REVIEW AND APPRAISAL: COST-BENEFIT ANALYSES OF EARTH RESOURCES SURVEY SATELLITE SYSTEMS

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INTERPLAN

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

INTERDISCIPLINARY PLANNING IN AN INTERNATIONAL CONTEXT

REVIEW AND APPRAISAL: COST-BENEFIT ANALYSES OF EARTH RESOURCES SURVEY SATELLITE SYSTEMS

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"First Europe, and then the globe, will be linked by flight, and nations so knit together that they will grow to be next-door neighbors. This conquest of the air will prove, ultimately, to be man's greatest and most glorious triumph."

Claude Grahame White
and Harry Harper (1914)

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SUMMARY

Ten studies concerned with the benefits and costs of remote sensing of earth resources were reviewed and appraised to assess:

- The extent to which the findings can be considered to be adequate indicators of the cost-benefit effectiveness of future operational ERS satellites
- The value of these studies to the ERS Program in directing R&D activities.

The findings of this review and appraisal were used in formulating conclusions on the appropriate nature of future studies in the ERS Program.

THE REVIEW

The review was conducted in two stages

The first stage of the review comprised a document-by-document review of the scope, contents, and analytical techniques employed in each study in order to elucidate differences and similarities among the studies. In the second stage the findings of all the documents were reviewed synoptically with respect to their cost and benefit estimates.

The Document-by-Document Review

The studies differed greatly in objectives, scope, and depth

Five of the ten documents reviewed contained only estimates of either costs or benefits. Cost-benefit comparisons were made in the remaining five studies but, of these, only three could be considered system cost-benefit studies. Descriptions of the technologies required to realize the benefits which were estimated ranged from no description to detailed definitions in the three system cost-benefit studies.

The Synoptic Review

A system cost per satellite-year of $20-50 million is indicated

System costs were estimated in four studies. In spite of differences in the kind, complexity, and program size of the seven systems studied, the estimated system costs per satellite-year (exclusive of user costs) ranged from $20-50 million.

Benefit estimates for 85 applications were reviewed

Of the several hundred applications cited in the ten studies reviewed, benefit estimates for 85 applications from eight studies were supported by sufficient discussion and documentation to be compared in the synoptic review.

These applications were placed into *same*, *better*, or *new* information classes

Each of the applications reviewed was placed in one of three classes depending upon whether the proposed observation would yield the *same* information as now is being used, *better* information, or *new* information. In each information class, applications were further grouped according to whether they required mapping of static phenomena or monitoring of dynamic phenomena.

Validity criteria were developed and used to assess each benefit estimate

Benefit estimates, based either on case analysis or expert judgment, were termed "valid" if the rationale and supporting documentation were judged sufficient to be convincing to a professional. Only one estimate of world benefits was considered to be valid. Although numerous valid estimates were made, at the prefeasibility level of estimation it is felt that these estimates indicate with certainty only the order-of-magnitude of benefits which may, in fact, be realized.

Valid estimates of gross annual benefits to the U.S. total $1.4 billion and represent 43 applications

The benefit estimates that were considered valid order-of-magnitude estimates totaled $1.4 billion to be realized annually by the U.S. from implementation of 43 non-overlapping applications. The distribution of applications and benefit estimates across the three information classes and two application types is:

ITEM	CLASS OF INFORMATION						TOTAL
	SAME		BETTER		NEW		
TYPE OF APPLICATION	MAP-PING	MONITOR-ING	MAP-PING	MONITOR-ING	MAP-PING	MONITOR-ING	
Gross Annual Benefits ($millions)	27	27	135	987	-	179	1355
Number of Applications with Valid Estimates	11	6	5	17	-	4	43
Total Number of Applications	16	22	14	23	-	10	85

Five applications are estimated to be worth a total of $1 billion annually to the U.S.

Five applications accounted for one billion dollars of the total estimated benefits which were considered valid. These applications and the U.S. estimated benefits were:

1. Minimizing flood damage—$306 million
2. Improving forecasts of irrigation water availability—$282 million
3. Detecting fungi stresses in small grains—$231 million
4. Expediting exploration of petroleum—$125 million
5. Providing world wheat production forecasts—$114 million.

THE APPRAISAL

The Extent To Which The Findings Can Be Considered Adequate Indicators Of The Cost-Benefit Effectiveness Of Future Operational ERS Satellites

System cost estimates are considered adequate indicators. Benefit estimates are considered to be very conservative

The system cost estimate of $20-50 million per satellite-year is considered to be an adequate prefeasibility indicator of the cost of a future operational system. The benefits estimated for the *same* information class of applications are considered conservative since the total user market was not covered and valid estimates were not made for important applications. The benefits estimated for the *better* information applications are considered adequate indicators of U.S. benefits to be realized. The benefits estimated for *new* information applications are fragmentary and are considered to greatly underestimate the benefits which will be realized from applications using new information. (The applications in the *new* information class represent only 5 percent of all of the applications for which documented benefit estimates were made.)

The Value of the Studies to the ERS Program in Directing R&D Activities

A data base was acquired which is of value in R&D planning

The main value of the studies lies in the fact that they indicate those earth resources that potential users feel are worthwhile observing, the type of information which appears to be most desirable to acquire, and the order of magnitude of the benefits which can be expected if various applications are implemented. However, in order to provide R&D guidance, INTERPLAN considers that a priority ranking based on the estimated economic value of technological developments (as opposed to a priority ranking of applications) is needed. This ranking, in conjunction with development costs, time-frames, and other criteria could be used to optimize the effectiveness of the R&D program. In the studies reviewed technological requirements for many of the applications were not defined well enough to provide a basis for establishing such a priority ranking.

Development of an R&D decision model would permit these study findings to be integrated and used in providing guidance for R&D

The PRC and GE studies define the informational requirements which link the benefits from applications to required technological developments. Concepts are also developed which indicate how the interdependencies between predicted benefits, types of information to be acquired, measurements, sensors, and system capabilities can be quantified. By extending these concepts an ERS system cost-benefit effectiveness model and a multicriteria R&D decision model could be developed which could be used to optimize the effectiveness of the total ERS system.

THE APPROPRIATE NATURE OF FUTURE STUDIES

R&D Decision Model

In view of the accomplishments of the past studies no further cost-benefit studies on systems of applications are recommended at the prefeasibility level of development. However, work to develop an R&D decision model for use in planning ERS R&D activities is suggested and defined. This model would integrate (at the ERS system level) the findings of past and supplementary studies on benefits, costs, and technologies required by all major applications studied.

Supplementary economic studies	Since (1) valid and/or comprehensive benefit estimates for a few important applications were not obtained in past study work and (2) some valid benefit estimates were not accompanied by the detailed descriptions of required technologies which are needed to provide R&D guidance, INTERPLAN also suggests that supplementary work be conducted on seven application areas.
Four noneconomic studies	Studies on the following subjects are suggested: 1. Elucidation of noneconomic criteria 2. Education of potential users 3. Conceptualization of the organizational form and management of an operational ERS system 4. Development of a biospheric model.

The scope, contents, duration, and estimated cost of the suggested future studies are outlined.

CONTENTS

TABLES

FIGURES

SECTION 1

INTRODUCTION

BACKGROUND

Since 1965 the National Aeronautics and Space Administration, Federal user agencies, the National Academy of Sciences, and others have been conducting economic studies in an attempt to estimate the costs of and benefits from earth-orbiting satellites used to survey earth resources. Some of these studies are broad in scope, addressing numerous potential applications; other studies comprise in-depth analyses of a few specific applications. Most of these studies were conducted independently to attain various objectives and, hence, are often based on different assumptions. For these reasons, the findings and conclusions of the studies were difficult to evaluate.

In an effort to provide NASA with an understanding of their value (and the value of similar economic studies) to the ERS Program, INTERPLAN Corporation was asked to integrate the findings of some of these studies through a review and appraisal.

PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of this study is to review and appraise certain cost-benefit studies which relate to the economic benefits to be obtained from Earth Resources Survey Satellite Systems. The objectives of the study are to:

1. Assess the extent to which these previous studies are adequate indicators of the expected cost-benefit effectiveness of future operational ERS.
2. Assess the value of these studies for directing R&D activities.
3. Indicate the appropriate nature of future economic studies in the ERS Program.

SCOPE OF THE STUDY

The study was limited to a review and appraisal of ten cost-benefit studies selected by NASA and relating to remote sensing of earth resources from earth-orbiting satellites. The following additional constraints were imposed on the study with the concurrence of the Technical Director:

- Review and examine only potential applications in the following five disciplines: Agriculture (including Forestry), Geology, Geography, Hydrology, and Ocean Sciences.
- Appraise and analyze only *economic* indicators and *economic* criteria.

APPROACH TO THE STUDY

At the prefeasibility level of analysis characterized by these studies "Benefit analysis should be thought of as an iterative process: the details to be treated should be related to the evolutionary phase of the system development. During the early stages of a system configuration, quantitative treatment (if attempted at all) should be thought of as yielding magnitude indicators rather than absolute values."*

INTERPLAN concurs in this view and approached the review and appraisal of findings from the perspective that only order-of-magnitude economic indicators could be obtained at this level of analysis.

The Review

The review was conducted in two stages. In the first stage each report was read and analyzed to determine its scope, contents, and the analytical techniques employed. In the second stage, a synoptic review of all of the documents was conducted, with an emphasis on the review of benefit estimates since costs were not treated in sufficient depth in most of the studies to permit comparison. A common basis for comparison of benefit estimates in the synoptic review was provided by classifying each of the estimates according to whether the satellite observations will yield (1) the same information as now exists, (2) better information

*Summary volume of the Summer Study on Space Applications, page 67.

than now exists, or (3) new information. Benefit estimates in each of these information classes were further grouped according to whether the application was a mapping or a monitoring task.

The Appraisal

A basis for appraisal was established by considering how adequately economic studies (at the prefeasibility level of development) could indicate the expected cost-benefit effectiveness of the operational ERS system and the value they might have in providing guidance for R&D activities. The findings of the review were then appraised to determine the extent to which these conditions were met. The results of the appraisal were utilized in drawing conclusions on the appropriate nature of future studies in the ERS Program.

ORGANIZATION OF THE REPORT

The findings of the review are presented in Section 2, and the results of the appraisal are presented in Section 3. Conclusions on the nature of future studies are given in Section 4.

Appendix A contains a brief description of the present ERS Program to aid the reader's understanding of this report, as well as to summarize INTERPLAN's understanding of the Program. Appendix B contains the annotated bibliographies produced as a result of the document-by-document review. Appendix C describes in greater detail an R&D decision model (suggested in Section 4) and the work entailed in developing it to integrate the findings of the studies reviewed at the ERS system level. Appendix D is a bibliography of additional documents read by the INTERPLAN team to supplement their understanding of the subject area. Appendix E contains the Statement of Work under which this study was performed.

Time-phasing of the Study

The duration of the study was 9 months and comprised 18 man-months effort. The study was divided into three principal tasks, time-phased as shown in Figure 1.

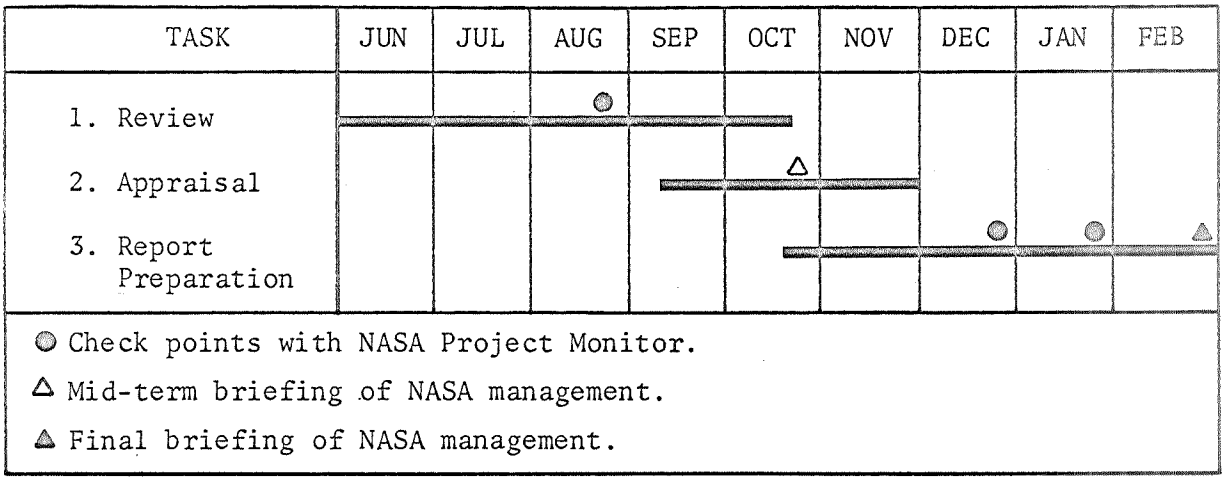

Figure 1. Time-phasing of the study.

SECTION 2

THE REVIEW

SCOPE AND ORGANIZATION

Documents Reviewed

Ten documents furnished by NASA were reviewed by INTERPLAN during the course of this work (see Table 1). Some of these documents were prepared under direct NASA contract, others under contract to various agencies or organizations who are either potential users of satellite-derived information or who are potential suppliers of equipment to the Earth Resources Survey Program. The contents of the documents naturally reflect the diversity of their origin in such things as differences in scope, subject matter addressed, objectives to be attained, and the approach used by the authors in obtaining estimates of pertinent costs and benefits.

Document-by-Document and Synoptic Reviews

In this study it was necessary first to review each of the documents to determine the nature of the contents as well as to record and compare differences (and similarities) between documents. This part of the review was considered to be a document-by-document review since the emphasis was on drawing comparisons between the documents.

To attain the objectives of INTERPLAN's work, however, it was also necessary to consider the contents of all of the documents as a whole. This part of the review was considered to be synoptic, since the emphasis was on obtaining a contextual opinion on the findings of past studies irrespective of document source.

THE DOCUMENT-BY-DOCUMENT REVIEW

Review Procedure

In the initial phase of the study, INTERPLAN team members read all of the documents to determine the purpose, nature of contents, findings,

Table 1. Documents reviewed and appraised by INTERPLAN.

DOCUMENT NO.	ORIGINATING ORGANIZATION, REPORT IDENTIFICATION, AND PUBLICATION DATE	REPORT TITLE	IMMEDIATE SPONSOR
1	Stanford Research Institute, Project M-5465, September 1965	Priority Analysis of Manned Orbital Research Applications	Douglas Aircraft Co., MSSD
2	International Business Machines, Federal Systems Division, NASw-1215, February 1966	Orbiting Research Laboratories (ORL) Experiment Program	NASA
3	Cornell University, The Center for Aerial Photographic Studies, December 1967	Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest, and Range Resources	NASA/USDA
4	Westinghouse, Defense and Space Center, 7145A2, Dec. 1967 (Final Summary Report February 1968)	EROS Applications Benefit Analysis	USDI
5	Planning Research Corporation, PRC R-1218, January 1968	A Study of the Economic Benefits and Implications of Space Station Operations	NASA
6	General Electric Co., Missile and Space Division, March 1968	Final Report on the Space/Oceanographic Study	National Council on Marine Resources and Engineering Development
7	Mathematica, GLM, September, 1968	Cost Benefit Study of the Earth Resources Observation Satellite System: Grazing Land Management	RCA, AED
8	Mathematica, ECM, June, 1969	Cost Benefit Study of the Earth Resources Observation Satellite System: Estuarine and Coastal Management	RCA, AED
9	Planning Research Corporation, PRC R-1224, November, 1969	A Systems Analysis of Applications of Earth Orbital Space Technology to Selected Cases in Water Management and Agriculture	NASA/Bureau of the Budget

Table 1. Documents reviewed and appraised by INTERPLAN (continued).

DOCUMENT NO.	ORIGINATING ORGANIZATION, REPORT IDENTIFICATION, AND PUBLICATION DATE	REPORT TITLE	IMMEDIATE SPONSOR
10	Summer Study on Space Applications, National Academy of Sciences, National Research Council, January, 1969	Useful Applications of Earth-Oriented Satellites	NASA

conclusions, and recommendations of each. An annotated bibliography was prepared for each of the documents to record pertinent information regarding its content as well as the team's consensus with respect to the major strengths and weaknesses displayed. To supplement the team's understanding of the ERS Program numerous other documents and publications were read throughout the course of work.

Differences in Scope and Content of the Documents

As anticipated, the document-by-document review revealed that the studies varied widely in scope and content. These differences are summarized in Table 2 in terms of the number of benefit estimates made, the disciplines represented, and the scope of the subject matter. Only those benefit estimates for applications pertaining to the five earth resources disciplines included in the scope of this review (Agriculture, Geology, Geography, Hydrology, and Ocean Sciences) were tabulated. Of those tabulated, many were for the same or similar applications.

As shown in Table 2, the number and kinds of earth-resources-observation applications which were examined varied from document to document. Four studies covered an array of applications across all five of the earth resources disciplines considered, four were oriented toward in-depth analyses of a few topics within a single discipline, and two studies examined applications in two or more, but not all, of the five disciplines.

All of the studies reviewed outlined at least the sensor requirements or alluded to the sensor type and/or resolution required to attain the estimated benefits; several studies also alluded to, or specified, the required orbital parameters. As shown in Table 2, some of the reports

Table 2. Comparison of documents by number of benefit estimates and scope.

DOCUMENT NO.	REPORT IDENTIFICATION	NUMBER OF BENEFIT ESTIMATES MADE FOR APPLICATIONS IN THE EARTH RESOURCES DISCIPLINES						SCOPE
		AGRICULTURE	GEOLOGY	GEOGRAPHY	HYDROLOGY	OCEAN SCIENCES	MULTIDISCIPLINE	
1	SRI M-5465	3	1	1	1	4	1	U.S. and world benefits from a Manned Orbital Research Laboratory. Not a system study.
2	IBM NASw-1215	12	3	2	5	6	-	U.S. and world benefits from a Manned Orbital Research Laboratory. System orientation, but not a system study.
3	Cornell	126	-	-	-	-	-	U.S. and world benefits to agriculture, forestry, and range management. Not related specifically to satellite observation. Not a system study.
4	Westinghouse	9	11	4	4		1	Benefits estimated in USDI areas of interest as a function of resolution and frequency of observation. Not a system study. Unmanned.
5	PRC R-1218	6	2	3	4	2	5	System studies on cases pertaining to rice production, wheat rust control, malaria control, hydroelectric power generation, fish production. Unmanned.
6	GE	-	-	-	-	3	-	Detailed system study on fishing and shipping applications. Unmanned.

Table 2. Comparison of documents by number of benefit estimates and scope (continued).

DOCUMENT NO.	REPORT IDENTIFICATION	NUMBER OF BENEFIT ESTIMATES MADE FOR APPLICATIONS IN THE EARTH RESOURCES DISCIPLINES						SCOPE
		AGRICULTURE	GEOLOGY	GEOGRAPHY	HYDROLOGY	OCEAN SCIENCES	MULTIDISCIPLINE	
7	Mathematica GLM	3	-	-	-	-	-	Cost-benefit analysis of a grazing land management application. Not a system study. Unmanned.
8	Mathematica ECM	-	-	-	1	-	-	Cost-benefit study of estuarine and coastal management applications. Not a system study. Unmanned.
9	PRC R-1224	11	-	-	4	-	-	Detailed system studies on cases in agriculture and hydrology—an extension, in-depth, of the PRC R-1218 study. Unmanned.
10	NAS Summer Study	6	1	-	-	1	-	An assemblage of expert opinion on the usefulness of ERS observations in all major disciplines. System cost estimates for separate disciplines and common-use systems. Unmanned.

investigated data acquisition from manned satellites, others from unmanned satellites, while still others from both manned and unmanned satellites. One report (Document 3, Cornell) estimated only the potential benefits from remote sensing, per se, without designating whether the data was to be collected from a satellite or aircraft platform or from the ground.

Detailed cost analyses were performed in the PRC, GE, and NAS Summer Study reports (Documents 5, 6, 9, and 10) for the applications or application areas investigated. Of these, only in Documents 5, 6, and 9 were both system costs and benefits analyzed in sufficient detail for the studies to be considered as system cost-benefit studies. Although both costs and benefits were estimated by Mathematica (Documents 7 and 8), the treatment of system costs was too superficial to consider the studies to be system cost-benefit studies. The remaining studies (Documents 1 through 4) contained only estimates of benefits for a variety of applications. Because of these differences, it was necessary for INTERPLAN to review and appraise the cost and benefit aspects of the studies separately.

Differences in Coverage of Technological Requirements

The technology required to make the postulated observations was investigated in depth in some studies and omitted entirely in others (see Table 3). In initial *prefeasibility* level studies, however, the order-of-magnitude estimates that can be made of gross benefits are not affected materially by technological considerations—except to the extent that development of the technological capability premised should be at least foreseeable. In these studies, gross benefit estimates are often made by defining a maximum benefit which could not be exceeded even with perfect satellite information. The upper-limit benefit estimate is then scaled down (for reasons other than technological capability) to obtain an estimate of expected benefits. (Naturally, at the *feasibility* level of economic analysis where quantified estimates can be made of the viability of the operational system, the level of technology available is of major significance in estimating the size of net economic returns to be realized.)

Table 3. Coverage of technological requirements in studies reviewed.

