President and to the Congress. 246 p. Gov't Print. Off. Wash., D.C. 1962.

67. Poulton, Charles E. and Schrumpf, Barry J. "Comparative Merits of Multispectral...Data and Aerial Photography for the Analysis of Range...Features...". Quarterly Prog. Rep. for Earth Resources Survey Program, Office of Space Sci. & Applications, NASA for Remote Sensing Lab., Berkeley, Calif., 31 March 1969.

68. Select Committee on Astronautics & Space Exploration "Space Handbook: Astronautics and its Applications". U.S. Gov't Printing Office. Washington D.C. 1959.

69. Sherr, Paul E.,et. al. 'Worldwide Cloud Cover Distributions for Use in Computer Simulations". Final Report to Marshall Space Flight Center under contract by Allied Research Assoc., Concord, Mass. 1968.

70. Smith, F.M., et. al., 'Measuring Snow Depths by Aerial Photogrammetry". Proc. of 35th Ann. Meeting, Western Snow Conference, April,1967.

71. Society of American Foresters "Forestry Handbook". The Ronald Press Company, N.Y. 1955.

72. Spurr, Stephen H. "Forest Inventory". The Ronald Press Co. New York. 1952.

73. Spurr, Stephen H. "Photogrammetry & Photo-Interpretation". The Ronald Press Co. New York. 1960.

74. State of California Division of Forestry "Soil Vegetation Surveys in California". Sacramento, Calif. Nov.,1958 (Rev.1969).

75. Stroud, William G. 'Weather Satellites". Fourth Nat'l Confer. on the Peaceful Uses of Space. NASA SP-51, pp. 133-153. U.S. Gov't Print. Off. 1964.

76. Tarble, Richard D. "Snow Surveys of Western United States With Aid of Satellite Pictures". Proc. of 31st Ann. Meeting, Western Snow Conference, April,1963.

77. Tepper, Morris. "Meteorological Satellites". Second Nat'l Conf. on Peaceful Uses of Space, NASA SP-8, pp. 85-101. U. S. Gov't Print. Off. Wash.,D.C., May, 1962.

78. Thoms, M. E. "Application of Aerial Snow Cover Observations to Forecasting Flathead Lake Inflows". Proc. of 30th Ann. Meeting, Western Snow Conf. April, 1962.

79. USDA, Agriculture Research Service. "Losses in Agriculture". Agric. Handbook No. 291, U. S. Gov't Printing Office. Wash.,D.C. August, 1965.

80. USDA, "A National Program of Research for Remote Sensing". Prepared by a Joint Task Force of the USDA and the State Universities and Land Grant Colleges. Wash.,D.C. Dec., 1967.

81. USDA, Economic Research Service. "Agricultural Application of Remote SensinglllThe Potential From Space Platforms". Ag. Info. Bull. No. 328. U. S. Gov't Printing Office, Wash.,D.C. Sept., 1967.

82. USDA, Economic Research Service. "An Appraisal of the Potential for Agricultural Resources Surveys by Remote Sensing, Summary Report". A Report of Research Performed for the Earth Resources Survey Program, Space Applications Program, NASA, Wash.,D.C., March, 1969.

83. USDA, Economic Research Service. "Airphoto Use in Resource Management". Ag. Info. Bulletin No. 336. U. S. Gov't Printing Office, Wash., D.C., May, 1969.

84. USDA, Forest Service. "Wildlife Management Plan, Wetlands of the Chippewa National Forest, Minnesota". Published in cooperation with USDI Bur. of Sport Fisheries and Wildlife and the Minn. Dept of Conservation. Nov., 1965.

85. USDA, Forest Service. "Range Allotment Analysis and Management Planning". Wash.,D.C., July, 1964.

86. USDA, Forest Service, Pac. SW For & Range Exper. Sta. "Wildland Resource Information System". Berkeley, California, March, 1969.

87. USDA, Forest Service. "Field Instructions for Integrated Forest Survey-Timber Management Inventories in California". PSW and PNW Forest and Range Exper. Stations and Region 5, Forest Service, San Francisco, Calif. 1966.

88. USDA, Forest Service. "Timber Trends in the United States". Forest Resource Report No. 17. U. S. Gov't Printing. Off. Feb., 1965.

89. U. S. Dept. of Commerce, Environmental Science Services Admin. "Lightning". Wash.,D.C. 1966.

90. Wear, John F. "The Development of Spectro-Signature Indicators of Root Disease Impacts on Forest Stands". Quarterly Prog. Rep. for Earth Resources Survey Program, Office of Space Sciences & Applications, NASA Forestry Remote Sensing Laboratory, Berkeley, Calif., 31 March, 1969.

91. Weber, F. P. and C. E. Olson, Jr. "Remote Sensing Implications of Changes in...Tree Seedlings Under...Stress". Ann. Prog. Rep. Forestry Remote Sensing Laboratory for Earth Resources Survey Program, OSSA/NASA. Berkeley, Calif. 1967.

92. Willow Run Laboratories, Instit. Sci. & Tech., Univ. of Michigan. "Peaceful Uses of Earth-Observation Spacecraft". Three volumes. Ann Arbor, Mich. Feb., 1966.

93. Wilson, Ralph A. "Fire Detection Feasibility Tests and System Development". Fifth Symp. on Remote Sensing of Environment. Proc. pp 465-477. Univ. of Mich., Ann Arbor. 1968.

94. Wilson, Richard C. "The Relief Displacement Factor in Forest Area Measurements by Dot Templets on Aerial Photographs". Photogrammetric Engineering, 15(2):225-236. 1949.

95. Wilson, Richard C. "Surveys Particularly Applicable to Extensive Forest Areas". Proc. of Fifth World Forestry Congress. pp 257-263. The National Publishing Co., Wash.,D.C. 1960.

96. Wilson, Richard C. "Space Photography for Forestry". Photogrammetric Engineering 23(5):483-490. May, 1967.