DOCUMENT NO.	REPORT IDENTIFICATION	INDICATIVE PHENOMENA TO BE OBSERVED	SENSING REQUIREMENTS		FREQUENCY OF OBSERVATION
			MODE-SPECTRAL BAND	RESOLUTION	
1	SRI M-5465	Discussed in general terms for most applications	Discussed in general terms only	Sometimes mentioned as "high" or "low"; sometimes quantified	Not generally discussed
2	IBM NASw-1215	Described in fairly specific terms	Defined for experimental packages	Defined	Can generally be inferred
3	Cornell	Not specifically defined	Imagery implied	Not defined	Not defined
4	Westinghouse	Not specifically defined	Defined as pairs of red and green filter photographs for all applications	Defined	Defined
5	PRC R-1218	Defined in case studies and in certain others	Defined as to equipment type	Not defined specifically for all cases	Defined for some applications
6	GE	Defined	Defined	Defined	Defined
7	Mathematica GLM	Not defined	Imagery implied	Not generally discussed	Not defined
8	Mathematica ECM	Not defined	Imagery implied	Not generally discussed	Defined, implicitly, as infrequent
9	PRC R-1224	Defined	Defined	Defined	Defined
10	NAS Summer Study	Either specified or described in general terms	Defined	Defined or implied in general	Defined in general

Although technological requirements do not influence the estimates of gross benefits made in the studies reviewed, a definition of these requirements is necessary even at the prefeasibility level in order that (1) estimates of net benefits can be obtained and (2) estimates can be made of the kind and intensity of development effort which will be entailed in attaining an operational capability. Unless the required technological developments are defined well enough so that operational time-frames can be postulated for each application, the relative importance of different developments cannot be assessed with respect to when the benefits from the various applications will be realizable. (This subject is amplified in Sections 3 and 4.)

In the documents reviewed, only in the following were operational time-frames postulated for the applications studied:

Document Number	Report Identification	Operational Time-frame
5	PRC R-1218, 1968	1970-1989
6	GE, 1968	1970-1974
9	PRC R-1224, 1969	mid or late 1970's

THE SYNOPTIC REVIEW

Approach to the Synoptic Review

INTERPLAN's objective in conducting the synoptic review was to organize and analyze elements which were common to all of the studies in such a way that their total content could be appraised. As a result of the document-by-document review the following common elements were isolated: system cost estimates, classes of information for which benefit estimates were made, and types of applications studied.

SYSTEM COST ESTIMATES. Analyses leading to system cost estimates were performed in only four studies: PRC R-1218, GE, PRC R-1224, and the NAS Summer Study (Documents 5, 6, 9, and 10). While each estimate refers to systems that were different in terms of scope, complexity, and function, an interesting agreement among the estimates is revealed if each is compared on the basis of the cost per satellite-year over the program described.

Doc. No.	Report Identification	System Identification	Number of Satellites	Length of Operational Program (years)	Total System Cost* ($millions)	Satellite-Years	Cost/ Satellite-Year ($millions)
6	GE	1	1	2	83.4	2	41.7
		1	2	2	116.0	4	29.0
		2	1	2	95.7	2	47.8
		2	2	2	129.0	4	32.3
		3	1	2	164.2	2	82.1
		3	2	2	216.0	4	54.0
9	PRC R-1224**	4	4	18	2504.5	72	34.8
		5	4	18	1554.0	72	21.6
10	NAS Summer Study	6	12	3.83(avg.)	1019	46	22.2
		7	7	4	936	28	33.4

*Not discounted.

**Since the PRC R-1224 analysis is more recent and more exhaustive than that of PRC R-1218, the PRC R-1224 cost estimate has been used in the comparison.

The cost estimates listed above refer to seven postulated systems of sensors to be flown in the number of satellites indicated for the operational periods shown. As might be expected, due to differences in system complexity and program size, the total system costs vary greatly. In spite of these differences, however, if one considers the number of satellite-years in each program, estimates of the system cost per satellite-year fall between relatively narrow limits. The exceptionally high cost for System 3 (GE) is the result of including a side-looking, high-resolution, synthetic-aperture radar in the sensor package. Since, according to the authors of the GE report, this more costly sensor package results in increasing the effectiveness of the system by only 0.05, this configuration is not only an unusual one but also one which would probably not be selected for implementation. Therefore, based on the remaining cost estimates, INTERPLAN concludes that at the prefeasibility level of development one can assume that the system cost per satellite-year will be on the order of $20-50 million, depending on system complexity and program size.

The costs in the above comparison refer only to the cost of the satellite information system and not to costs incurred by users. (User costs are estimated in a preliminary fashion in PRC R-1224, but are not included in the above comparison.) Exclusion of user costs from system cost estimates was

considered advisable by the Economic Analysis Panel of the NAS Summer Study in view of the approximate nature of the systems' configurations. The following user costs were recognized as major cost items, but were excluded from their estimates:

1. Costs incurred by user agencies for education or extensive training and upgrading of personnel and procedures
2. Costs of analysis and interpretation (e.g., photographic interpretation) of the data received by user agencies
3. Any costs incurred by individuals or organizations "downstream" from user agencies, e.g., costs incurred by a farmer for spraying to control crop disease in response to information provided by the satellite system.

INTERPLAN agrees with the Panel conclusion that these costs should not be included in system cost estimates until the system is well defined. However, estimation of user costs which would be incurred in implementing specific applications is an important factor in arriving at estimates of net benefits and, hence, is considered by INTERPLAN to be essential to the prefeasibility benefit analysis.

THE THREE CLASSES OF INFORMATION FOR WHICH BENEFIT ESTIMATES WERE MADE. Benefits to be gained from various applications were estimated in all of the studies reviewed. In spite of the fact that these estimates were for different applications and were made using a variety of techniques, a common basis for review and appraisal of the findings can be provided by considering that all of the benefit estimates found in the studies can be placed into one of three classes based upon whether the authors postulate that the satellite observations will yield (1) the same information as now exists, (2) better information than now exists, or (3) new information.

Estimates of Benefits from Satellite Observations Yielding the *Same* Information as Now Exists. For satellite observations yielding the same information as is currently being gathered by other methods, no attempt was made in the studies reviewed to estimate the value of this information, per se. Rather, estimates of benefits represent the savings which would be realized by potential user groups if ERS information were furnished to them. In most instances the cost of the ERS information was not considered.

Estimates of Benefits From Satellite Observations Yielding *Better* Information Than Now Exists. For satellite observations yielding information which would improve upon the quality of information now being acquired (by virtue of greater timeliness, frequency, detail, etc.), the estimates of benefits represent the value which would be added to the user either through the improved quality of actions which could be taken or through the increase in productivity the user would realize.

Estimates of Benefits From Satellite Observations Yielding *New* Information. For satellite observations yielding new information, the estimates of benefits represent the absolute value the new information would have in terms of postulated actions which might be taken. In this classification new information is defined as information of known content that can be obtained only by observations from a space platform since the resources to be observed are dispersed over a great area of the earth's surface.

THE TWO TYPES OF APPLICATIONS THAT WERE STUDIED. Although the individual applications postulated in the studies differ, two general types are implied: either mapping or monitoring.

Mapping applications, as defined in this study, refer to observations which are made on relatively static phenomena. Since the phenomena to be observed do not change over long periods of time, mapping applications can be accomplished by a finite, predictable number of observations; when these observations have been made and the data reduced, the mapping application can be considered to have been completed. Updating of the information is required only after relatively long periods of time.

Monitoring applications refer to observations which are made on transient phenomena which require continuing surveillance over an unpredictable length of time. During execution of the monitoring applications, repetitive patterns of change may be observed or predictive parameters noted which will lead to a reduction in the frequency or number of observations which need to be made, but, by and large, these tasks are not likely to ever be "completed" and thus a "completion date" cannot be predicted.

While it is obvious that a particular satellite system or sensor array can simultaneously perform both types of applications, because the economics of mapping and monitoring applications are different it was useful to review mapping and monitoring applications separately under the three classes of information for which benefit estimates were made.

STUDIES EXCLUDED FROM THE SYNOPTIC REVIEW. The Cornell study and the NAS Summer Study (Documents 3 and 10) were excluded from the synoptic review. Although a number of large benefits were cited in the Cornell report, the expected benefits from remote sensing for many of the 260 applications which were isolated are listed without identifying the platform from which the observations are to be made. That is, the benefits from remote sensing of agriculture, forest, and range resources are estimated, but not with reference to satellite-derived information. Additionally, no documentation is provided for individual benefit estimates other than a title identifying the benefit. Costs and technical requirements are discussed only in general terms.

The Summer Study Panel Reports comprise an impressive assemblage of expert opinions on the benefits and system costs which will result from implementing earth resources applications in various disciplines and the operational technology which will be required. However, the potential benefits which can be expected to accrue are discussed primarily in relationship to the disciplines and are not, for the most part, related to specific applications. Therefore, the findings could not be incorporated into the synoptic review.

Conduct of the Synoptic Review

ORGANIZATION OF APPLICATIONS FOR REVIEW PURPOSES. In the course of the synoptic review, all applications in each of the studies for which there was a discussion supporting the benefit estimate were tabulated and placed into one of the three information classifications depending upon whether the postulated observations were to yield the same, better, or new information. The applications were further categorized by type as either mapping or monitoring.

TABULATION OF BENEFIT ESTIMATES. The applications for which benefit estimates were made in the eight reports included in the synoptic review are listed in Tables 4 to 8. These tables categorize the applications as follows:

Table No.	Application Numbers	Information Class	Application Type
4	1-16	same	mapping
5	17-38	same	monitoring
6	39-52	better	mapping
7	53-75	better	monitoring
8	76-85	new	monitoring

The tables comprise a summary of information on the applications, estimated benefits, potential users (or user agency), rationale for the estimates of benefits, and discipline served by the applications. Since the tables also include the report name, volume, and page on which the benefit in question is discussed, they can also serve as an index to the ERS cost-benefit oriented literature published between 1965 and 1969.

The following general observations apply to the information included in Tables 4 to 8.

Gross, Net, and Discounted Benefits. The greatest number of benefit estimates made in the eight reports reviewed are presented as gross, annual values on an undiscounted basis. Although in some cases net benefits were calculated (phased over an assumed program life and discounted), for uniformity of comparison these estimates were not used in the tabulation and assessment. In all cases, the equivalent gross benefit on a nondiscounted basis is reported. In some cases this value represents an average annual value over some postulated operational time interval.

Secondary Benefits. Economic multipliers were synthesized and used in some of the studies to estimate the effect of a benefit in one sector of the economy on secondary sectors or on the total economy (U.S. and foreign). Only estimates of primary benefits, however, were used in the tabulations and analysis.

Worldwide Benefits. Worldwide benefits (which include U.S. benefits unless otherwise noted) are included in the tabulations primarily for reference purposes. In general, estimates of worldwide benefits were not considered valid economic indicators because they were usually obtained by multiplying a benefit estimate made for the United States by a factor which assumes that U.S. conditions broadly apply to worldwide situations. This assumption was considered to be tenuous enough to invalidate the estimates.

ORGANIZATION OF THE DISCUSSION OF FINDINGS. The findings of the synoptic review are presented in the sequence of the "same," "better," and "new" information classes. Within each information class, benefits for mapping applications are reviewed first and benefits for monitoring applications are reviewed next. The sequence of discussion of individual applications is in decreasing order of validity of the estimates, i.e., the benefit estimates considered by INTERPLAN to be valid order-of-magnitude indicators are discussed first.

VALIDITY OF THE BENEFIT ESTIMATES. The review of benefit estimates was made from the perspective that at the prefeasibility level of analysis only order-of-magnitude economic indicators can be obtained. The emphasis of the review, however, was on isolating those estimates which could be considered to be valid, although approximate, indicators of the future benefits to be realized through the ERS Program.

A cross-check on the validity of estimates between documents was not possible since there is little commonality between the specific applications discussed in the various documents and, further, where the same application was discussed in more than one study, the assumptions used and the scope of the application frequently differed.

The validity of the benefit estimates was assessed, therefore, by judging:

1. The amenability of the subject matter to analysis
2. The adequacy of the analysis performed.

The first judgment considers the applicability of rigorous analytical treatment to the application. The second judgment considers the soundness of the assumptions made and the degree to which factual points of reference are given and documentation is presented, either through expert opinion or by case study analysis.

REVIEW OF BENEFIT ESTIMATES PERTAINING TO SATELLITE OBSERVATIONS YIELDING THE "SAME" INFORMATION AS NOW EXISTS

Nature of the Benefit Estimates

Of a total of 85 applications in the studies reviewed, 38 applications were classified as producing benefits from satellite observations which yield the same information as now exists. Since the purpose of these applications is to furnish the same information as is now being obtained, the value of the information itself was disregarded in the benefit analysis. Instead, estimates of benefits were made on the basis of the cost savings which would be realized by potential user groups if ERS information were furnished to them. These estimates do not include the cost of providing the information from satellite observations to the user in a useable form.

For some applications, estimates were reported as direct savings, i.e., the benefiting group would incur lower costs if furnished with ERS information. For other applications, cost savings were reported as "increased productivity," i.e., the resources saved would be redirected and would thus result in greater productivity of the user group.

In both cases, because cost savings are actually estimated for these applications, the estimates are gross measures of cost effectiveness rather than benefits as normally estimated in a cost-benefit analysis. The distinction between "cost savings" and "gross benefit" in this instance is, however, largely academic, particularly in view of the fact that in almost all cases the savings are to be realized by public agencies.

Applicability of Benefit Analysis to "Same" Information Class

Since the benefits for this class of information relate to ongoing activities, verifiable data can be obtained and used as a basis for making

informed estimates or in arriving at estimates through analysis. This data can also be used in checking the reasonableness of the estimates so obtained. Nevertheless, it still appears difficult to arrive at definitive estimates even though (1) data dissemination and use mechanisms can be established, (2) the demand for the information is either known or can be obtained, and (3) the funds which are currently being expended by potential users can be ascertained. As stated in the Cornell report: "Even with clarification of the concepts and methodology appropriate to our analysis, it is still a major problem to attach values to the anticipated savings and improvements. Other investigators have said 'If we assume a (savings) (improvement) of (5%) (10%) then total benefits would be . . .,' and this is often almost all that can be done."

Almost all of the documented estimates of benefits made for this class of information were obtained using the procedure cited in the Cornell report. That is, the current cost incurred by a potential user group in some ongoing activity was determined and used as the upper limit of the benefit estimate. The savings which would accrue to that user group by using information provided by satellite were then estimated (using either expert judgment or analysis) as a percentage of the upper limit.

Although the validity of the amount of the upper limit which is estimated to be saved as a result of ERS information depends on the adequacy of the subsequent analysis and/or the quality of expert judgment used, the verifiable upper limit obtained for these types of applications keeps the final benefit estimate within the bounds of reason.

Therefore, INTERPLAN considers that valid order-of-magnitude estimates can be made of the benefits which would result from the use of satellites as an alternative source for collecting information currently obtained by other methods. In the studies reviewed, a number of estimates were made which can be considered valid; however, in many cases only one potential user group was considered. Therefore, since other user groups can also use the same information, these estimates represent less than total U.S. benefits.

Discussion of Study Findings for Mapping Applications

Of the 38 applications in the same information class, 16 are mapping applications (see Table 4). Of these 16, the estimates made for applications 1 to 11 (all from the Westinghouse report) are considered by INTERPLAN to be valid order-of-magnitude indicators of the benefits to be realized by the user groups cited, since in each of these 11 applications a verifiable upper limit to potential savings was documented and the amount of this upper limit to be realized as savings was estimated by knowledgeable potential users who were cited in the report. None of the estimates are overlapping in coverage.

Applications 1 to 11

		U.S. Annual Benefit
1.	Mapping Relative to U.S. Mineral Exploration	$12,500,000
2.	U.S. Continental Shelf Mapping	2,000,000
3.	U.S. Regional Geologic Mapping	200,000
4.	Small Scale Geologic Mapping of U.S. and Metallogenic Mapping of North America	300,000
5.	Geologic Mapping in Brazil	1,300,000
6.	Military Geology Mapping	500,000
7.	Topographic Mapping	500,000
8.	Land Use Mapping	5,600,000
9.	Cadastral Surveys	300,000
10.	Geographic Mapping, in General	1,600,000
11.	Hydrologic Mapping	2,100,000

Although an upper limit reference point is documented for application 12, the estimate of the amount of savings to be realized appears to have been made by the analysts rather than by knowledgeable users.

Application 12

		U.S. Annual Benefit
12.	Preparing Small-, Medium-, and Large-Scale Maps of Selected Regions	$3,500,000

In general, less validity can be attributed to estimates made by the analysts than to those made by knowledgeable users. For this reason, as well as because application 12 overlaps a number of the preceding applications, this

Table 4. Mapping applications yielding the same information as now exists; estimated benefits represent savings.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
1. Mapping relative to mineral exploration in the U.S.	0.5*	--	USGS Office of Minerals Exploration	50 percent of the mapping budget of about $1 million could be redirected.	Westinghouse 7145A2 Page 3-3 and/or Page A-8	Geology
	12*	--	Private industry engaged in mineral exploration in the U.S.	50 percent of a mapping budget of about $24 million could be redirected.	Page A-8	
2. U.S. Continental Shelf mapping at 1:1,000,000	2.0*	--	USGS Marine Geology & Hydrology	25 or 30 percent effectivity increase in a 5-year, $30 million mapping project.	Page A-14	
3. U.S. regional geologic mapping	0.2*	--	USGS Geologic Division	Savings in mapping time over present mapping cost of about $1.75 million.	Page A-19	
4. Small-scale geologic mapping of U.S. and metallogenic mapping of North America	0.3*	--	USGS Small-Scale Mapping	30 to 50 percent increase in accuracy and speed of compilation in two ongoing projects.	Page A-22	
5. Geologic mapping in Brazil	1.3*	--	USGS Foreign Geology	A 30 to 75 percent increase in effectivity for remote area mapping in Brazil.	Page A-90	
6. Military geology mapping	0.5*	--	USGS Military Geology	Time savings in the work of 40 people.	Page A-16	
7. Topographic mapping	0.5*	--	USGS Topographic Division	Savings in the National Topographic Mapping Program.	Page A-41	Geography
8. Land use mapping	5.6*	--	600 U.S. geographers	Simplify and possibly eliminate need for data gathering in land use studies.	Page A-31	
9. Cadastral surveys	0.3*	--	Bureau of Land Management	10 percent effectivity increase in the cadastral survey effort.	Page A-59	
10. Geographic mapping in general	1.6**	--	Community of professional geographers	10 percent of annual salaries and support costs of a membership of 800.	Page A-83	

Table 4. Mapping applications yielding the same information as now exists; estimated benefits represent savings.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
11. Hydrologic mapping (all scales)	2.1*	--	USGS Water Resources Division	With 100-ft resolution, about a 15 percent effectivity increase in the work of 500 to 1000 people. To over $5 million with better resolution.	Westinghouse 7145A2 Page 3-3 and/ or Page A-36	Hydrology
12. Preparing large scale (1:24,000) maps of selected regions, small and medium scale (1:250,000 to 1:1,000,000) maps of the world, and contour maps (100 ft resolution) of selected regions	3.5 (80)***	23 (480)***	All public and private mapping agencies, U.S. and worldwide	Savings in the estimated $400 million per year spent in the U.S. on mapping activities.	IBM NASw-1215 Vol. B, Part IV Page IV-12	Geography
13. Locate and survey potentially useable lands and catalogue soil fertility and environmental characteristics	1	100	Not identified	None cited.	Part I Page I-19	Agriculture
14. Identifying transporation facilities, surveying sites for new facilities, surveying and classifying industrial facilities, surveying sites for new construction, inferring population distribution and assessing extent, shape, and	5.5 (20)***	10 (320)***	These benefit estimates are almost completely undocumented relative to user identification or current expenditures.		Part IV Page IV-12	Geography

Table 4. Mapping applications yielding the same information as now exists; estimated benefits represent savings.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
(continued) rate of change of major settlements						
15. Assessing extent, shape, and rate of change of major settlements	1	--	Not cited	Few advantages over aerial photographs.	SRI Project M-5465 Page 58	Geography
16. Identification of phenomena indicative of petroleum accumulations and mineral deposits of economic importance	1	2	Not cited	Not cited.	IBM NASw-1215 Vol. B, Part II Page II-21	Geology
	-	10 (over several years)	Not cited	Reduction in number of ground-truth samples. No reference costs.	SRI Project M-5465 Page 57	

*Estimate based on informed judgment of potential user.
**Not included in Westinghouse summary of benefits.
***Figures in parentheses are for benefits resulting from improvements over several years due to improved techniques.

estimate is not included in the summary of benefits for mapping applications at the end of this discussion.

The benefit estimates for applications 13-16 are not considered valid since (1) no upper limit reference points are given, (2) the potential users or beneficiaries are not explicitly identified, and (3) in certain cases the time period over which the cited benefits are expected to occur is unspecified.

Applications 13 to 16

		U.S. Annual Benefit
13.	Land Survey	$1,000,000
14.	Site, Facilities, and Population Survey	5,500,000
15.	Monitor Changes in Settlements	1,000,000
16.	Assist Oil and Mineral Exploration	1,000,000

Although the benefits estimated for these applications cannot be considered valid, these (and other applications which were found during the review to have been inadequately treated in past studies) are valuable as potential subjects for further work.

Discussion of Study Findings for Monitoring Applications

Twenty-two benefit estimates were made for monitoring applications which would yield the same information now being acquired by other means (see Table 5, applications 17-38). Of these 22, the estimates made for applications 17 to 22 are considered by INTERPLAN to be valid order-of-magnitude indicators of the benefits to be realized by the user groups cited.

Applications 17 to 22

		U.S. Annual Benefit
17.	Location and Identification of Major Cultivated Crops	$ 1,000,000
18.	Estimates of Crop Vigor and Yield	20,000,000
19.	Monitor Waterfowl Breeding Grounds	200,000
20.	Wetland Surveys of Columbia and Colorado River Basins	1,100,000
21.	Monitoring of Ocean Surface Phenomena	4,000,000
22.	Coastal Study and Development	1,000,000

Table 5. Monitoring applications yielding the same information as now exists; benefits represent savings.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
17. Location and identification of major cultivated crops	1 (2)*	2	USDA Crop Board, USDA Agricultural Stabilization & Conservation Service, Bureau of Census	The three listed potential users spend about $65 million annually for crop census information. Data from space is estimated to result in savings of $10-20 million in current U.S. crop reporting expenditures.	IBM NASw-1215, Vol.B Part I Pages I-19 and I-A-2	Agriculture
18. Estimates of crop vigor and yield	20	20 (5000)*				
19. Monitor seasonal water conditions on waterfowl breeding grounds	0.2**	--	USDI - Bureau of Sport Fisheries and Wildlife	Replace aircraft surveys — cost of these surveys is not given.	Westinghouse 7145A2 Page 3-3 and/or Page A-62	Hydrology
20. Extend wetland surveys of Columbia Basin and monitor water salinity in Lower Colorado	1.1**	--	Bureau of Reclamation	Increase effectiveness of survey by 15 man-years on Colorado and 30 man-years on Columbia @ $25 thousand per man-year.	Page A-73	
21. Monitoring of ocean surface phenomena	2	--	All public and private oceanographic agencies and groups	Release of about 200 ships from surface monitoring duties.	SRI M-5465 Page 73	Ocean Sciences
	2	--		Partial replacement of surface buoys costing in excess of $5 million annually.		
22. Coastal study and development	1	--	USGS Coast & Geodetic Survey, Coast Guard, etc.	Replacement of air surveys @ $250 thousand per year and projected buoy network @ $750 thousand per year.	Page 75	
23. Monitoring urban air pollution	0.55	--	U.S. Govt.	Reduction by 50 percent in the 2750 ground stations required to monitor all cities over 100,000 in population. Net benefit of $.35 million.	PRC R-1218 Vol. III Page 225	Interdisciplinary
24. Monitoring water pollution	6.6	--	U.S. Govt.	Reduction by 25 percent in the 2400 ground-based sampling points required to monitor all lakes and streams. Net benefit of $6.4 million	Page 227	

Table 5. Monitoring applications yielding the same information as now exists; benefits represent savings.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
(continued)	1.5**	--	Federal Water Pollution Administration	Benefit represents the cost of alternative non-satellite means of monitoring certain water pollution effects.	Westinghouse 7145A2 Page A-45	Interdisciplinary
25. Discover ecological relationships	1	2	The IBM report cites these benefits as accruing from the reduction in annual costs over present data-collection methods. The basis of these savings is almost completely undocumented, the benefiting agencies or users are not identified, nor are current expenditures cited for ongoing activities.		IBM NASw-1215, Vol. B Part II Page II-21	Geology
26. Identification of indicators of potential earthquake mechanisms and monitoring of earthquate damage	75	330				
27. Identification of precursor indicators of igneous activity and monitoring progress of volcanic eruptions	--	1				
28. Flood monitoring; damage warning and assessment	20 (250)*	90 (1000)*				Hydrology
29. Surveys related to snow and ice fields and prediction of icing conditions	15 (500)*	70 (1300)*				
30. Survey of soil moisture & extent & depth of frost, water inflow (control and quality of large	40 (350)*	90 (800)*				

Table 5. Monitoring applications yielding the same information as now exists; benefits represent savings.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
(continued) basins and streams), basin shape and relief and drainage patterns affecting run-off and streamflow, and erosion patterns and correlation with downstream sedimentation			same	same	IBM NASw-1215, Vol. B Part II Page II-21	Hydrology
31. Survey of day and night and seasonal transpiration in arid & semi-arid regions	4 (400)*	14 (1000)*				
32. Survey of dynamics of natural, biologic, and industrial polution outfalls in major rivers and streams	15 (1000)*	23 (1900)*				
33. Location of fisheries and short-term prediction of paths of schools of fish	100 (380)*	150 (760)*			Part III Page III-13	Ocean Sciences
34. Identification and location of hazards to navigation and favorable conditions	75 (890)*	150 (1800)*				
35. Monitoring of magnitude and	60 (80)*	130 (180)*				

Table 5. Monitoring applications yielding the same information as now exists; benefits represent savings.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
(continued) patterns of disposal in industrialized regions			same	same	IBM NASw-1215, Vol. B Part III Page III-13	Ocean Sciences
36. Warning of tidal waves and prediction of high sea states	40 (60)*	140 (320)*				
37. Monitoring of ocean effects on beaches, harbors, and cultural features	50 (2000)*	120 (3800)*				
38. Damage assessment in support of disaster relief	25 (90)*	110 (140)*				

*Figures in parentheses are for benefits resulting from improvements over several years due to improvements in techniques.
**Estimate based on informed judgment of potential user.

In each of these six applications a verifiable upper limit to potential savings was documented. The amount of the upper limit to be realized as savings for applications 17 and 18 appears to have been estimated either by the report authors or by members of the academic community. Although greater validity, in general, can be given to estimates made by a knowledgeable potential user, these estimates appear to be valid, based on the widely accepted belief that satellite crop monitoring will make a major contribution to ongoing United States crop-census programs. Estimates of realizable benefits for applications 19 and 20 were made using the expert judgment of potential users, while those for applications 21 and 22 were obtained through analysis.

The benefit estimates made for applications 23 and 24 are not considered to be valid by INTERPLAN primarily because the information upon which the estimates were based has changed substantially between the time the estimates were made (1967-1968) and the present (1971).

Applications 23 to 24

		U.S. Annual Benefit
23.	Monitor Urban Air Pollution	$ 550,000
24.	Monitor Water Pollution	6,600,000 and 1,500,000

These estimates (both from the PRC R-1218 study) were made in 1968 when there were no specific national goals with respect to air or water pollution. Such national goals have now been specified under the Environmental Protection Agency (EPA) and encompass specific and interrelated surveillance requirements for a defined, federal-state network. The present EPA requirements* appear to be far more extensive than postulated in the studies reviewed.

As indicated in the PRC study (with reference to air pollution only) "present ground-based methods of detection can give only partial information on large-scale dispersal . . . ." The potential contribution of monitoring air (and water) pollution by satellite to yield information on large-scale

*Environmental and Science Technology, Vol. 5, No. 2, February 1971, pp. 106-108, 114-119.

dispersal patterns, however, was not investigated. In view of the fact that one of the R&D needs cited by the EPA is the "development of aerial noncontact sensing technique for broad-scale evaluation of water quality conditions over vast geographical areas"*, it would appear that the potential economic benefits from the ERS Program both in savings to be realized in the ground-based program as well as better information which might result from orbital surveillance is so greatly underestimated in previous studies as to render the estimates invalid.

The remaining estimates of benefits for applications 25 to 38 in Table 5 are largely undocumented. Therefore, they cannot be considered to be valid estimates.

Applications 25 to 38

		U.S. Annual Benefit
25.	Discover Ecological Relationships	$ 1,000,000
26.	Earthquake Prediction and Monitoring	75,000,000
27.	Volcanic Eruption Prediction and Monitoring	1,000,000**
28.	Flood Monitoring, Damage Warning, and Assessment	20,000,000
29.	Prediction of Snow and Ice Conditions	15,000,000
30.	Survey of Soil Conditions	40,000,000
31.	Survey of Arid and Semi-Arid Regions	4,000,000
32.	Survey of Pollution in Rivers and Streams	15,000,000
33.	Location of Fisheries and Fish Location	100,000,000
34.	Location of Navigation Hazards	75,000,000
35.	Monitoring Disposal in Industrial Areas	60,000,000
36.	Warning of Tidal Waves	40,000,000
37.	Monitoring of Ocean Effects on Beaches, etc.	50,000,000
38.	Damage Assessment in Disasters	25,000,000

However, the listing of applications such as these is one of the greatest contributions of the studies. Ecological relationships, earthquakes and volcanoes, soil erosion, and movements of air, water, and their pollutants are all among the really high payoff, long-term objectives of the Program.

*Environmental and Science Technology, Vol. 5, No. 2, February 1971, p. 119.
**World benefit.

Since the estimates were reported as savings over present data collection methods and since efforts are being made today to monitor observable phenomena in all these applications, they were all listed in the "same" information class. It is more than likely, however, that within the next decade or two the ERS system will also provide "better" and "new" classes of information in these applications.

Summary of INTERPLAN's Findings on the "Same" Information Class of Applications

In the studies reviewed, 38 applications were for the purpose of making satellite observations to yield the same information now being obtained through other sources. The total value of benefit estimates for applications which could be considered valid is $54.2 million.

Of the 16 mapping applications, benefit estimates for 11 applications were considered to be valid order-of-magnitude economic indicators. A total of $26.9 million was estimated as the savings to ongoing mapping activities which would result from implementation of these 11 applications.

Of 22 monitoring applications, benefit estimates for six applications were considered to be valid order-of-magnitude economic indicators. A total of about $27.3 million in savings to ongoing activities is estimated to result from implementation of these six applications.

Thus, the benefit estimates which can be considered valid and not overlapping amount to a total of $54.2 million in savings that can be realized through implementation of satellite mapping and monitoring applications which will yield the same information now being acquired by other methods.

Type of Application	Number of Applications		Amount of Valid, Non-overlapping Estimates
	Total	With Valid Estimates	
Mapping	16	11	$26,900,000
Monitoring	22	6	27,300,000
TOTAL	38	17	$54,200,000

REVIEW OF BENEFIT ESTIMATES PERTAINING TO SATELLITE OBSERVATIONS YIELDING "BETTER" INFORMATION THAN NOW EXISTS

Nature of the Benefit Estimates

Out of 85 applications in the studies reviewed, 37 applications were for the purpose of making satellite observations which would yield better information, but of the same kind now being used in ongoing activities. The benefits estimated, therefore, represent the marginal value of the "better" information which is obtained. The following progression is implied:

1. Better information is obtained through satellite observations
2. Improved action can be taken as a result of the better information
3. A benefit results from the improved action.

Thus benefit estimates represent added value through use.

Applicability of Benefit Analysis to "Better" Information Class

In some cases benefit estimates were made by first estimating the greatest value which could result from "perfect" information, i.e., an upper-limit benefit was established. Then an estimate was made of the degree to which the "better" information would differ from "perfect" information and the maximum benefit was suitably scaled down. Subsequently, an estimate was made of the amount of this benefit which probably can be realized, based on the degree to which action will, in fact, be taken.

Only a few of the applications for obtaining "better" information could be analyzed using this procedure. In many cases a percentage of an upper-limit value (usually based on an informed judgment) was used to represent the added value which would be realized. INTERPLAN considers that if verifiable upper limits are documented, valid order-of-magnitude indicators for this class of information can be obtained using either procedure.

For some applications, upper-limit benefits could be defined or calculated reasonably well, i.e., maximum benefits for avoiding damage and disaster losses are approximately equal to the value of past losses; the increase in hydroelectric power which would result from perfect streamflow

forecasts could be calculated. For other applications, upper limits were more difficult to establish and had to be based on assumptions or analogies to ongoing or postulated expenditures. In these instances the validity of the estimate was judged on the basis of the soundness of the assumption or analogy used.

Discussion of Study Findings for Mapping Applications

As stated by the authors of the PRC R-1218 study: "It is extremely difficult to define and measure a link between maps and the benefits to users. While most users would prefer to use more detailed and accurate maps, it is difficult to determine the marginal benefit from this better map."

In spite of these difficulties, INTERPLAN considers that of the 14 mapping applications which are postulated to yield better information than now available (see Table 6), valid order-of-magnitude estimates were made for applications 39 to 43.

Applications 39 to 43

		U.S. Annual Benefit
39.	Expediting Exploration for Petroleum	$125,000,000*
40.	Mineral Examination on Public Lands	450,000
41.	Improving Maps for Road Construction on Public Lands	100,000
42.	Improved Maps for Road Building on Indian Lands	50,000
43.	Avoidance of Sea Losses	9,000,000**

*Includes Canada.
**World benefit.

For each of these estimates a verifiable upper-limit benefit is documented. For applications 39-42 the amount of the upper limit representing the marginal benefit was estimated with the assistance of a potential user or a person familiar with user requirements while the estimate for application 43 was arrived at through analysis.

Table 6. Mapping applications yielding better information than now exists; benefits represent added value.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
39. Expediting exploration for petroleum	125*	--	U.S. oil companies	About 25 percent effectivity increase in U.S. oil companies' geological and geophysical reconnaissance expenditures (which represent 10 percent of total exploration budget).	Westinghouse 7145A2 Page 3-3 and/or Page A-80	Geology
40. Land classification and mineral examination on public lands	0.45*	--	USDI Bureau of Land Management	Better utilization of $4.5 million budget for mineral exploration and land classification.	Page A-58	Geography
41. Improving maps for road construction on public lands	0.1*	--		Five percent better utilization of $2 million road construction budget.	Page A-59	
42. Improved maps for road building on Indian lands	0.05*	--	Bureau of Indian Affairs	Five percent increased effectiveness of $1 million budget.	Page A-55	
43. Avoidance of sea losses	--	9	All ocean shipping	0.75 percent of estimated world losses at sea of $1.2 billion would be saved by charting of uncharted ocean areas.	PRC R-1218 Vol. III Page 214	
44. Increased efficiency of petroleum exploration	3.9	16.0	Petroleum industry	About 1 percent of the $392 million spent annually in the U.S. and about 10 percent spent worldwide in exploration resulting in dry holes. Incidence of dry holes outside the U.S. is assumed to be about 3 times that of U.S.	Page 232	Geology
45. Increased efficiency of exploration for all minerals	--	42	Worldwide producers of all minerals, including petroleum. Includes U.S. producers	Assumed to be about 2.5 times as great as benefits for petroleum only.		
46. Reduce road construction costs in areas of the the U.S. not now	114	--	U.S. and state highway construction agencies	Savings of 30 percent in the $381 million current cost of cut and fill operations for areas in the U.S. now mapped only to 1:62,500 scale. Maps at 1:24,000 for these areas should permit	Page 237	Geography

Table 6. Mapping applications yielding better information than now exists; benefits represent added value.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
(continued) mapped at scales of 1:24,000, 1:250,000, and 1:1,000,000				design engineers to lay out routes more efficiently.		Geography
47. Estuarine survey	0.6	--	USGS	Ninety percent replacement of aerial photographs at intervals of 5 years. May be as great as $21.2 million for 90 percent replacement annually.	Mathematica E & CM Page 39	Hydrology
48. Catalog soil fertility and environmental characteristics	--	100 (over several years)	Not identified	Less field work required with satellite.	SRI Project M-5465 Page 56	Agriculture
49. Photographing grazing land conditions	0.10	--	USDI Bureau of Land Management and USDA Forest Service, state agencies, and private ranchers	Replacement of 10 percent of the $1,000,000 cost of making aerial surveys for 685,000 square miles. Benefit will grow from $100 thousand to $900 thousand after 10 years due to better resolution. Current costs of photographs are $175,000 annually and cover 70,000 square miles.	Mathematica GLM Pages 27-33	
50. Location of forest resources and identification of composition by type	(3.0)**	(100)**	Not identified	Saving of 20 percent of the $15.2 million which would be required to survey U.S. forests by conventional means. Value of world inventory of forest resources estimated at about $75 million.	IBM NASw-1215 Vol. B Part I Page I-A-17	
51. Estimating forest vigor and potential yield	(300)**	(1600)**	Not identified	The value of a forest inventory would double in the U.S. and triple in less developed areas if vigor and yield were also determined.	Pages I-19 and I-A-25	
52. Land boundary survey for tax assessment	--	8 (South America)	So. American Governments	Cost of an aerial survey of 4.5 million square miles would be $9,000,000 compared to about $800,000 for satellite survey.	PRC R-1218 Vol. III Page 234	Geography

*Estimate based on the informed judgment of potential user.
**Figures in parentheses are for benefits resulting from improvements over several years due to improved techniques.

The benefit estimate for application 39—Expediting Exploration for Petroleum, the largest benefit pertaining to mapping—is similar to application 1 (Mapping Relative to Mineral Exploration in the United States—$12.5 million) but is placed in the "better" information class since it refers to an increase in the effectiveness of oil reconnaissance. Both estimates are from the Westinghouse Report.

Mineral and oil exploration is also discussed in the Summer Study Report, Volume 2,Geology, where it is stated that potential ERS information "is expected to assist in the discovery of oil, gas, and minerals through more rapidly delineating promising areas for prospecting and to aid markedly in the planning of large engineering operations." In the Summer Study Report four potential sources of economic benefits are cited: (1) savings, or efficiency increase, in present exploration and mapping costs, (2) acceleration of oils and metals production, (3) improved effectiveness in the entire range of geological activities carried on by agencies of government, and (4) broad cultural benefits realizable through a better knowledge of the history of the earth.

No explicit estimate of economic benefits was given in the Summer Study Report. However, based on an estimated $500 million expenditure for geological and geophysical exploration and mapping of oil and mineral resources in the United States and Canada it was pointed out that only a 1 percent savings or effectivity increase in this amount would make satellite data collection cost effective. Present annual oil exploration costs in the United States were estimated at about $2 billion annually.

The Westinghouse estimate (application 39) of $125 million refers to an expected 25 percent annual increase in effectiveness of the U.S. oil industry's reconnaissance expenditures which are estimated to be about 10 percent of the total exploration benefit—an implied U.S. worldwide oil exploration budget of about $5 billion. Although the benefit estimate refers only to savings in exploration costs of the U.S. oil industry, INTERPLAN considers that it is an important indicator of potential benefits which may be realized in this application area. (An interesting frame of

reference with respect to potential benefits to countries other than the United States and Canada is given in the recent announcement* of Litton Industries' 39-month, $8 million plus contract with the Algerian government to survey Algeria—about one-fourth the size of the United States—for location of mineral deposits, oil, gas, and water.)

The estimate of worldwide benefits for application 43, derived through analysis, is considered valid since it is based on a documented upper limit representing world sea losses and is not an estimate obtained by factoring up an estimate of U.S. benefits.

In each of the benefit estimates made for applications 44-46 the assumption upon which the upper limit is based appears to be specious.

Applications 44 to 46

		U.S. Annual Benefit
44.	Increased Efficiency of Petroleum Exploration	$ 3,900,000
45.	Increased Efficiency of Exploration for All Minerals	42,000,000*
46.	Reduce Road Construction Costs in Areas of the U.S. Not Now Adequately Mapped	114,000,000

*World benefit.

For example, in application 44 the upper limit is established on the basis of the assumption that dry holes would be avoided through the use of better geological maps. This assumption is considered tenuous since there is significant geophysical exploration on the surface before drilling is undertaken, the results of which probably would not be affected even if better maps were available. The benefit estimate for application 45, the result of factoring up the estimate of application 44, is naturally subject to the same criticism.

The estimate for application 46 uses an upper limit representing U.S. roadbuilding cut-and-fill costs on the assumption that these costs might be reduced by 30 percent if larger scale maps were available. The assumption is questionable since all highway routes are now extensively surveyed before construction, aerial photography is available, and it is doubtful whether more detailed information could be provided through satellite observation.

*Los Angeles Times, Feb. 18, 1971.

Applications 47-52 are not considered valid since the upper limit in each case is a surrogate value representing the cost which would be incurred if the postulated information were to be obtained using conventional means.

Applications 47 to 52

		U.S. Annual Benefit
47.	Estuarine Survey	$ 600,000
48.	Catalog Soil Fertility and Environmental Characteristics	100,000,000*
49.	Photograph Grazing Land Conditions	100,000
50.	Location and Identification of Forest Resources	3,000,000
51.	Estimate Forest Vigor and Yield	300,000,000
52.	Land Boundary Survey for Tax Assessment	8,000,000*

*World benefit.

Implicit in the fact that these projects have not been implemented to the extent suggested in the application is the possibility that the cost of implementation by conventional means has been judged to exceed the value to be realized.

Discussion of Study Findings for Monitoring Applications

Benefit estimates were made for 23 monitoring applications which would yield better information than is now available (see Table 7). Estimates for 17 applications were considered by INTERPLAN to be valid order-of-magnitude economic indicators. Many of these estimates are for similar applications or are for the same application, but with differences in the scope of benefiting users covered by the estimate. To facilitate the discussion of these findings and the isolation of benefits which can be considered additive, these applications are grouped and discussed according to the disciplines which they represent.

ESTIMATES OF BENEFITS FOR BETTER INFORMATION IN THE DISCIPLINE OF HYDROLOGY. The Westinghouse and the two PRC studies list benefit estimates for four applications in the discipline of Hydrology which yield better information (applications 53 to 56).

Table 7. Monitoring applications yielding better information than now exists; benefits represent added value.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
53. Minimize flood damage	305.5* (1973)	--	U.S. managers of dams used for flood control	Based on calculations from four Pacific Northwest basins, about 83 percent of direct flood losses and 75 percent of indirect losses would be saved through utilization of improved runoff forecasts to reduce river levels at maximum flood stage by 2 feet to produce an estimated gross benefit of $18.5 million. Results factored up based on flood losses in all U.S. river basins.	PRC R-1224 Vol. II Page 150 and Page 159	Hydrology
54. Increase value of reservoirs for recreation	6.5 (1973)	--	Operators of reservoir recreation areas	Grand Coulee recreation use calculated as a function of water level during warm months—a gross benefit of $305,000 for the Pacific Northwest Basin. Results extrapolated to all U.S. reservoirs.	Page 159	
55. Increase hydropower generation	11	--	Bureau of Reclamation	Postulates 10 percent increase in income from increased power generated as a result of greater water availability from lowered irrigation water losses.	Westinghouse 7145A2 Page 3-3 and Page A-78	
	22.5 (1973)	--	Hydroelectric power producers in North Pacific drainage area	Increased power from reduction in "hedge," improvements in drawdown strategy and inter-reservoir coordinating made possible through improved long-term and short-term inventory and demand forecasts. Supercedes following estimate made in PRC R-1218 study.	PRC R-1224 Vol. II Page 150	
	100** (1990)	--				
	5.41	--		Increased power produced by reducing residual reservoir volume and spillage through reducing inflow forecast error from about 15 percent to about 5 percent.	PRC R-1218 Vol. III Page 159	
	8.26 (1965)	--	Hydroelectric power producers in North Pacific, South Pacific, Great Lakes-St.Lawrence River,	Factored up from preceding estimate of $5.41 million for North Pacific, based on relative amount of power produced.		
	19.3** (1989)	--			Page 162	

Table 7. Monitoring applications yielding better information than now exists; benefits represent added value.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
(continued)			and one-half Ohio River drainage area.		PRC R-1218 Vol. III	Hydrology
	--	36.50 (1965) 97.5 (1989)**	Hydroelectric power producers in U.S., Canada, France, Italy, Japan, Norway, Sweden, Switzerland, and USSR	U.S. represents 27 percent of world production. Benefits relate to 65 percent of U.S. total power. Countries included represent 60 percent of total world production. Factored up from the preceding estimate of U.S. benefits of $8.26 million according to the following equation: $8.26 + \left(\frac{8.26 \times .6}{.27 \times .65}\right) = 36.50$	Pages 159-160, 162	
	94.1 (1973)	--	U.S. producers of hydroelectric power	Factored up from the estimate of $22.5 million for Pacific Northwest based on amount of power produced, weighted by amount of power produced by reservoir dams and run of river dams and high and low rainfall records. Supercedes PRC R-1218 estimate.	PRC R-1224 Vol. II Page 159	
56. Improvements in irrigation, navigation, flood control, and recreation	--	373.5	Managers of dams in 9 countries	Based on estimates made for Grand Coulee Dam factored up according to current allocation of capital costs of Grand Coulee for uses other than power. Estimates include benefits to U.S., Canada, France, Italy, Japan, Norway, Sweden, Switzerland and USSR.	PRC R-1218 Vol. III Page 253	
57. Improved forecasts of irrigation water availability	44.8 (1973) 78 (1990)***	--	Irrigation farms in Pacific Northwest	Improving the forecast accuracy of the amount of water which will be available for irrigation from 80 percent to 95 percent would result in increased farm income averaging $9.03 per acre in the Pacific Northwest. U.S. benefits calculated on the basis of the number of acres under irrigation in 1959.	PRC R-1224 Vol. II Page 150	Agriculture
	282 (1973)	--	Irrigation farms in the U.S.		Page 159	
58. Detection of faulty irrigation practices	12****	--	Farmers on 20 Bureau of Reclamation projects and private farmers	Yield from 400,000 acres or problem lands would be improved through timely detection of faulty irrigation practice. Fifteen percent of this land (now valued at $65/acre) would show a 75 percent increase in value—a bene-	Westinghouse 7145A2 Page 3-3 and/or Page A-73	

Table 7. Monitoring applications yielding better information than now exists; benefits represent added value.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
(continued)			on similar land	fit of $3 million. There is about 3 times this acreage of problem lands under private irrigation which would benefit to the same degree.	Westinghouse 7145A2 Page 3-3 and/or Page A-73	Agriculture
59. Detection of losses of irrigation water and refined runoff estimates	319****	--	U.S. farmers on 40 million acres of irrigated lands	Yield increases of about 2.5 percent on 40 million acres currently yielding about $350 per acre.	Pages A-75 and A-76	
60. Planning, protection, and operation of the National Park Service	8****	--	National Park Service	A 10 percent increase in effectiveness in the use of the $80 million budgeted for planning, protection, and operation.	Pages A-51 and A-52	
61. Planning of Federal grants-in-aid for development of State recreational areas	17.0****	--	Bureau of Outdoor Recreation	Increased effectiveness in the expenditure of $125 million.	Page A-53	
62. Planning, development, operation, and maintenance of State recreation sites	15.0****	--	State Recreational Agencies	Increased effectiveness in the expenditure of $225 million.	Page A-53	
63. Improvements in soil and watershed conservation	1.47****	--	Bureau of Reclamation and Hydrology, Division of USGS	A 10 percent increase in effectiveness in the expenditure of $14.7 million.	Page A-59	
64. Range, forestry, and land management on Indian lands	.186****	--	Bureau of Indian Affairs	A 2 percent increase in effectiveness in the $5.3 million budget for forest and range management and 5 percent of a $1.6 million budget for soil and moisture surveys on Indian lands.	Page A-55	

Table 7. Monitoring applications yielding better information than now exists; benefits represent added value.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
65. Forest fire detection	15	645	Public and private forest managers	More rapid detection of forest fires would result in about 20 percent reduction in fire damage estimated at $75 to $100 million annually. World benefits are 43 times U.S. benefits.	PRC R-1218 Vol. III Pages 208 and 257	Agriculture
66. Forest fire detection and damage assessment	3	6	USDA Forest Service and foreign forest agencies	Activities which will be replaced by satellite observation are not cited.	IBM NASw-1215, Vol. B, Part I Page I-19	
67. Improved range management	0.54****	--	Bureau of Land Management	A 10 percent increase in effectiveness in expending a management budget of $5.4 million.	Westinghouse 7145A Page A-59	
	1.75	--	Public and private range management	The annual forage value of $175 million could be increased by at least 1 percent by forecasting range conditions and forecasting forage growth due to satellite monitoring.	Mathematica GLM Study Page 46	
68. Timely detection of wheat rust	146.3	757.2	Wheat farmers in the U.S. and 15 selected wheat producing countries	Annual losses due to wheat rust are $154 million. The value reported represents benefits estimated to accrue after 1976 at 95 percent control. These benefits were factored up to represent similar loss prevention in 15 other wheat producing countries.	PRC R-1224 Vol. II Pages A-534, A-537, and A-538.	
	--	554*****		Losses in 16 major producing countries due to wheat rust are estimated to average $554 million annually over 1970-1989 period. Secondary benefits and multiplier effects for less than full employment economies are estimated at $75 million annual increase in GNP.	PRC R-1218 Vol. III Pages 91 and 107	
69. Detection of wheat-rust-like (fungi) stresses in small grains other than wheat	84.9	369.2	Small grain farmers in the U.S. and 15 selected small grain producing countries	Same rationale as in the preceding case, applied to U.S. losses of $89.4 million and world losses of $388.6 million. Benefit estimate represents 95 percent control.	PRC R-1224 Vol. II Page 251	

Table 7. Monitoring applications yielding better information than now exists; benefits represent added value.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
70. Reduction of forest insect infestation losses	9	--	Managers of U.S. forests	Early detection of insect infestation could prevent about 20 percent of $47 million losses in timber due to insect infestation.	PRC R-1218 Vol. III Page 210	Agriculture
71. Reduction of all crop disease and insect infestation	4533	27000	Farmers	Based on U.S. losses of $7.4 billion. U.S. benefits multiplied by a factor of 6 to obtain world benefit.	Pages 248, 250, and 251	
72. Location of areas conducive to breeding of mosquitos	--	2906 to 28,886	Governments of tropical countries	Gross benefits represent sick days saved times daily wage times 0.9 factor representing employment level. Range of benefits represents 10-100 percent spray effectiveness.	Pages 119-121	Multidiscipline
73. Improve search and rescue operations	--	38	Not stated	Twenty-five percent of current search costs could be saved through more rapid location of persons in distress.	Page 240	
74. Control of solid-waste-related diseases	--	189	Not stated	Analogy to an in-depth study made of malaria, assuming 10 percent effectiveness of sensor system.	Page 219	
75. Detecting epidemic disease in animals	--	1350	Unspecified government agency	Benefits factored up for world animal diseases from foot and mouth disease losses in England in one year.	Page 223	Agriculture

*A discrepancy in the tabular totals of flood damage losses in the report is noted.
**Forecast based on AEC (1980) projections of installed capacity.
***Forecast based on projected increases in acres to be irrigated.
****Estimate based on informed judgment of potential user.
*****Average annual gross benefit.

Applications 53 to 56

		U.S. Annual Benefit
53.	Minimize Flood Damage	$305,500,000
54.	Increase Value of Reservoirs for Recreation and Improve Navigation	6,500,000
55.	Increase Hydropower Generation Benefits:	
	a. (For Bureau of Reclamation)	11,000,000
	b. (For North Pacific Drainage Area Producers)	22,500,000 (5,410,000)*
	c. (For North Pacific, South Pacific, Great Lakes, St. Lawrence River, and 1/2 of Ohio River Drainage Area Producers)	(8,260,000)*
	d. (For Hydropower Producers in 9 Countries)	36,500,000
	e. (For U.S. Producers)	94,100,000
56.	Improvements in Irrigation, Navigation, Cloud Control, etc.	373,500,000**

*Values in parentheses are initial estimates superseded by a later, more exhaustive case study.
**Benefit to 9 countries, including the United States.

INTERPLAN considers that valid benefit estimates were made for the first three applications listed (53 to 55). The estimates of benefits for applications 53 and 54 were arrived at through analysis of verifiable data. These applications do not overlap and, hence, can be considered additive.

The five benefit estimates for application 55, however, do overlap. Estimate (a) in application 55 was arrived at by using the expert judgment of a potential user, while the other estimates (b, c, d, and e) were made on the basis of closely reasoned analysis. Only the most inclusive U.S. estimate (e) which covers all U.S. producers of hydropower is included in the summary of benefits for "better" information applications. It is interesting to note that estimate (a) of $11 million for benefits to the Bureau of Reclamation is in reasonably good agreement with estimate (e) of $94.1 million, considering that in 1968 the 49 Bureau of Reclamation hydropower plants produced about 14 percent of the total hydropower generated in the United States (94.1 x .14 = $13.2 million). The benefit estimate (d) for increased hydropower generation in 9 major hydropower producing countries (including the

United States), was made by factoring up benefit estimate (c). This estimate is not considered valid since it was superseded by later work and since in most instances INTERPLAN does not consider that valid estimates of world benefits can be made through the extrapolation of U.S. estimates.

Application 56—which relates to benefits to be realized by the same 9 hydropower-producing countries through improvements in irrigation, navigation, and flood control—is derived from an extrapolation of U.S. data and likewise is not considered valid.

In summary, the total, additive benefits which are considered valid for monitoring applications yielding better information in the field of hydrology are (305.5 + 6.5 + 94.1) = $406.1 million annually.

ESTIMATES OF BENEFITS FOR BETTER INFORMATION IN THE DISCIPLINE OF AGRICULTURE. The Westinghouse, IBM, Mathematica GLM, and the two PRC studies list benefit estimates for 14 applications in the discipline of Agriculture which yield better information (applications 57 to 70).

Applications 57 to 70

		U.S. Annual Benefit
57.	Improved Forecasts of Irrigation Water Availability Benefits:	
	a. (For Irrigation Farms in Pacific Northwest)	$ 44,800,000
	b. (For Irrigation Farms in United States, 33 Million Acres)	282,000,000
58.	Detection of Faulty Irrigation Practices (Benefits to Farmers on 20 Bureau of Reclamation Projects and Private Farmers on Similar Problem Lands—a Total Acreage of 1,600,000)	12,000,000*
59.	Detection of Losses of Irrigation Water and Refined Runoff Estimates (Benefits to U.S. Farmers on 40 Million Acres of Irrigated Land)	319,000,000*
60.	Planning, Protection, and Operation in the National Park Service	8,000,000*
61.	Planning Federal Grants-in-Aide for Development of State Recreational Areas	17,000,000*

*Estimate based on the informed judgment of a potential user.

		U.S. Annual Benefit
62.	Planning, Development, Operation, and Maintenance of State Recreational Sites	$ 15,000,000*
63.	Improvements in Soil and Watershed Conservation	1,470,000*
64.	Range, Forestry, and Land Management on Indian Lands	186,000*
65.	Forest Fire Detection	15,000,000
66.	Forest Fire Detection and Damage Assessment	3,000,000*
67.	Improved Range Management Benefits:	
	a. (For Bureau of Land Management)	540,000*
	b. (For Public & Private Range Management)	1,750,000
68.	Timely Detection of Wheat Rust	146,300,000
69.	Detection of Wheat-rust-like (Fungi) Stresses in Small Grains other than Wheat	84,900,000
70.	Reduction of Forest Insect Infestation Losses	9,000,000

*Estimate based on the informed judgment of a potential user.

INTERPLAN considers that valid benefit estimates were made for applications 57 to 70. The benefit estimates for applications 57 to 59, relating to benefits which would be realized by farmers on irrigated land (due to better reservoir management), are overlapping. As noted, some were made through analysis and some on the basis of informed judgment. The estimate for application 58 from the Westinghouse report refers only to "problem" lands and is additive to the benefit estimate for application 59 (also from the Westinghouse report)—a total of (319 + 12) = $331 million annually. Since applications 58 and 59 are similar to application 57, they are considered to overlap. The estimate for application 57 is included in the summary of benefits since the documentation was more thorough and the estimate is more conservative.

Benefit estimates for applications 60 to 64, all from the Westinghouse report, are considered valid estimates of benefits for the applications considered and are additive. Each is based on a percentage increase in the effective use of funds in an ongoing activity.

Applications 65 and 66 overlap since benefits are claimed for more timely detection of forest fires in each. Application 66 appears to be

more inclusive in scope since it includes benefits to be realized from early damage assessment. However, the estimate is less inclusive in its coverage of potential users since it represents benefits to the USDA only, while the benefit estimate for application 65 refers to all U.S. public and private forest managers. Since the estimate for application 65 is more thoroughly documented, more inclusive, and is based on a percentage reduction in verifiable forest fire losses, it is used in the summary of benefits.

The two benefit estimates for application 67 also overlap. The estimate of $1.75 million annual benefit (from the Mathematica report) is used in the summary of benefits for the same reasons cited for application 65.

In application 68, gross annual benefits of $146.3 million are estimated in the PRC R-1224 report to be realizable if wheat farmers in the United States have timely enough information on wheat rust infection to control the spread of the disease by spraying. INTERPLAN considers that this estimate is valid; however, it is noted that this estimate and other similar estimates that purport to anticipate to what an extent a broad base of independent users will use better (or new) information must be considered less certain indicators of the total economic impact of the information than when the ultimate user is an organized group. In this estimate the degree of farmer participation was considered and the participation rate used (90 percent after 6 years of the program) seems reasonable, based on current use of agricultural information by U.S. farmers.

The benefit estimate for application 69 is considered valid and additive to the benefit estimate for application 68. Signature technology will have to be well advanced in order to distinguish between different types of small grains and, hence, any ERS information on fungal diseases (in the foreseeable future) will probably pertain to all small grains. It is reasonable to assume that all small-grain farmers are likely to be included in the program and will participate since spray controls and the value realized by various grain farmers will be similar.

The benefit estimate for application 70 is likewise considered valid since it is based on preventing a percentage of verifiable losses due to forest insect damage.

In summary, total additive benefits which are considered valid for monitoring applications yielding better information in the field of agriculture are (282.0 + 8.0 + 17.0 + 15.0 + 1.5 + 0.2 + 15.0 + 1.8 + 146.3 + 84.9 + 9.0 = $580.7 million).

ESTIMATES OF BENEFITS FOR BETTER INFORMATION WHICH ARE NOT CONSIDERED VALID. The PRC R-1218 study lists benefit estimates for five applications (applications 71 to 75).

Applications 71 to 75

		U.S. Annual Benefit
71.	Reduction of All Crop Disease and Insect Infestation	$4,533,000,000
72.	Location of Mosquito Breeding Areas	2,906,000,000*
73.	Improved Search and Rescue Operations	38,000,000*
74.	Control of Solid-Waste-Related Diseases	189,000,000*
75.	Detecting Epidemic Diseases in Animals	1,350,000,000*

*World benefit.

The benefit estimates for applications 71 to 75 are not considered valid. In application 71 the same rationale used in deriving benefit estimates for fungal damage to small grains is applied to the early detection and control of all crop diseases. INTERPLAN considers that a simple extrapolation of the wheat rust case to all crops and diseases is not valid since each disease differs not only with respect to detection techniques but also with respect to the possibility of and cost of control and the degree to which farmer participation in the program might be expected. The ERS Program appears to have promise in reducing crop losses—not only in the United States, but worldwide; however, INTERPLAN considers that valid estimates of potential benefits can only be obtained on the basis of a case by case analysis.

Application 72 which pertains to the location of areas conducive to breeding of mosquitoes is important since it isolates one major area where ERS information can be useful in improving health on a worldwide scale. INTERPLAN considers, however, that the subject matter is not amenable to

economic analysis. Apart from the fact that the assumptions of the analysis seem optimistic with respect to user participation and spray effectiveness, the derivation of economic benefit on the basis of the average wage and unemployment statistics published for subsistence economies is considered unrealistic. Unquestionably, the application has merit, but its value requires justification on other than economic grounds.

The benefit estimate for application 73 is not considered valid since the documentation and analysis presented is inadequate.

The benefit estimate for application 74 is not considered valid since it appears unreasonable to assume that at any time in the near future small quantities of solid wastes will be detected effectively by ERS observations. Further, the existence of these solid wastes is not due to lack of observation, but lack of action.

The benefit estimate for application 75, likewise, is not considered valid since, in the foreseeable future, it is not probable that the information could be obtained through ERS observations. In addition, the analysis exhibits a lack of understanding of the foot and mouth disease problem. Foot and mouth vaccine is highly effective, when used. However, the fact that the vaccine is a viable culture prevents its use in breeding stock—and in England, where a large proportion of the stock is exported as breeding stock, use of the vaccine is prevented by law.

Summary of INTERPLAN's Findings on the Better Information Class of Applications

In the studies reviewed, 37 applications were for the purpose of making satellite observations which would yield better information than is now being obtained. The total value of benefit estimates which could be considered valid is $1,121.4 million.

Of the 14 mapping applications, benefit estimates for 5 applications were considered valid for a total of $134.6 million. Of the 23 monitoring applications, valid benefit estimates were made for 3 hydrology applications totaling $406.1 million and for 14 agricultural applications totaling $580.7 million.

Type of Application	Number of Applications		Amount of Valid, Non-overlapping Estimates
	Total	With Valid Estimates	
Mapping	14	5	$ 134,600,000
Monitoring	23	17	986,800,000
TOTAL	37	22	$1,121,400,000

REVIEW OF BENEFIT ESTIMATES PERTAINING TO SATELLITE OBSERVATIONS YIELDING "NEW" INFORMATION

Nature of the Benefit Estimates

Of the 85 applications in the studies reviewed, 10 applications (all monitoring) were classified as producing benefits from satellite observations which would yield new information. Two types of new information can be distinguished: (1) information of known content that can be obtained only by observations from a space platform since the resources to be observed are dispersed over the entire earth's surface, and (2) information of unknown content which might be obtained as a result of synoptic satellite observations. Only new information of the first type is referred to in this classification. It is recognized that the economic benefits which might be realized from the latter type of information could be substantial but, unfortunately, these benefits are not quantifiable until the information content becomes known.

Since the information is new, the benefit analysis was approached by the authors by estimating the absolute value of the information based on case examples of how the proposed new information might be used.

Applicability of Benefit Analysis to the "New" Information Class

Since the information is not now used in an ongoing activity, upper limits were not established by reference to current expenditures. Rather, to obtain an upper limit assumptions were made that if the information were used in a specified case the benefit would be related to some aspect of the current value of the resource.

INTERPLAN considers that if the cases specified are clear-cut and not dependent upon a series of interrelated actions, valid estimates of benefits can be made for each case examined. However, since an inestimable number of unanticipated and interrelated actions—with both positive and negative economic results—are likely to be taken in real life, there will always be uncertainty as to whether sufficient cases (and the right cases) have been examined. If, however, on the basis of one or two clear-cut cases the benefits appear to justify the necessary ERS expenditures for

implementation and no major negative results can be anticipated, INTERPLAN considers that the estimates obtained are valid indicators at the prefeasibility level of analysis of the relative importance of the application.

Discussion of Study Findings for Monitoring Applications

Benefit estimates were made for 10 monitoring applications which would yield new information (see Table 8). Of these, INTERPLAN considers that valid benefit estimates were made for applications 76 to 79.

Applications 76 to 79

		U.S. Annual Benefit
76.	More Timely and Accurate Predictions of Southeast Asian Rice Yield	$ 45,300,000
77.	Improve Timeliness and Accuracy of World Wheat Production Forecasts Benefits:	
	a. (For U.S. Commodity Credit Corp.)	85,700,000
	b. (For U.S. Wheat Farmers, Due to Reduction in Unit Production Costs)	28,000,000
	c. (For Wheat Farmers in 6 Major Wheat Producing Countries—Extrapolated from 70 b.)	(44,000,000)*
	d. (For U.S. Agribusiness)	190,000
	e. (For U.S. Wheat Farmers, Due to More Effective Use of Producer Options)	78,000,000
	f. (For Wheat Farmers in 6 Major Wheat Producing Countries—Extrapolated from 70 e.)	(148,000,000)*
78.	Provide More Economic Ship Routing Benefits:	
	a. (For Operators of U.S. Flag Ships Engaged in Foreign Trade)	20,000,000 decreasing to 8,000,000
	b. (For Operators of U.S. Flag Ships Engaged in Foreign Trade)	7,000,000
79.	Increase U.S. Tuna Catch	12,000,000

*Values in parentheses are estimates for countries other than the United States.

INTERPLAN considers the benefit estimate for application 76 to be valid since (1) it is based on the clear-cut and apparently sound assumption that U.S. rice farmers will respond to new and timely market information and either

Table 8. Monitoring applications yielding new information; benefits represent value through use.

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
76. More timely and accurate predictions of Southeast Asian rice yield	45.3*	--	U.S. rice producers	Observation and prediction of Asian rice yields would permit increasing U.S. rice production in years of short supply and planting of alternate (soybean) crops in years of surplus. Price and production values assumed for 1970-1989 period are based on historical activity of rice export industry.	PRC R-1218 Vol. III Pages 43 and 65	Agriculture
77. Improve timeliness and accuracy of world wheat production forecasts	85.7	--	U.S. Commodity Credit Corporation	Through daily monitoring of world wheat production and environmental conditions, more timely and accurate information would be available to reduce wheat production projection errors. This would permit reduced storage resulting in savings in operating costs and in costs on investment capital.	PRC R-1224 Vol. II Page 207	
	28	--	U.S. wheat farmers	A reduction in the fluctuation in acres used for producing wheat will lower unit production costs.	Page A-468	
	--	44	Wheat farmers in Argentina, Australia, Canada, France, West Germany, Italy	U.S. value of $28 million extrapolated to selected countries on the basis of relative acreage represented (1:1.6).		
	.19	--	U.S. agribusiness	Savings to farm machinery, fertilizer, and pesticide industry from reduced storage due to advance predictions of farm income in preceding year.	Page A-509	
	78	--	U.S. wheat farmers	More timely and accurate forecasts of precipitation and soil moisture would permit taking improved action with respect to crop rotation, cattle grazing, fertilizer application, and custom work.	Page A-490	
	--	148	Wheat farmers in Argentina,	U.S. value of $78 million extrapolated on the basis of relative acreage represented (1:1.9).		

Table 8. Monitoring applications yielding new information; benefits represent value through use. (Sheet 2 of 3)

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
(continued)			Australia, Canada, France, West Germany, Italy			
78. Provide more economical ship routing	20 decreasing to 8	--	Operators of U.S. flag ships engaged in foreign trade	MSTS estimates savings of $2000 per average ocean crossing if optimally routed. Maximum savings of $37 million could be realized for 18,500 annual crossings.	SRI M-5465 Vol. II Page 77	Ocean Sciences
	7	--		Assumes 20 percent utilization of information leading to 20 percent savings of $37 million maximum.	PRC R-1218 Vol. III Pages 216-217	
79. Increase U.S. tuna catch	12	--	U.S. fishing industry	Improved oceanographic techniques would permit the elimination of U.S. tuna imports valued at $42 million annually; $30 million of this could be realized without space operations.	GE Pages 8-13 and 8-14	
80. Monitoring of national quota for various schooling fish and enforcement of international agreements	74 to 215	900 to 2000	World fishing industry	International quota program may be necessary to prevent extinction of many species. Estimate represents 10 percent of estimated value of world catch and about 16 percent of value of U.S. catch—1965 and 1975.	Page 8-10	
81. Increase catch of albacore tuna fish	--	388**	U.S. and Japanese fishermen	Through application of conservation and feeding techniques the total catch is increased. Greater numbers of tuna and reduction in search time increases the efficiency of the fishing effort. Benefit estimates are calculated from 2 conservation and 1 efficiency model. Total net benefits equal $3,124.5 million for a 20-year program or an average of $156 million annually.	PRC R-1218 Vol. III Pages 201 and 203	
82. Increase catch of all applicable fish	--	3880*	Fishermen of the species monitored	Tuna catch is 1/10th the value of all fish for which a satellite system could be developed. Net benefits = $1.56 billion/year.	Pages 256 and 201	

Table 8. Monitoring applications yielding new information; benefits represent value through use. (Sheet 3 of 3)

APPLICATION	ANNUAL BENEFITS ($millions) U.S.	ANNUAL BENEFITS ($millions) WORLD	USER OR USER AGENCY	RATIONALE OR BASIS FOR ESTIMATE	DOCUMENT	DISCIPLINE
83. More timely and accurate world-wide inventory/ yield crop predictions	--	11,300	World agriculture	The value of world trade in all agricultural commodities is about 256 times world trade in rice. U.S. benefits for Application 76 are multiplied by 256 (based on U.S. net benefits of $44.3 million).	PRC R-1218 Vol. III Page 251	Agriculture
84. Predicting world food-grain crop conditions	22*	567*	U.S. Economic Assistance Program and 14 less developed countries	Stabilization of 4.5 percent of total food grain output of 14 less developed countries would result in a higher growth rate for agricultural sector and 1 percent savings in U.S. foreign assistance investments.	PRC R-1224 Page A-499	
85. Evaporation mapping	--	10	Not specified	Not cited.	SRI M-5465 Vol. II Page 62	Hydrology
	400	1000			IBM NASw-1215 Vol. B Part II Page II-21	

*Average, annual gross benefits over 20-year program.
**Average, annual gross benefit.

increase or decrease rice production (substituting an alternative soybean crop) and (2) since the estimation of resulting value is based on an extrapolation of historical data which can be verified.

In application 77 four principal cases were analyzed in estimating the benefits to be realized through more timely and accurate world wheat production forecasts. Benefit estimate (a) assumes that actions might be taken by the U.S. Commodity Corporation to lower the amount of wheat stored and hence reduce storage costs. This assumption is clear-cut and, although (as noted by the authors) enabling legislation would be required, it is reasonable to assume that appropriate measures would be passed if the ERS capability were demonstrated. Therefore, this estimate is considered to be valid.

Benefit estimate (b) assumes that farmers will respond to new and timely market information and will adjust their wheat crop acreage accordingly, thus stabilizing the number of acres planted to wheat each year. This stabilization will, in turn, result in lower unit production costs. Since the assumption of farmer response is reasonable (based on the past response of U.S. farmers to market information) and since stabilizing productive output usually does result in lower unit production costs, INTERPLAN considers this estimate to be valid and additive to estimate (a). Benefit estimate (c), however, is not considered valid since it results from an extrapolation of estimate (b) to cover 6 countries where INTERPLAN considers that farmer response cannot be predicted on the basis of U.S. data.

Benefit estimate (d) assumes that producers of farm-related equipment and products will adjust their production to minimize inventories (and hence reduce costs) if advance predictions on farm income can be made. This assumption is sound since the agribusiness community now does attempt to adjust its production at least partially on this basis. However, the implicit assumption is that the current overestimation and underestimation of the world wheat market and resulting over and under production of wheat causes a measureable change in farm income. The relationship between farm production and farm income is influenced so greatly by a multiplicity of subsidies, acreage allotments, and other government price stabilizing

influences that INTERPLAN considers the implicit assumption to be false and, hence, the estimate is not considered valid.

Benefit estimates (e) and (f) assume that farmers will more effectively utilize various producer options if satellite-assisted weather information provides improved weather forecasts. The assumption would appear valid for U.S. farmers; however, the benefits are not due to more accurate forecasts of wheat production but rather to improved weather forecasting. Therefore, although the estimates were related to wheat management by the authors for evaluation, they are not considered valid estimates of benefits which would be realized by making ERS observations for forecasting wheat yield and production.

Two benefit estimates were made for application 78 based on the assumption that if timely information on sea states were provided, operators of U.S. Flagships engaged in foreign trade would be able to route their ships more economically. Both estimates (one from the SRI study and one from the PRC R-1218 study) appear to be based on the same statistical data (an MSTS estimate that a maximum of $37 million could be saved annually if U.S. foreign trade vessels were optimally routed). Both benefit estimates are close to the same value although each was based on different assumptions. The SRI estimate of $8 million annual savings is considered to be the more valid estimate since the analysis is better documented and more closely reasoned.

In view of the high quality of the analysis (GE study) and the fact that the estimate is conservative, INTERPLAN considers that the estimate for application 79 is valid.

Applications 80-85 are not considered valid.

Applications 80 to 85

		U.S. Annual Benefit
80.	Monitoring of Fishing and International Agreements	$ 74,000,000
81.	Increase Catch of Albacore Tuna	388,000,000*
82.	Increase Catch of All Fish	3,880,000,000*

	U.S. Annual Benefit
83. More Timely and Accurate Crop Predictions	$11,300,000,000*
84. Predicting Food-Grain Crop Conditions	22,000,000
85. Evaporation Mapping	400,000,000

*World benefit.

Applications 80 and 81 assume that the new information will be used in international programs which do not exist now. It appears, first of all, optimistic to assume that such programs will be implemented by 1975 as is assumed in the cases examined and, secondly, until the programs and international agreements are evolved, specific uses for the information can not be postulated with any certainty. [These estimates are similar to those made in the PRC R-1218 and Westinghouse studies relative to pollution monitoring (applications 23 and 24). At the time the estimates were made no single group in the United States was responsible for pollution monitoring activities and, hence, the way in which the information might be used could not be postulated with certainty. Now, however, since these activities are defined and are the responsibility of the EPA, INTERPLAN considers that estimates can be made with sufficient certainty to provide a valid indication of benefits.]

The benefit estimate for application 83 results from an extrapolation of U.S. data to world conditions and, hence, is not considered valid.

The benefit estimate for application 84 is based on a highly imaginative postulated use of new information on world food grain production which, by increasing the food grain output of developing countries, would reduce the requirements for U.S. foreign assistance investments. Although the case is logical, INTERPLAN considers that the estimate is not valid since too many factors other than actual production output affect the size and direction of U.S. foreign assistance programs.

The benefit estimate for application 85 cannot be considered valid due to lack of documentation and supporting rationale.

Summary of INTERPLAN's Findings on the "New" Information Class of Applications

In the studies reviewed, 10 applications were for the purpose of making satellite observations which would yield new information, all applications being in the monitoring category. The total value of benefit estimates for the four applications which could be considered valid is $179 million. A benefit estimate of $78 million for more effective use of producer options by wheat farmers was considered valid, but is not included in the summary of benefits since it depended on provision of improved weather forecasts rather than on observation of earth resources.

Type of Application	Number of Applications		Amount of Valid, Non-overlapping Estimates
	Total	With Valid Estimates	
Monitoring	10	4	$179,000,000

SUMMARY OF INTERPLAN'S FINDINGS FOR ALL INFORMATION CLASSES OF APPLICATIONS

INTERPLAN reviewed benefit estimates for a total of 85 applications in all three classes of information. Of these, applications for 43 were considered to have valid benefit estimates, totaling about $1.4 billion in gross annual benefits to the United States. The distribution of applications and benefit estimates across the three information classes and two application types is:

ITEM	CLASS OF INFORMATION						
	SAME		BETTER		NEW		
TYPE OF APPLICATION	MAP-PING	MONITOR-ING	MAP-PING	MONITOR-ING	MAP-PING	MONITOR-ING	TOTAL
Gross Annual Benefits ($millions)	26.9	27.3	134.6	986.8	-	179.0	1354.6
Number of Applications with Valid Estimates	11	6	5	17	-	4	43
Total Number of Applications	16	22	14	23	-	10	85

SECTION 3

THE APPRAISAL

The results of INTERPLAN's review (Section 2) of ten studies relating to the economic benefits to be obtained from Earth Resources Survey Satellite systems are used in this section to appraise:

1. The extent to which the findings of these previous studies are adequate indicators of the expected cost-benefit effectiveness of future operational Earth Resources Survey Satellites
2. The value of these previous studies to the ERS Program for directing R&D activities.

THE EXTENT TO WHICH THE FINDINGS OF THE PREVIOUS STUDIES ARE ADEQUATE INDICATORS OF THE EXPECTED COST-BENEFIT EFFECTIVENESS OF FUTURE OPERATIONAL EARTH RESOURCES SURVEY SATELLITES

General Appraisal

COST ESTIMATES. Early in the review it was observed that five of the ten studies could not be considered cost-benefit studies since estimates were made for either benefits or costs, but not both. Of the five studies where both benefits and costs were estimated only three (PRC R-1218, PRC R-1224, and GE) were of sufficient scope to be considered system cost-benefit analyses. None of these three, however, considered the total scope of the potential ERS system benefits.

However, a valid order-of-magnitude indication of the ERS system cost per satellite-year of $20-50 million was obtained from four studies where system costs were estimated. This estimated system cost per satellite-year includes estimates for R&D and data reduction, processing, and distribution but not the costs which may be incurred by the user in incorporating the information into his present activity. For some users (e.g., cartographers) these costs may be high. However, INTERPLAN concurs with the opinion of the NAS Summer Study Economic Panel that these costs should not be included in system cost estimates and agrees with the authors of the PRC R-1224 report

that such user costs should be considered part of the benefit analysis and estimated on an application-by-application basis. INTERPLAN concludes, therefore,that the system cost estimate of $20-50 million per satellite-year is an adequate prefeasibility indicator of future ERS system costs.

BENEFIT ESTIMATES. A general appraisal of the findings of the review of benefit estimates reveals that a number of difficulties are encountered in attempts to provide an adequate indication of the benefits which may be realized from the ERS Program. One difficulty is that of determining the extent to which benefit analysis can be used in evaluating applications in the various classes of information (same, better, new), and another difficulty is that of determining who is properly to be considered the benefactor and to what extent cost-benefit techniques can be applied in estimating the size of benefits which may be realized by these benefactors.

NASA's charter contains the broadest statement regarding the proper benefactors of NASA's efforts; these efforts are ". . . for the benefit of all mankind."* In appraising the results of the review, it is apparent that it is not possible to estimate fully the economic benefits which will be realized by such a broad base of users (to say nothing of the many non-economic benefits).

During the review, however, judgments were made by INTERPLAN on the extent to which user benefits can be estimated for applications in each class of information and the point at which such efforts become counterproductive. Similarly, judgments were made for each class of information on the extent to which applications in each information class could be subjected to analysis.

Based on these judgments used by INTERPLAN during the review, the following benefit estimates were considered valid and, hence, in the opinion of INTERPLAN the findings of past studies indicate that on the order of $1.4 billion in annual returns can be expected from the future ERS Program.

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*National Aeronautics and Space Act of 1958.

(Since in most cases INTERPLAN did not consider the world benefit estimates to be valid, this amount represents principally U.S. benefits.)

Valid Benefit Estimates for U.S. ($million/year)

Type of Application	INFORMATION CLASS			
	Same	Better	New	Total
Mapping	26.9	134.6	—	161.5
Monitoring	27.3	986.7	179.0	1193.0
TOTAL	54.2	1121.3	179.0	1354.5

If the sum of benefits considered valid by INTERPLAN is used in conjunction with the system cost per satellite year of $20-50 million, the potential cost-benefit effectiveness of the Program appears large.

In the following discussion these valid benefit estimates, as well as estimates for major applications which could not be considered valid, are appraised to determine the extent to which the valid benefit estimates shown above provide an adequate indication of the magnitude of future benefits which can be expected to result from the operational ERS Program.

Appraisal of Benefit Estimates for the "Same" Information Class of Applications

BASIS FOR THE APPRAISAL. In estimating benefits to be realized from this class of information there was no need to attempt to place a value on the information itself since the information to be obtained from the ERS satellite is assumed to be the same as is presently used. Rather, the benefit which was estimated is the potential savings which might be realized in an ongoing activity if information from the ERS Program were substituted for the information obtained by current information-gathering processes.

Although the applications in the "same" information class appear pedestrian when compared to some of the more imaginative ERS applications which can be visualized, benefit estimates for this class of information can be made with greater certainty than for the "better" or "new" information classes. Verifiable data on the current cost of performing the task is available for analysis, and the knowledgeable judgment of users presently engaged in collecting and disseminating the same kind of information can be utilized in formulating the estimates. Therefore, the extent to which benefit estimates for the "same" class of information can adequately indicate

the benefits which can be expected from the ERS Program is limited only by how thoroughly the studies have covered the potential user market.

APPRAISAL OF STUDY FINDINGS—$54 MILLION, ANNUALLY. In the studies reviewed, benefit estimates for mapping applications in the "same" information class were made for the following users: USDI, U.S. Mineral Exploration Industry, and U.S. Community of Professional Geographers.

Appraising these results INTERPLAN feels that the estimates for the mapping applications, viewed as a whole, are valuable but represent only a small portion of the potential users who may benefit from substituting satellite-acquired information for that gathered by conventional techniques. Also, the benefit estimates made for mapping applications in the "same" class of information were only gross benefit estimates. In no case were estimates made of the cost of reducing the satellite data in such a way that the output is, in fact, the same as now being used. The Summer Study Geodesy-Cartography Panel Report indicates (regarding satellite photography) that these costs may be substantial. For example, an investment of about $5 million is suggested for reconciliation of formats and focal lengths to current data-reduction instrumentation. In addition the Panel states:
"The significance of satellite photography as an economical data-acquisition system for cartographic end products rests almost entirely on quantitative considerations in terms of the large number of photographs obtainable in relatively short periods and the staggering wealth of information content in each single photograph. A major problem consequently is to develop the technology of data extraction, analysis, and processing. Each of these steps presents requirements incompatible with present mapping techniques. A representative list of initial research and development projects in support of the problem includes: automatic map compilation equipment, cartographic data banks (containing coastlines, road information, topography, vegetation, and the like) with automatic map data extraction, simplification, editing, and printing; and sophisticated pattern analysis and recognition techniques."

CONCLUSIONS. In reference to mapping, INTERPLAN concludes that a more comprehensive survey of the potential user market as well as the cost of necessary R&D for data reduction would have to be accomplished before the

estimates that were made for mapping tasks could be considered to be adequate indicators of the benefits which are to be expected from the operational ERS Program in providing the same mapping information now being collected by other means.

In reference to monitoring, INTERPLAN concurs with past studies which regard the major contribution of monitoring tasks of the ERS to be in providing "better" and "new" information, but with one important exception—that of monitoring pollution effects: air, water, and thermal. As discussed in the review,*the benefit estimates made in past studies (PRC R-1218 and Westinghouse) were based on information which must now be considered obsolete. INTERPLAN concludes, therefore, that an investigation of cost savings which might be realized in the current Environmental Protection Agency program through use of ERS information would also be required before the benefit estimates for monitoring applications in the "same" class of information could be considered to adequately represent the future effectiveness of the ERS Program in providing the same information now being collected by conventional means.

Appraisal of Benefit Estimates for the "Better" Information Class of Application

BASIS FOR THE APPRAISAL. Estimates of the benefits which will be realized from producing "better" information were found to be more difficult to make than similar estimates for the "same" information class. This is basically due to the fact that in order to make such an estimate, first the way in which more timely, more comprehensive, or more detailed information could be used has to be defined and, second, a judgment has to be made of the extent to which the resulting information could or would, in fact, be used.

The benefit estimates for this class of information represent the value which is added through use of information, and hence the size of these benefits can be expected to be much greater than the cost savings estimated for the "same" information class. Concomitantly, the benefits will probably require a longer term for realization.

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*Page 30.

The study results indicate that since potential users of the better information are now engaged in using similar information, the way in which the better information might be used and the extent to which action will be taken can be estimated reasonably well. The PRC R-1224 study's estimate of the additional hydropower which might be generated as a result of better long-term and short-term water inventory and demand forecasts is a case in point. Based on current dam management practices, the way in which better information would be used in reducing hedge and improving drawdown strategy, inter-reservoir coordination, and head efficiency could be defined and (in spite of the fact that a predictive model would be required before the information would be useable) the effects could be simulated for evaluation.

Since in this case the user group is organized, the extent to which the information will, in fact, be used depends more on technological developments (e.g., the "Moving Forecast Scale" of the PRC R-1224 study) than the degree of user participation in the program (which can be assumed), providing its use is shown to be cost effective.

However, when the primary users are a large body of independent agents (such as farmers), estimating the extent to which the information will be used is less certain. For example, in the PRC R-1224 analysis leading to benefit estimates for the more timely detection of wheat rust it was assumed that over a 20-year period U.S. farmer participation in a spray control program will increase from 10 percent in the first year to 90 percent in the sixth to twentieth year. A similar estimate for farmer participation in 15 selected wheat producing countries was 10 percent in the first year increasing to 90 percent in the seventeenth to twentieth year. Predictions such as these regarding the extent to which better information will be used can be made with less certainty than similar predictions for organized groups. Nevertheless INTERPLAN considers that agencies now disseminating similar information to these users are in a position to make these predictions with sufficient certainty that the resulting benefit estimates can be valid order-of-magnitude indicators.

Therefore, the extent to which benefit estimates for this class of information can adequately indicate the benefits from ERS satellites in providing better information depends on (1) how thoroughly the studies have covered the potential user market, and (2) how well the actions which can and will be taken by the proposed users have been anticipated.

APPRAISAL OF STUDY FINDINGS: U.S. BENEFITS—$1.1 BILLION, ANNUALLY. Appraising the results of the review, INTERPLAN feels that the estimates made in past studies for "better" information applications are adequate prefeasibility indicators of U.S. benefits which can be expected to result from the ERS Program in inproving upon the timeliness and quality of information. More applications were analyzed in this class of information than in other classes and large payoffs for several applications could be considered valid.

Three of the largest benefit estimates in this class of information, although they are judged to be valid order-of-magnitude estimates based on the material presented, are subject to uncertainties which might be removed with a modest amount of additional work. They are: Expedite Exploration for Petroleum (application 39), Minimize Flood Damage Losses (application 55), and Improve Forecasts of Irrigation Water Availability (application 59).

The order of magnitude of the Westinghouse gross estimate of benefits to be realized from expediting the exploration of petroleum ($125 million) is partially confirmed by the Summer Study Report discussions. However, the documentation of the Westinghouse estimate is scant, there are discrepancies between the text and accompanying text figures, and the user costs which may be incurred in order to utilize the information (which may be large) are not investigated.

The PRC R-1224 estimate for minimizing flood damage ($306 million) is derived from estimates of flood damage losses that would be averted in two specific North Pacific basins if the maximum flood stage were reduced by 2 feet. U.S. benefits were obtained by extrapolation of these results across all U.S. basins depending on the flood damage losses which were sustained in these basins. The fact that the flood control capabilities of the various basins were not considered and, hence, whether a 2-foot reduction in peak flood level could be attained exposes the estimate to uncertainty beyond the normal uncertainties which accompany any extrapolation. Since this application

was treated in much less depth than other aspects of the water management case and since the benefit estimate of $306 million is the largest single benefit which could be considered valid in the studies reviewed, INTERPLAN feels that reducing this principal uncertainty is warranted.

The PRC R-1224 estimate of irrigation benefits ($282 million) due to improved water management assumes 100 percent farmer participation in the program. Although estimates of the degree of participation by independent individuals are subject to some uncertainty, good estimates can be made by informed experts (as was apparently done in the PRC R-1224 wheat rust case where 90 percent farmer participation after 6 years is predicted). Therefore, in view of the size of the estimate, removal of this uncertainty is felt to be warranted.

APPRAISAL OF STUDY FINDINGS: WORLD BENEFITS. For the most part, INTERPLAN feels that it is counterproductive to make estimates of worldwide benefits, either on the basis of extrapolation from U.S. data or on the basis of a consensus of world-user opinion. An exception to this opinion is made, however, for the case of the potential worldwide benefits which might be attained from improved water management. Dam building and irrigation schemes have been the preoccupation of emerging nations for the last two decades. In spite of the billions of dollars that have been expended (much of it from U.S. sources), it is difficult to find a single water project that has performed as expected. While the failures can be attributed in part to inadequate or unrealistic planning, unquestionably a large proportion of the problem rests with the lack of adequately trained management personnel and lack of adequate hydrological information.

It is felt that valid estimates of benefits from a possible substitution of automated dam management assistance and improved hydrological information could be made if the appropriate sources (such as hydrology experts in the World Bank) are consulted and that these estimates would constitute a significant improvement in indicating the non-U.S. benefits which might be realized through the Program. Naturally similar estimates could be sought from water management experts in the developed countries to complete the coverage of potential worldwide users.

CONCLUSIONS. Although an adequate prefeasibility indication of the future effectiveness of the program has been made for the "better" information class of applications for U.S. benefits, INTERPLAN concludes that an improved indication might be gained if the cited uncertainties in three of the largest estimates were removed. Also, a significant indication of potential world benefits would be gained if consideration were given to the global user market for improved water management information.

Appraisal of Benefit Estimates for the "New" Information Class of Applications

BASIS FOR APPRAISAL. Obtaining new information on earth resources is the most exciting area of the Earth Resources Survey Program—and also the area where the largest payoffs, economic and noneconomic, are expected. It is simultaneously the area where estimation of the full benefits which may be realized is subject to the greatest amount of uncertainty.

Since the information does not currently exist, areas where the synoptic satellite capability can be used to produce new kinds of information had to be postulated first. Then the ways in which the information might be used, and by whom, had to be hypothesized and the effect of these postulated uses evaluated on a case-by-case basis.

Whether the ultimate users are independent agents or organized groups, an inestimable number of unanticipated and interrelated actions—with both positive and negative results—are likely to be taken in response to new information. Thus the extent to which the estimates will actually indicate the eventual benefits to be realized from new information depends partly on how well the cases selected represent the probable uses of the information. After probable uses are isolated, further uncertainty exists in estimating how the postulated users will act, and, further what benefits they may derive.

The possibility of obtaining new information on earth resources is related, for the most part, to the synoptic perspective which the satellite platform offers. For the first time truly global information can be obtained and disseminated to potential users, worldwide. Estimating the extent to which these worldwide potential users will act upon postulated new information

of a global nature is, therefore, a natural temptation presented to any investigator. INTERPLAN considers, however, that making estimates of the global benefits to be realized from new information is too speculative to yield order-of-magnitude indications. For this reason it is felt that estimates of benefits for this class of information should be restricted to examining how users in the United States might benefit, on a case-by-case basis, with the recognition that the results will be subject to many uncertainties and that adequate indicators may not be obtainable. Therefore, the extent to which benefit estimates for the "new" class of information can adequately indicate the benefits of ERS satellites depends upon (1) how well clear-cut and important uses for new information have been imagined and defined, (2) how thoroughly the studies have covered the potential U.S. user market, and (3) how well the actions which can and will be taken by proposed U.S. users have been anticipated.

APPRAISAL OF STUDY FINDINGS—$179 MILLION, ANNUALLY. Appraising the findings of the review, it is interesting to note that of the 85 potential ERS applications which were isolated in previous studies, only 10 could be considered in the "new" information class (i.e., dependent on the synoptic capability of the satellite) and of these 10, six refer to very similar applications for increasing the catch of the tuna or herring families of fish. Although the way in which the applications were classified by INTERPLAN is admittedly arbitrary, the fact that only about 5 percent of all the distinctly different applications (which were defined well enough to be included in the comparisons) depended upon the synoptic capability of the satellite is an indication of how limited our ability is to comprehend the full potential of ERS observations.

The combined effect of limitations in imagining uses for new information and the number of potential uses which cannot be estimated with certainty is that the estimates which were obtained for this class of information ($179 million) are likely to vastly underestimate the future benefits of the operational ERS Program in providing new information.

The fact that the traditional systematic cost-benefit analysis is difficult to apply to the "new" information class of applications does not imply

that thinking about these problems should be discontinued. Quite to the contrary, it should be encouraged because it is an undisputed fact that the quest for "new" information has been the driving force of human progress. Most of the possessions and values of modern man are due to that quest.

Within the realities of life, certain elements of the cost-benefit analysis are most helpful in increasing the efficiency of human search for new information. When a proposal is prepared, or a study is carried out, it is probable that progress is being made in the following areas:

- Novel areas of applications (of the ERS system, for example) are isolated
- An idea of the value of the novel application is formed
- Technological needs for novel applications are perceived, conceptualized, and eventually defined
- An operational system is conceptualized
- Costs of development and operation of a novel system are estimated.

The last (i.e., cost) area is of paramount importance to NASA, prospective user agencies, and individual users. If the order of magnitude of the cost involved becomes known, a reference point is established for judging whether it is "worthwhile" to develop a novel system, even if the eventual payoff cannot be estimated. This kind of reasoning was behind the financing of Columbus, Watts, Edison, and the nuclear power reactor. It should be noted that in all these cases the costs of the venture (system) were estimated quite accurately in advance; the technology needed was specified and—when and where needed—invented; the magnitude of benefits arising from the new ventures was invariably underestimated by several orders of magnitude, and beneficiaries were never correctly identified. Also, the reasons originally isolated for proceeding with the venture were invariably wrong but, as experience indicates, the incidental benefits were sufficient to cover costs of development and operation within, say, two decades.

While reasoning by analogy is dangerous, historical evidence appears to point out that the "new" information class of ERS applications might best be approached from the side of costs (as distinct from benefits). Once costs are estimated (e.g., on the basis of system requirements for technology) the

judgment of NASA, user agencies, and the financial and industrial community should be relied upon with respect to whether an investment (equivalent to the estimated cost) should be made to enable the exploitation of a novel application. Both the future ERS Program and NASA's moon exploration are cases in point.

CONCLUSIONS. It has been pointed out in Section 2 that many of the valid estimates were based on expert opinions. In the class of "new" information where a rigorous analysis of potential benefits is not possible, the use of expert opinions to obtain a "feel" for the ventures' costs and, possibly, benefits should therefore be encouraged.

NASA recognized the value of collective expert judgment in its sponsoring of the NAS Summer Study. In a similar way, potential users whose fields of interest are covered in the "new" information class should be given the opportunity to express their professional opinions on whether the presently conceptualized systems for acquiring new information are worth implementing. Such a collection of opinions may well be the best and only way to obtain reasonable effectiveness indicators.

Past studies have concentrated more on estimating the benefits (however imaginary) of new information. Since estimating the costs of acquiring new information can be accomplished with much greater certainty, a more valid indication of effectiveness may be obtained by starting first with cost estimates. INTERPLAN concludes therefore that the initiation of a modest, organized collection of such opinions, starting with an assembly of well-reasoned and complete cost estimates would result in an improved indication of the effectiveness of the ERS Program in producing new information.

THE VALUE OF THE PREVIOUS STUDIES TO THE ERS PROGRAM IN DIRECTING R&D ACTIVITIES

Basis for the Appraisal

In formulating a basis for appraising the value of past studies in directing R&D activities, INTERPLAN attempted to visualize what kind of information an ERS manager of R&D would require in order to implement an orderly R&D program. It was concluded that the R&D manager should have (1) a knowledge of

what applications are desired by the real world of users, (2) an estimate of the economic benefits expected from these applications, and (3) a definition of the technological developments which are required for each of the applications and their cost and related time-frames. Then, if the relative importance of the required technological developments (in realizing the benefits from each application) were expressed quantitatively as a function of the total benefits to be gained, the values which are assigned to the developments in each application could be combined for those technological developments which are common to more than one of the applications.

Thus, a priority ranking based on the economic value of technological developments (as opposed to a priority ranking of applications) could be evolved which could be used in conjunction with development costs, time-frames, and other noneconomic criteria to optimize the effectiveness of the R&D program. The degree to which past studies have provided this information was, therefore, considered to be the basis for appraisal.

Discussion of Study Findings

The concept that the optimum cost-effectiveness of the future ERS system could best be realized by isolating common user requirements was implicit in many of the past studies and explicitly stated in several.*

**Westinghouse*, page 6-2: "Obviously, a commonality and centralization of the interpretive function must be identified to minimize the total cost over an expected mix of application traffic."
IBM, Vol. D, pages D-1 and D-2: "Heretofore, experiment programs have been compiled from among candidate experiment ideas submitted by interested investigators. This approach builds the experiment program 'from the bottom up,' . . . The diverse and far reaching potential of the ORL experiment program dictates that a more comprehensive and explicit procedure be used for identifying and interrelating the significant ORL experiments. The principal output of this study is a user-oriented framework for experiment synthesis which meets these requirements."
Summaries of Panel Reports, Summer Study, pages 61 and 62: "Two approaches [the separate-discipline approach and the common-use approach] were taken to costing the hypothetical system proposed by the earth-resources disciplines . . . . The total quantifiable savings that result from replacing the separate-discipline approach with the common-use approach over the 7-year time frame is approximately $83 million . . . . In many instances these common-use systems increased the range of coverage and information obtainable for several of the disciplines. Thus, such qualitative benefits appears to augment the quantitative savings in cost obtained by the common-use approach."

The way in which economic studies can provide this information to the ERS R&D manager is alluded to in the IBM and Summer Study reports, suggested in the PRC R-1218 study, and most clearly demonstrated in the PRC R-1224 and GE studies. The first three studies indicate that the applications desired by users need to be isolated first and that when estimates of benefits for these applications are made, commonalities in the equipment required to satisfy the applications can be determined and used in optimizing the benefits from proposed operational systems. In order to permit optimization of the ERS system cost-benefit effectiveness, however, information is needed on more than estimated benefits from applications and the cost of equipment development. This additional information is described for specific applications in the PRC R-1224 study in the form of relevancy matrices which show the chain of information requirements which link the benefits to be realized from an application to the technologies which must be developed in order to provide the information (see Figure 2).

As shown in Figure 2, in order for benefits to be realized by prospective users, forecasts (or predictions) on various earth conditions are needed before improved management decisions can be taken. This predictive information, in turn, is derived from information on earth resources, earth physics, and meteorological phenomena acquired by sensors which measure the status of these phenomena. A similar chain of information requirements is described in the GE study for the four cases examined by GE, although the terminology differs from that of the PRC study.

INTERPLAN concurs with an opinion expressed on this aspect of the PRC R-1224 work: "Through the use of modeling techniques and multi-stage relevance matrices, an analytical format is developed for synthesizing and examining future operational Earth resources survey systems. The procedure also gives promise of utility in planning the extensive R&D efforts which must precede most operational systems."*

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*Robert A. Summers, "Systems Analysis Techniques in Earth Resources Satellite Systems Planning," presented at the Sixth International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Michigan, 14 October 1969.

									MANAGEMENT DECISIONS AND BENEFITS	LEGEND
	2	2	2	3	3	2	2		DRAWDOWN-REFILL STRATEGY	1 SUFFICIENT
	3	3	2	3	3	3	2		INTER-RESERVOIR COORDINATION	2 MAJOR CONTRIBUTION
	3	3	2	3	2	2	2		HEAD EFFICIENCIES AND HEDGE	3 CONTRIBUTION
	2	2	3	3	2	3	4		FLOOD CONTROL	4 SLIGHT CONTRIBUTION
	2	2	3	2	3	3	4		IRRIGATION	
										SENSORS
PREDICTIONS	SEASONAL SNOW-MELT RUNOFF	SEASONAL RAIN-FALL RUNOFF	STREAM FLOW: SURFACE	STREAM FLOW: GROUND WATER	STREAM FLOW MAXIMA	STREAM FLOW MINIMA	LOAD VARIATION (POWER)		MEASUREMENTS	MULTISPECTRAL TELEVISION	MULTISPECTRAL SCANNER	MULTIBAND RADAR	MICROWAVE RADIOMETER	INFRARED SCANNER
	3	3	2	2	2	2	4		STREAMFLOW (ANTECEDENT)	3	3	3		
	4	2	2	2	2	3	4		RAINFALL	3	3/4	2	3	3
	2	4	3	2	3	3	4		SNOW AREA - HIGH LEVEL	2	2/3	2/3	3	3
	3	4	3	3	2	3	4		SNOW AREA - LOW LEVEL	2	2/3	2/3	3	3
	2	4	3	2	3	3	4		SNOW WATER EQUIVA-LENT - HIGH	2/3	2/3	2/3	3	3
	3	4	3	3	2	3	4		SNOW WATER EQUIVA-LENT - LOW	2/3	2/3	2/3	3	3
	3	4	3	3	3	3	4		SNOW TEMPERATURE - HIGH		2		3	2
	4	4	3	3	3	3	4		SNOW TEMPERATURE - LOW		2		3	2
	3	4	3	3	3	3	4		SNOW ALBEDO - HIGH	2/3	2			
	4	4	4	4	3	3	4		SNOW ALBEDO - LOW	2/3	2			
	3	3	3	3	3	3	2		AIR TEMPERATURE		2		2	2
	3	3	3	3	3	3	4		GROUND TEMPERATURE		2		2/3	2
	3	2	2	2	2	3	4		SOIL MOISTURE	2/3	3		2	2/3
	2	2	2	3	3	3	4		EVAPOTRANSPIRATION		3		2/3	2/3
	4	3	4	4	4	4	2		CLOUD COVER	1/2	1/2			1/2

Figure 2. Sequential matrices relating sensors to water management decisions and benefits.
SOURCE: PRC R-1224, Volume I, page 29.

INTERPLAN also believes that the GE attempt to quantify the interdependencies between predicted benefits, types of information to be acquired, measurements, sensors, and system capabilities (as expressed in the "system effectiveness model"*) is a significant contribution to further elucidation of the way in which information of value for R&D planning purposes can be acquired from economic studies.

If these efforts are extended so that the technological developments (predictions, measurements, and sensor requirements) common to all of the major applications isolated in past studies are related quantitatively to the benefits which will be realized from their use in specific applications and these results are pooled (after being weighted appropriately) across all the applications considered, an ERS System Effectiveness model could be developed which could be used to optimize the cost-benefit effectiveness of the ERS Program. The optimum R&D strategy, however, is influenced by a number of factors in addition to optimum cost-benefit effectiveness. For example:

1. Some benefits (or returns) probably should be realized reasonably early in the program—they must be readily identifiable and of a size sufficient to justify continued expenditure of R&D funds.
2. The long-term return should be kept in mind and a balance maintained between high payoff developments requiring significant effort (and longer development periods) and lower payoff developments yielding quickly obtainable benefits.
3. The benefits should be time-phased in such a way that they are spread fairly evenly over the envisioned program period—there must be no long succession of "lean" years.
4. Efforts should be carried on in developing more than one technology—the program must be flexible enough to permit shifting the development emphasis as new facts come to light.

If constraints such as these were incorporated into an ERS system effectiveness model (by weighting the benefits from technological developments according to the importance of short-term return versus long-term return, developing constraints on the spread of benefits across time, etc.) a multi-criteria

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*GE, "Final Report on the Space/Oceanographic Study," (Section 6), March 1968.

decision model would be evolved which should be of great value in directing R&D activities.

If these models were developed at an early stage, i.e., before or concurrent with the ERTS series, then as experimental results are obtained the degree of technological attainment could be measured against the technology required in various applications and appropriate adjustments made in the paramters of the model. The optimum system of proposed operational applications which resulted from the initial ranking of technological developments could thus be updated to reflect the current technological state of the art.

Appraisal of Study Findings

Since the scope of many of the studies reviewed was limited, the benefit estimates made for most of the applications were not supported by a definition of the chain of informational requirements which link the user benefits to technological developments. Therefore, integration of the benefit estimates for use in R&D planning is not presently possible. Further, since each study was designed to accomplish different, suboptimum goals—even in instances (PRC and GE studies) where informational requirements were defined in detail —additional work would be required to integrate the findings at the ERS system level in spite of the fact that many required technological developments are common to several of the applications analyzed, e.g., measurements of wind direction and velocity, and surface temperature. (It should be noted that the realization of benefits from many of the applications depends on having information on meteorological phenomena as well as earth resource phenomena.)

In view of these facts, the findings of past studies (in spite of the excellence of some) do not provide much total system guidance for determining the scope and direction of R&D efforts. Their main (and significant) value lies in the fact that the studies indicate those earth resources that potential users feel are worthwhile observing, the type of information which appears to be most desirable to acquire, and the order of magnitude of the benefits which can be expected if various applications are implemented.

Conclusions

INTERPLAN concludes from this appraisal that although an important data base has been acquired through past work on the benefits to be realized from ERS applications (and to a lesser extent on technological requirements), this data base would be of greater value for planning R&D activities if an extension and supplementation of past work were performed. Specifically, a multi-criteria decision model for R&D planning would have to be conceptualized and the information required by the model defined. (The relevancy matrix concept of the PRC R-1224 study and the system effectiveness model of the GE study provides an excellent starting point for this work.) Supplementary work would then have to be undertaken, at least on high pay-off applications, to obtain information on technological requirements if they have not already been documented. Finally, the findings would have to be integrated through use of the multi-criteria R&D decision model and updated as experimental results are obtained.

SECTION 4

THE APPROPRIATE NATURE OF FUTURE STUDIES

FUTURE ECONOMIC STUDIES

The findings of the ten economic studies reviewed and appraised by INTERPLAN constitute an impressive data base of information on the estimated costs of and benefits from the future ERS Program. Two of the system studies (PRC R-1224 and GE), in addition to providing valuable cost-benefit information, contain important insights into the way in which the findings of past economic studies can be of value in giving guidance for R&D activities at the ERS system level.

In view of these accomplishments it is concluded that no further detailed cost-benefit studies are required at the prefeasibility level of development. Rather, it is concluded that a modest amount of additional work in certain areas to supplement the findings of past studies would:

1. Improve the adequacy of estimates of benefits to be realized from the future ERS Program
2. Permit integration of the major findings of past studies to provide an indication of ERS system effectiveness as well as to provide guidance for R&D planning.

Supplementary Economic Studies

The seven areas where INTERPLAN considers that supplementary effort is warranted are:

1. Cartography—including at least geologic, land use, and geographic maps. To extend the scope of potential users covered by the benefit estimates for applications 1-11 and to provide a more detailed definition of required technologies and their costs (see pages 22-23, 64-65).
2. Monitoring pollution effects—including air, water, and thermal. To update the benefit estimates of the PRC R-1218 and Westinghouse studies (applications 23 and 24) and to provide descriptions of the technologies required (see pages 26-27, 30-31, 65).

3. Expediting exploration of petroleum and minerals with improved mapping capability. To extend, in greater depth, the benefit estimates of the Westinghouse study (application 39) and to provide a more detailed definition of required technologies and their costs (see pages 35, 37-38, 67).
4. Minimizing flood damage losses through improved water management. To extend, in greater depth, the benefit estimate of the PRC R-1224 study for application 53 (see pages 40, 67-68).
5. Increasing the yield from irrigated land due to improved water management. To extend, in greater depth, the benefit estimate of the PRC R-1224 study for application 57 (see pages 41, 68).
6. Improving worldwide water management. To extend and analyze in greater depth world benefits for applications 55 and 56 of the PRC R-1224 study (see pages 40-41, 68-69).
7. Uses for " new" information. To extend, in scope and depth, the benefit estimates of past studies and to define required technologies (see pages 69-72).

A more specific description of work to be accomplished is shown in Table 9 and amplified by notes at the end of this section. The amount of effort which INTERPLAN suggests could be devoted to each of these areas is indicated in terms of a suggested funding level and duration of effort. The total funds suggested are $300,000, extending over a period of 12 months.

System Integration of Findings—The R&D Decision Model

As a result of the appraisal of the value of past studies in providing direction to R&D activities, INTERPLAN concludes that the development of an ERS system-effectiveness model and a related multi-criteria R&D decision model would permit integration of the economic findings of past studies. The results of this integration would give an improved indication of ERS system effectiveness and also would permit use of the large data base of information which has been acquired in the rational formulation of the ERS R&D program. INTERPLAN concludes that a study should be initiated to develop these models (prior to and concurrent with the ERTS series) and that the information acquired from past and supplementary studies be used as inputs to the models during the study. The objectives of the study would be to:

Table 9. Suggested future supplementary economic studies.

STUDY AREA	SUG-GESTED COST ($000)	SUG-GESTED DURATION (months)	WORK TO BE ACCOMPLISHED					
			BENEFIT ESTIMATES			TECHNOLOGICAL DEVELOPMENTS (see Note 1)		
			APPROACH*	OBJECTIVE	USER-RELATED COSTS	PREDICTIONS**	MEASUREMENTS**	SENSORS
1. Cartography, including at least geological, land use and geographic maps	60	9	Same (see Note 2)	Provide a comprehensive coverage of potential U.S. user market	Estimate for promising uses	Define for each type of map	Supplement, where required, findings of past work	Supplement, where required, findings of past work
2. Monitoring pollution effects, including air, water, and thermal	50	9	Same (see Note 2)	Cover potential uses for National (EPA), state, and local pollution agencies	Estimate for promising uses	Define for potentially cost-effective uses	Define for potentially cost-effective uses	Define for potentially cost-effective uses
3. Expediting exploration of petroleum and minerals with improved mapping capability	60	9	Better—informed judgment (see Note 3)	Define specific map uses for U.S. industry and document benefit estimate for each use isolated	Estimate for promising uses	Define for promising uses	Define for promising uses	Define for promising uses
4. Minimizing flood damage losses through improved water management	30	6	Better—analysis (see Note 3)	Improve upon PRC R-1224 extrapolation of Columbia Basin benefits to U.S. benefits	None	None	None	None
5. Increasing the yield from irrigated land due to improved water management	10	3	Better—informed judgment (see Note 3)	Improve PRC R-1224 estimate by including farmer participation rates	None	None	None	None
6. Improving worldwide water management	50	9	Better—informed judgment (see Note 3)	Obtain worldwide benefit estimate through concensus of worldwide user opinion (based on PRC R-1224 estimate for U.S. benefits)	None	None	None	None
7. Uses for "new" information resulting from global observations	40	12	New (see Note 4)	Search for and assess new applications	Estimate for uses isolated	Define for uses isolated	Define for uses isolated	Define for uses isolated

*The study approach suggested is defined in the notes referenced.
**Refers to terminology used in the PRC R-1224 study.

1. Define quantitatively the relationship (at least for several major application areas) between the total dollar benefits expected from the application and the technological developments ("predictions," "measurements," and sensors) required. The techniques developed in the GE study should be evaluated for possible use during the course of work.
2. Describe the "necessary and sufficient conditions" which would constitute the constraints on pooling the benefits which are expected from technological developments common to several application areas.
3. Develop appropriate sets of equations to describe the effectiveness of the ERS system and to simulate the effect of various R&D decisions on the size of economic returns which can be expected if the returns are optimized with respect to the desired relative importance (to NASA) of short-term returns, long-term returns, balanced output over time, spread of R&D resources among developments, and/or other relevant economic and noneconomic criteria.
4. Prepare formats for use in future studies that define the specific cost and benefit information and technological information to be acquired so that the findings of these studies can serve directly as inputs into a total system integration (see Note 5).

This effort (described in greater detail in Appendix C) might be completed in 24 months at a cost of about $200,000.

FUTURE NONECONOMIC STUDIES

Although this study was limited to economic considerations, four important noneconomic areas appeared to be so closely related to the findings of past economic studies that it was concluded that future studies in these areas would be warranted. The four areas are:
1. Elucidation of noneconomic criteria
2. Education of potential users
3. Conceptualization of the organizational form and management of an operational ERS system
4. Development of a Biospheric Model.

Elucidation of Noneconomic Criteria

It is recognized that the R&D manager in assigning funding priorities to various potential technological developments must consider more than economic criteria. INTERPLAN concludes, therefore, that an effort should be sustained to isolate, elucidate, categorize, and evaluate the impact of non-

economic criteria on the ERS Program (see Note 6). These criteria should be studied methodically and the estimated effects should be incorporated into both R&D and budgetary planning processes. INTERPLAN suggests that one or two such studies could be initiated, each not to exceed about 9 months and $40,000.

Education of Potential Users

Many of the studies reviewed stress the importance of early education for future users of ERS information. INTERPLAN agrees with this opinion and believes that some prospective users should be sufficiently motivated to either voluntarily participate in NASA-sponsored studies for applications in their sphere of interest or to undertake these studies independently if NASA's full support is offered. During the course of such work, these strongly motivated potential users would not only become fully aware of ERS potentialities and problems but they may also uncover new applications and/or provide further technical guidance in the light of their own expertise. Therefore, it is concluded that it might be worthwhile for NASA to offer some seed money to government agencies (including foreign governments), industrial organizations, or research organizations who will also assign matching funds to the effort.

For example, an oil company might be induced to study in depth the ERS applications which might reduce petroleum exploration costs, or the World Bank might be willing to examine the potential value of ERS observations in its hydroelectric or irrigation projects (see Note 7). NASA might offer, say, specialized information on ERS capabilities and technical personnel and might conduct educational conferences, etc., but the bulk of the study would actually be financed by the potential users. If potential users participate in such a program, the dollar base of the R&D manager might be broadened and findings might be obtained which are unobtainable in any other way. INTERPLAN suggests that money might be offered initially to sponsor two studies for a total cost of $50,000 to be completed within 12 months.

Conceptualization of the Organizational Form and Management of an Operational ERS System

Although a truly operational system is several years away, INTERPLAN believes that it is not too soon to commission a study which would consider possible organizational forms and the management of an operational system. These operational aspects of the system were not considered in any of the studies reviewed. This study would consider such topics as the advantages and disadvantages of a governmental agency operating the system versus a private company (e.g., NOAA versus COMSAT), foreseeable organizational and administrative costs, outlays for ground facilities, user education, etc. During the study a *pro forma* profit and loss statement would be formulated covering about the first 5 years of operation.

It is suggested that the first phase of the study should concern an operational system but be limited to U.S. benefits only. The second phase of the study, to be conducted only after the experimental results from the ERTS series are known, would conceptualize an operational ERS system with global benefits. Many intricate political problems of an international nature would have to be carefully thought through. For example, many policy questions will have to be explored on the availability, dissemination, and price structure of information derived from the ERS observations.

The objective of the second phase of the study would be to postulate certain worldwide objectives (e.g., increased agricultural production, improved water management, minimization of damage and disaster losses) and to examine how an ERS system could best contribute to implementing these objectives. (The unique synoptic capability of the ERS system and additional benefits which might be secured due to economies of scale should also be considered.)

The second phase of the study of the worldwide ERS system would be based on the information acquired in past studies as well as the additional information which would be acquired in the supplementary studies discussed in this section. Since it appears advisable to include the experimental data from the ERTS series, the second phase of the study probably would not be initiated before the end of 1972.

The cost of the Phase 1 effort is estimated at about $100,000 and should be completed within about 12 months.

Development of a Biospheric Model

INTERPLAN's appraisal of the value of past studies for directing R&D emphasized the immediate value these findings might have in isolating which technological capabilities should be developed, i.e., the development aspects of the R&D program. INTERPLAN also feels that as the ERTS series progresses and "predictions" on earth conditions are quantified a data base may be established which would be of value to a longer-range research aspect of the R&D program, i.e., construction of a biospheric model which simulates biospheric conditions and, hence, can be used to formulate improved "predictions" on these conditions.

Although it is far too early to describe with any clarity the elements of a biospheric model, INTERPLAN believes that an initial attempt to provide such a description might be made by concurrently studying changes in the status of those earth resources, earth physics, and meteorological conditions which are monitored in various earth observation programs. Such a study would attempt to isolate basic relationships between the changes in observed conditions which could be used to predict future changes in these conditions.

A representative example of the sort of relationship which might emerge is the recently discovered correlation between unusually warm basins in the Pacific (located as a result of ocean buoy measurements) and the abnormally cold winter weather conditions which have been experienced recently in nearby land masses. Naturally the work would include a study of man-caused changes in biospheric phenomena. For example, the effect of the creation of large reservoir basins on increased earthquake activity or the effect of global pollution on specific ecologies might be studied.

Although the initial raw data on earth resources from which these relationships might be isolated will not be available until the first experimental ERS results are obtained, INTERPLAN feels it is not too soon to initiate a modest attempt to outline the kinds of data required and the approach which might be used in the search for fundamental relationships and to describe, in skeletal outline, the elements of the model. Since meteorological phenomena are now being monitored, the raw data from the current meteorological model could serve as a factual basis for the study.

Figure 3 shows how the biospheric model might fit into the earth-observation/user-decision cycle. It is noted that if such

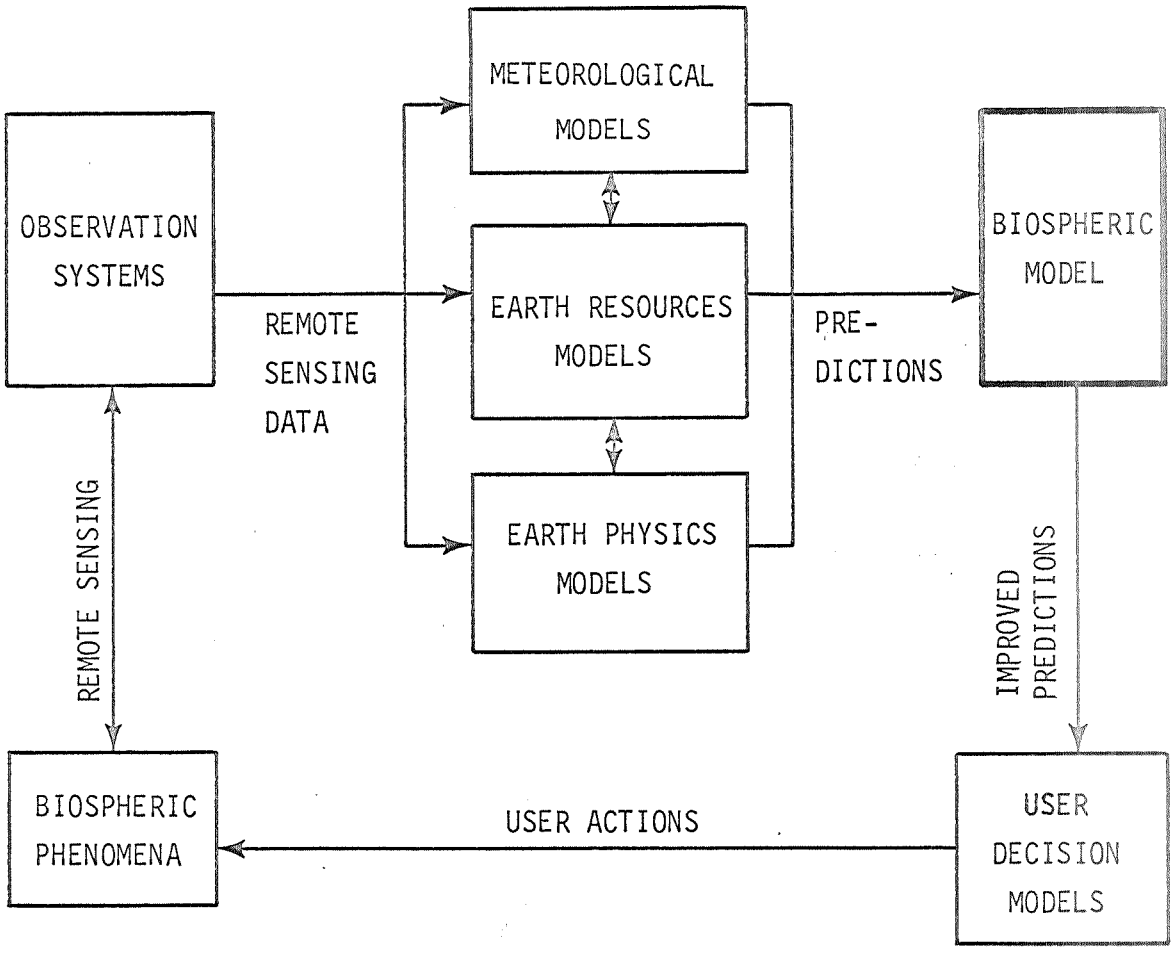

Figure 3. The biospheric model in the earth-observation/user-decision cycle.

a model were developed in the ERS Program, there might also be some ramifications of possible significance to the organizational form of the operational Program. That is, the output of the model might be generalized in such a way that all users were served through provision of information of general (as well as specific) use to all—the way in which weather forecasts are now furnished. In this way the Program might be organized as a public (or worldwide) service ". . . for the benefit of all mankind," rather than as a service of value to special users.

It is suggested that the initial effort might cost about $120,000 and would be completed in about 12 months. This effort would use data from the meteorological model as a starting point for conceptualizing the skeletal model and would prepare the ground for utilization of ERTS data in future work.

SUMMARY OF SUGGESTED FUTURE STUDIES

As a result of the review and appraisal, INTERPLAN concludes that a modest amount of additional effort to supplement and extend the findings of past studies would be of value to the ERS Program. These future studies and their suggested funding and duration are:

SUGGESTED FUTURE STUDIES	SUGGESTED FUNDING ($000)	SUGGESTED DURATION (months)
ECONOMIC		
1. Cartography	60	9
2. Monitoring Pollution	50	9
3. Expediting Petroleum and Mineral Exploration	60	9
4. Minimizing Flood Damage	30	6
5. Increasing Yield from Irrigated Land	10	3
6. Improving Worldwide Water Management	50	9
7. Uses for "New" Information	40	12
8. ERS System-Effectiveness Model and a Decision Model for R&D Planning	200	18
TOTAL ECONOMIC	500	

SUGGESTED FUTURE STUDIES	SUGGESTED FUNDING ($000)	SUGGESTED DURATION (months)
NONECONOMIC		
9. Elucidation of Noneconomic Criteria	40	9
10. Education of Potential Users	50	12
11. Conceptualization of the Organizational Form and Management of an Operational ERS System	100	12
12. Development of a Biospheric Model	120	12
TOTAL NONECONOMIC	310	
TOTAL	810	

NOTES

NOTE 1. The definition of technological requirements and estimation of development costs should be at least as detailed as in the PRC R-1224 and GE studies.

NOTE 2. INTERPLAN suggests that the benefits estimated for the "same" information class of applications be derived so as to represent the savings which can be realized by users through substituting ERS observations as a source of information for conventional sources. At the prefeasibility level of development these estimates should (1) be made on the basis of the informed judgment of the potential users, (2) include the magnitude of related user costs which probably will be incurred, and (3) be limited to the savings realizable by U.S. users only.

NOTE 3. INTERPLAN suggests that the benefit estimates for the "better" information class of applications be derived so as to represent the incremental value which can be expected from the use of improved information in an ongoing activity where the present use is definable. These estimates should include user-related costs. The choice of estimating technique (either informed judgment or analysis) should be made on an application-by-application basis. However, when the realization of benefits depends on the joint participation of a body of independent agents, estimates of the anticipated degree of participation should be based on informed judgment. At the prefeasibility level of development, INTERPLAN suggests that the

estimates of benefits be limited to potential U.S. users (with the exception of applications in the area of water management, as noted in Section 3).

NOTE 4. In view of the uncertainties in estimating benefits for the "new" information class of applications, INTERPLAN suggests that estimates of the value of the applications be approached from a consideration of costs. As applications for uses of new information are isolated, the technological development requirements should be defined in sufficient detail so that a comparison can be made (at the system level) of the new application requirements which are common to applications in the "same" and "better" classes of information. The incremental cost of developing special technologies, in addition to related user costs, should then be presented to experts in the application area (in the United States and worldwide) for a consensus on whether the value seems to be worth the estimated additional cost for development and implementation.

NOTE 5. Separate formats would be prepared for the analysis of "same," "better," and "new" information classes of applications (or an alternative method for classifying different types of applications may be evolved). The studies shown in Table 9 should be conducted in conformance to these formats so that the utility of the formats are tested and verified before being applied to new areas.

NOTE 6. The major noneconomic criteria might be isolated, for example, by considering the contribution ERS observations could make toward solving pressing problems in the United States in the early 1970's such as unemployment, the national balance of payments, societal health and safety, etc.

NOTE 7. A growing interest within the World Bank in potential uses for satellite information is noted. The Special Projects Office and the Regional Directorates (especially the Southeast Asia Directorate) have indicated an interest in several ERS applications. Therefore, there may be a possibility that NASA and the World Bank might undertake this work jointly.

APPENDIX A

EARTH RESOURCES SURVEY PROGRAM

INTRODUCTION

This appendix contains a brief description of the present ERS Program to aid the reader's understanding of this report, as well as to summarize INTERPLAN's understanding of the current ERS Program.

PURPOSE AND OBJECTIVES OF THE ERS PROGRAM

The ERS Program (a component of NASA's Earth Observations Program) is concerned with mapping and monitoring the earth's environment and its natural resources using remote sensors placed in aircraft and space platforms. The data obtained by these means can be applied in such disciplines as oceanography, hydrology, agriculture, geology, forestry, and geography, thus contributing to a more efficient land use, to improved utilization of the earth's natural resources (both land and sea), and to more effective control of the atmospheric environment. The specific objectives of the ERS Program are*:

"1. Define real world problems to which space technology can make a beneficial contribution.

2. Determine performance of remote sensors, establish signature recognition criteria.

3. Develop sensors, subsystems, and experimental spacecraft, along with efficient means for getting into orbit.

4. Determine scope and configuration of operational systems (including spacecraft, aircraft, and ground segments).

5. Develop data handling techniques.

6. Assist user agencies in developing a community of experts prepared to utilize space-derived remote-sensing data."

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*NASA, Office of Space Science and Applications, Earth Observations Program Review, Washington, D.C., November 1969, page 6.

STRUCTURE AND FUNCTION OF THE ERS PROGRAM

The ERS Program is divided into three components—the Aircraft Program, the Spacecraft Program, and Supporting Research and Technology.

The Aircraft Program

This component of the ERS Program is being used to evaluate remote sensor systems and to obtain multispectral data of earthly phenomena for analysis by users in the various disciplines. The aircraft are used as platforms to carry combinations of sensors for evaluating their utility and their performance over specified instrumented test sites on the ground. Two types of remote sensors are being evaluated: those that "'illuminate' targets and receive reflected radiation and those that operate as passive monitors of natural and cultural emissions or reflections from the earth's surface." The ERS Aircraft Program uses two types of aircraft—the low-to-medium altitude aircraft (the Convair 240 which ranges up to 15,000 feet and the Electra P-3A and Hercules C-130B which range up to 25,000 feet) and the high altitude aircraft (the RB-57F which ranges up to 60,000 feet). The RB-57F carries a variety of sensors (an RS-7(IR) infrared scanner-imager, IR spectrometer and radiometer, two RC-8 metric and six Hasselblad multiband cameras) on a pallet, while microwave sensors are carried in the nose of the aircraft. The Hercules C-130B will carry a 24-channel multispectral scanner, and two metric and six Hasselblad cameras. A mobile ground-truth vehicle will also be utilized as part of the Hercules C-130B sensor verification equipment.

The Spacecraft Program: Unmanned

The Earth Resources Technology Satellites (ERTS) comprise a major portion of the spacecraft program; six satellites (A, B, C, D, E, F) are now in various stages of planning and construction.

ERTS-A AND B. Funding for the ERTS-A and B satellites has been approved and the ERTS-A is scheduled for launch during the first quarter

of 1972. These satellites are designed to determine the usefulness and the operating efficiency of the system, to flight test the sensors, and to provide data to the user community in order to develop useable information such as plots of geological features, coastal areas, snow and ice cover, etc. The principal performance and design characteristics of the ERTS-A and B have been specified as a sun-synchronous, circular, near-polar orbit (496 n mi), an orbit-adjust capability, an attitude control of less than 0.7°, an onboard data recording facility, 20-minute sensor operation per orbit, wideband data transmission (20 MHz, S-band), a payload capacity of 350 pounds, a spacecraft weight of approximately 1200 pounds, and the ability to repeat coverage every 17 days during a lifetime of 1 year. The proposed sensors to be included in the ERTS-A payload include three high-resolution return beam vidicon TV cameras (with a resolution of 300-600 feet per line pair, a coverage of 100x100 n mi, and green, red, and near IR spectral bands), a 4-channel multispectral point scanner (with resolution of 440 feet per line pair, a 100 n mi swath coverage, and green, red, near-IR, and IR spectral bands), and data collection equipment.

ERTS-C AND D. It has been proposed that the film recovery satellites, ERTS-C and D, function during the lifetime of ERTS-A and B to provide a correlative base for the lower-resolution electronic return data of ERTS-A and B. The data from ERTS-C and D is expected to provide an early high-quality record of the earth's features, a benchmark to be used in observing earth changes on later flights, and an early mapping capability. The cameras proposed for use in the ERTS-C and D are similar in resolving power to those used in the Apollo spacecraft but would have, in addition, metric fidelity.

ERTS-E AND F. While ERTS-A and B and the film recovery satellites ERTS-C and D will focus primarily on surveying land (and adjacent water areas) targets, ocean surveys will be the main objective of ERTS-E and F flights. Although the spacecraft and subsystems proposed are similar to ERTS-A and B, the sensors and orbit of ERTS-E and F would be optimized for surveying the ocean. It is expected that the ERTS-E and F satellites will acquire information on sea state, ocean surface temperature, ocean

color, ocean currents, sea ice, coastal processes, and other sea-oriented phenomena. To gather this type of data it is proposed that ERTS-E and F carry a thermal infrared scanner and radiometer, an imaging spectrometer, and a passive microwave scanner. Oceanographic research ships are expected to provide ground-truth information.

SMALL APPLICATIONS TECHNOLOGY SATELLITES. The Small Applications Technology Satellites (SATS) are proposed to supplement the ERTS series in order to provide an early, rapid space-flight testing of sensors and subsystems. These satellites will test critical subsystem improvements and establish the reliability and utility of advanced sensors. Since the proposed spacecraft are small (Scout size) and experiments basically single-purpose, missions will be simplified and equipment can be optimized for the particular experiment carried.

The Spacecraft Program: Manned

The ERS Program also employs manned spacecraft for acquiring data via remote sensors. Early color photographs taken on Mercury, Gemini, and Apollo flights demonstrated the potential of remote sensing from space platforms and led to the first controlled multispectral experiment (S065). This experiment was performed from Apollo 9 using four Hasselblad cameras—one with color IR film and three with black and white film used with filters to match the near-IR, green, and red bands proposed for the ERTS television camera. The experiment confirmed the choice of bands for the TV camera, provided data for user analysis, and also provided initial information on attempts to evaluate the utility of simultaneous spacecraft-imagery and of sequential aircraft imagery for use in resources inventory.

The 1972 SKYLAB series of the Manned Orbiting Research Laboratories (MORL) (a related program) also will carry, as a part of its equipment, an Earth Resources Experiment Package (EREP) which will collect data on earth resources. This equipment will consist of six rigidly mounted 70 mm multispectral cameras with six different filter/film combinations,

four black and white and two color (S-190); one infrared spectrometer with a 0.4 to 15.5 micron range (S-191); one 10-band multispectral scanner (S-192); and one K-band radiometer-scatterometer-altimeter (S-193/194).

Supporting Research and Technology (SR&T)

SENSOR-SIGNATURE RESEARCH. Efforts in sensor-signature research have been directed towards establishing quantitative relationships in remote sensing analysis by using spacecraft imagery concurrently with aircraft and ground data. Research has also been going on in the area of automatic classification of the earth's features. In this area, digitized data obtained from a multispectral scanner has been used quite successfully as a means of identifying crops, and shows potential for use in classifying soils, identifying terrain classes, and recording coastal processes such as sedimentation flow patterns.

INSTRUMENTATION RESEARCH AND DEVELOPMENT. The Instrumentation Research and Development area of SR&T develops and procures instruments for data management and for remote sensing of earth resources. For instance a significant recent development is that of the 24-channel multispectral scanner. The large number of channels in this scanner will provide researchers with the ability to classify different objects with better accuracy which will enable the equipment to be optimized for the specific types of data desired.

ADVANCED STUDIES. The primary objective of the Advanced Studies segment of SR&T is to provide insights into the future nature of the ERS Program—future data requirements and future data utilization experiments—so that a research program can be planned to effectively meet these needs and allocate funding.

BUDGET AND FUNDING

Out of NASA's total estimated budget of $2.7 billion for FY 1971, moneys set aside for space applications total approximately $180 million; of this amount approximately $60 million will be earmarked for the ERS

Program. Within the ERS Program, in FY 1971, the ERS Aircraft budget will be some $10 million; ERTS-A and B, some $30 million; and ERTS-C and D and Supporting Research and Technology, less than $20 million. The ERS funding is planned to increase to some $100 million annually by 1975, including ERTS follow-on projects. In addition, user agencies (USDA, USN, ESSA) will jointly spend some $5 million on ERS-oriented activities.

APPENDIX B

DOCUMENT-BY-DOCUMENT REVIEW

PART I: DISCUSSION

The following ten documents were reviewed by the INTERPLAN team:

1. Stanford Research Institute, SRI Project M-5465, Sept. 1965
2. International Business Machines Corporation, Federal Systems Division, NASw-1215, February 1966
3. Cornell University, The Center for Aerial Photographic Studies, December, 1967
4. Westinghouse, Defense and Space Center, 7145A2, Dec. 1967 (Final Summary Report, Feb. 1968)
5. Planning Research Corporation, PRC R-1218, Jan. 1968
6. General Electric Company, Missile and Space Division, March 1968
7. Mathematica, Grazing Land Management, September, 1968
8. Mathematica, Estuarine and Coastal Management, June, 1969
9. Planning Research Corporation, PRC R-1224, November, 1969
10. Summer Study on Space Applications, National Academy of Sciences, National Research Council, Division of Engineering, 1969.

Eight documents (2, 3, 4, 5, 6, 7, 8, and 9) were cited in the contractual agreement; two additional documents (1 and 10) were reviewed at the suggestion of NASA's Technical Director of the study since they contain valuable background information and, hence, merited inclusion in the review and appraisal.*

At the conclusion of the document-by-document review, annotated bibliographies of the ten documents were prepared (see Part II) covering the following items of information:

1. Purpose of the Document
2. Nature of Contents

*In addition to these ten documents, INTERPLAN read (but did not formally review) the document "Report of the Task Force Syracuse/NASA Project on Non Economic Criteria for Evaluating Satellite Application Projects," May 1969, which was received by INTERPLAN shortly before the conclusion of this study.

3. Summary of Findings

4. Document Conclusions

5. Document Recommendations

Comments on the major strengths and weaknesses of the documents are also included in each bibliography.

After completing the synoptic review and appraisal (Sections 2 and 3), team members then assessed these ten documents with respect to the contribution each made in indicating the economic benefits which can be expected to result from the future operational ERS. This contribution was evaluated as a function of both the scope of the study and the validity of the benefit estimates (amenability of the subject matter to economic analysis and the adequacy of the analysis performed). For each document, therefore, both contributing factors, i.e., scope and validity of findings, were assigned a score from 1 (least) to 10 (greatest) by concensus of the team members. In view of the highly subjective nature of the rating, no attempt was made to weight the importance of validity vis-à-vis scope—instead, a simple product of the two factors was used as an overall document rating. These scores and their products are given in Table B-1.

Table B-1. INTERPLAN's rating of the contribution each document made in indicating the economic benefits expected from ERS.

Document No.	Document	SCORE		Product
		Validity	Scope	
1	SRI M-5465	1	6	6
2	IBM NASw-1215	2	8	16
3	Cornell	1	8	8
4	Westinghouse 7145A2	8	5	40
5	PRC-1218	*	*	*
6	General Electric	8	3	24
7	Mathematica (Grazing)	**	**	**
8	Mathematica (Estuaries)	8	2	16
9	PRC-1224	8	8	64
10	National Academy Summer Study	4	8	32

* Combined with Document No. 9
**Combined with Document No. 8

In the opinion of the review team, the PRC and Westinghouse studies made the greatest direct contribution toward indicating the expected economic benefits to be obtained from ERS, although all the studies contributed to increasing the team's understanding of earth resources benefit analysis. The validity of the findings was judged equally high in the Westinghouse, PRC, Mathematica, and GE studies in spite of the fact that each used a different approach in estimating benefits. In the Westinghouse study, estimates of benefits were based on the mature judgments of experienced people; in the PRC studies, estimates were mainly evolved analytically through case studies; in the Mathematica studies, estimates were based on refined, deductive analysis; and in the GE study, a combination of mature judgment and analysis was employed. The consensus of the team (reflected in the scores given) is that, at the prefeasibility level of analysis (if properly executed), valid order-of-magnitude estimates can be obtained using any of these approaches.

Because the reports reviewed differ so much—in scope, purpose, volume, context, and presentation—no satisfactory way was found to express in one score the consensus of the team in balancing the value, for example, of the managerial wisdom of the National Academy Summer Study against the strikingly obvious technical and costing competence of the General Electric study, the academic finesse (and concomitant lack of technical depth) of the Mathematica studies, or the analytical thoroughness of the PRC studies. Also no way was found to appraise in one score the thoroughness and coverage of reports whose study methods varied from conducting a variety of interviews in one agency (Westinghouse) to a more speculative but analytical coverage (PRC). The team's opinions also were swayed unavoidably by the quality of presentation and report readability. Thus, the PRC and GE reports were a real pleasure to read—some of their passages (especially in executive summaries) were examples of the best professional report writing ever encountered by the team.

PART II: ANNOTATED BIBLIOGRAPHIES

DOCUMENT NO. 1

Stanford Research Institute. PRIORITY ANALYSIS OF MANNED ORBITAL RESEARCH APPLICATIONS. SRI Project M-5465. September 1965.
Volume I. Summary Report. 25 pp.
Volume II. Detailed Reports by Individual Study Teams. 196 pp.
Project Manager: John G. Meitner

CONTRACTING AGENCY

Prepared for the Douglas Aircraft Company, Inc., Missiles & Space Systems Division as part of a contract for NASA.

PURPOSE OF THE DOCUMENT

To define U.S. and world benefits derived from a manned orbiting research laboratory (MORL).

NATURE OF CONTENTS

The report is a collection of loosely integrated individual reports which evaluate a NASA-compiled list of MORL candidate experiments. A table is presented in which various experiments are graded according to criteria which are developed in the report. The report contains a section on the evaluation of social benefits to be derived from MORL experiments and three sections on economic benefits to be derived from an operational MORL.

Economic benefits are discussed and/or estimated for the purpose of identifying high payoff applications of a MORL which might operate concurrently with unmanned ERS and aerial photography programs. The three sections on economic benefits deal, respectively, with benefits associated with land resources, ocean resources, and meteorology. In addition, appendix material is presented which contains (1) a mathematical model for estimating the value of rainfall forecasts to agriculture,

(2) a case study for evaluating rainfall forecasting in India, (3) a brief review of electromagnetic sensing technology, and (4) the use of radar as a meteorological tool.

SUMMARY OF FINDINGS

- It appears that 95 percent of the total worldwide economic benefits (almost $700 million) from the use of MORL result from two ocean applications, fish mapping and ship routing.

- Benefits to the United States represent less than 20 percent of the total ocean applications benefit.

- Relatively minor immediate benefits are foreseen for land applications, i.e., agriculture, forestry, geology, and hydrology. This is due to some extent to the ability of aircraft and unmanned ERS to perform certain missions with equal or greater efficiency.

DOCUMENT CONCLUSIONS

- The greatest social benefit from MORL will accrue from enhanced national prestige. This goal is best served by fundamental research experiments and missions which hold the promise of major economic returns (hundreds of millions of dollars per year).

- A priority of MORL missions can be established; the highest ranking category contains selected fundamental research experiments and earth-oriented application experiments arranged in order of decreasing anticipated economic payoffs.

- The great value of a MORL—in comparison with an unmanned orbital station—resides (a) in the vast complexity of tasks a man can perform reliably, e.g., research and (b) in the efficiency of a man in collecting only pertinent information, again during the research phase. A man provides a unique recognition element and any response times involved in manned experiments are equal to real time. The reliability of satellite experimentation that is initially very complicated can therefore be provided by manned missions at less than the prohibitive costs involved in unmanned missions.

DOCUMENT RECOMMENDATIONS

- A MORL should be launched with priority given to those missions which will conduct fundamental research experiments as well as those designed to yield economic returns but also have social and political value.

STRONG POINTS

1. Addresses the subject of evaluating the incremental benefits to be derived from manned observation satellites vis-à-vis unmanned observation satellites or aircraft platforms.

WEAK POINTS

1. The report is poorly organized.
2. The depth of benefit analysis varies greatly, and many of the estimates are undocumented.
3. A wide range of topics is addressed with little integration of the findings.

KEY WORDS

MORL, Manned Orbital Research, Social Benefits, Economic Benefits, Earth Oriented, Land Resources, Ocean Resources, Meteorology, Electromagnetic Sensing, Radar.

DOCUMENT NO. 2

International Business Machines Corporation, Federal Systems Division. ORBITING RESEARCH LABORATORIES (ORL) EXPERIMENT PROGRAM. Contract No. NASw-1215. February 1966.

Volume A. Framework for Synthesis. 29 pp.

Volume B. Part I - Agriculture/Forestry. 127 pp.
Part II - Geology/Hydrology. 143 pp.
Part III - Oceanography/Marine Technology. 80 pp.
Part IV - Geography. 120 pp.
Parts V to XIII (These documents do not treat earth-oriented applications and thus were not reviewed.)

Volume C. Guidelines for Comprehensive Flight Program. 33 pp.
Annex 1. 158 pp.
Annex 2. 192 pp.

Volume D. Summary of Results. 30 pp.

Volume E. Bibliographical References for Illustrations and Tables. 29 pp.

CONTRACTING AGENCY

The study was undertaken for NASA.

PURPOSE OF THE DOCUMENT

To present a framework for synthesizing a meaningful earth-orbital experiment program for the National Aeronautics and Space Administration.

NATURE OF CONTENTS

Particular goals of earth observation were identified in Agriculture and Forestry, Geology and Hydrology, Oceanography and Marine Technology, and Geography. Earth observation applications to aid in attaining these goals were then identified in terms of knowledge requirements. First-order estimates were then made of the phenomena to be observed and experimental equipment packages were specified for individual applications.

Multiapplication equipment packages were then synthesized which would take advantage of common requirements with regard to instrumentation and orbital paths.

U.S. and world benefits which might result from implementing the applications were also estimated. A total of 50 earth-related applications were discussed: 15 in Agriculture and Forestry, 12 in Oceanography and Marine Technology, 11 in Geography, and 12 in Geology and Hydrology. It should be noted that benefits were not estimated for all of these areas and that, in some cases, several applications were aggregated under one benefit estimate.

Two types of benefits were cited: savings (through reduction in annual costs over present collection methods) and improvements (through total increased yield accruing from improved techniques over a period of several years).

SUMMARY OF FINDINGS

- Estimated benefits resulting from use of a satellite survey system for four earth disciplines are:

	World ($million)		U.S. ($million)	
	Annual Savings	Long Term	Annual Savings	Long Term
Agriculture/Forestry	130	11,000	26	840
Geology/Hydrology	620	6,000	170	2,500
Oceanography/Marine Technology	800	7,000	350	3,500
Geography	33	800	9	100

DOCUMENT CONCLUSIONS

- "The functional analysis approach [the process of synthesizing equipment packages around particular applications and then developing multiapplication packages to take advantage of the use of particular equipments for several individual applications] developed and applied in the study establishes a workable framework for synthesizing a cohesive manned earth orbital experiment program."

DOCUMENT RECOMMENDATIONS

- Relative to the use of the methodology developed in the study, it was recommended that "the function analysis progress (sic) should be deepened by the extensive participation of scientists and engineers expert with the crucial problems and requirements of the individual S/T [scientific and technological] areas."

- "Processing and dissemination of the large quantities of information to be obtained from ORL is a fundamental problem which should receive early consideration . . . . Effective use of the data requires that channels of information flow be established with all prospective users, including agencies such as the Department of Agriculture and the U.S. Geological Survey and their counterparts in foreign nations which may wish to participate in the program."

STRONG POINTS

1. Discusses a method for developing integrated instrument packages and orbital paths which will satisfy the requirements for making observations across a wide range of applications in several disciplines.

WEAK POINTS

1. The benefit estimates in most cases are unsupported by analysis, documentation, or reference to expert opinion.
2. Benefits which are designated as improvements are cited in such a way that they cannot be translated into annual benefits.

KEY WORDS

Agriculture, Forestry, Geology, Hydrology, Oceanography, Marine Technology, Geography, Atmosphere, Communications, Navigation, Traffic Control, Flight Program, Food, Transportation, Mineral Resources, Wastes, Weather Forecasting, Weather Modification, Air Pollution, Remote Sensing, Apollo Systems, Biomedicine, Operations Techniques, Spacecraft Subsystems, Extra-Vehicular Engineering.

DOCUMENT NO. 3

Cornell University, The Center for Aerial Photographic Studies. POTENTIAL BENEFITS TO BE DERIVED FROM APPLICATIONS OF REMOTE SENSING OF AGRICULTURAL, FOREST, AND RANGE RESOURCES. December 1967. 120 pp. Project Manager: Donald J. Belcher

CONTRACTING AGENCY

The document was prepared for NASA under terms of a U.S. Department of Agriculture Economic Research Service contract.

PURPOSE OF THE DOCUMENT

To indicate the magnitude of potential benefits to the United States and the world from remote sensing of agricultural, forest, and range resources.

NATURE OF CONTENTS

The report presents a general overview of the state of the art and potential applications for remote sensing in the fields of agriculture, range management, and forestry. Three main subject areas are covered:

1. The capabilities of various sensor types
2. Capabilities, operations, and cost of aerial (i.e., aircraft) sensing
3. Applications of remote sensing.

Much of the technical discussion is oriented to aerial sensing. Current costs of aerial survey in the United States are quoted, and broad estimates are made for the cost of performing worldwide remote sensing missions using jet aircraft as the platform.

General areas of application are discussed in which remote sensing would be useful, but benefits were not estimated for these areas. Estimates of benefits were made, however, for many specific applications.

The coverage of the report relative to these specific applications and benefit estimates can be summarized as follows:

	Agriculture	Range Management	Forestry	Total
No. of Applications Listed	117	72	71	260
No. of Benefit Estimates	64	34	28	126

There is also a general discussion of benefits and benefit estimating and an appendix wherein the topic of economic multipliers is discussed. A format is developed for the evaluation of benefits and costs (development, operations, data acquisition, and user application). This format is not used, however, in the analysis of the potential applications.

SUMMARY OF FINDINGS

- The eight most promising *general areas* for the application of remote sensing are:

1. Resource evaluation and planning
2. Rural transportation development
3. Better distribution of food on a worldwide basis
4. Improved education
5. Soil classification and mapping
6. Mitigating disaster problems
7. Detection of new plants resistant to disease and insect damage
8. Veterinary medicine research.

- Total worldwide benefits which are attributable to *specific applications* are of an order of magnitude of $100 billion annually. Of this total, approximately $50 billion accrue in range management, about $40 billion in agriculture, and about $2 billion in forestry. The six specific applications for which the largest benefits were estimated are:

1.	Soil classification (range management)	$25 billion
2.	Rural roads (agriculture)	$15 billion
3.	Weather modification (range management)	$10 billion
4.	Locating irrigable areas (range management)	$10 billion
5.	Insect and disease damage control (agriculture)	$10 billion
6.	Soil mapping (agriculture)	$ 5 billion

- The total cost of initially photographing 31 million square miles of the world's arable range and forest lands by jet aircraft is estimated to be $15 million.

- Six jet aircraft are sufficient to provide regular aerial survey services for the world's croplands, ranges, and forests at an annual cost of some $30 million.

- To be useful in most agricultural applications, remote sensing data must be interpreted and placed in the users' hands within 20 to 30 days. The information must be made available in a still shorter time for applications which deal with the prevention of damage.

DOCUMENT CONCLUSIONS

- There are numerous potential applications for remote sensing which will result in major economic benefits.

- It will take time (at least until 1975) to develop satisfactory sensors.

- Black and white photography is presently the most technologically advanced sensor used in remote sensing. Color photography is second.

- Radar scanning holds great promise for the future but at present is difficult to interpret, is degraded by bad weather conditions, and the equipment is heavy and requires a large power supply.

- Infrared sensing is useful in many areas (especially in forestry). Although the technique currently lacks reliable ground calibration for use in sensing vegetation, it is highly promising.

DOCUMENT RECOMMENDATIONS

- Introduce jet aircraft into the field of aerial photography; expand the scope of such photography.

STRONG POINTS

1. Imaginative collection and listing of existing and potential applications for remote sensing.

2. Informative, although qualitative, comments on the possibilities and limitations for remote-sensing techniques.
3. Listing of some 120 knowledgeable individuals in the fields covered by the report.
4. Informative descriptions of aerial photography capabilities in the United States.
5. Good bibliography.

WEAK POINTS

1. No background material is presented to support the benefit estimates.
2. Benefits are not uniquely attributable to satellite-derived information.
3. Little emphasis is placed on current USDA activities.
4. Difficult to read because of incorrect page insertion and binding.

KEY WORDS

Aerial Photography, Remote Sensing, Sensors, Infrared, Photography, Data Acquisition, Agriculture, Forestry, Rangeland.

DOCUMENT NO. 4

Westinghouse Electric Corporation, Defense and Space Center. EROS APPLICATIONS BENEFIT ANALYSIS. 7145A 2.
Final Report. December 1967. 140 pp.
Final Summary Report. February 1968. 23 pp.

CONTRACTING AGENCY

The study was performed for the Geological Survey, U.S. Department of the Interior.

PURPOSE OF THE DOCUMENT

To identify a methodical, defensible set of specific applications for which an early satellite could be proven cost-effective.

NATURE OF CONTENTS

The document is devoted primarily to estimating benefits which would accrue from the use of EROS to agencies within USDI, to certain other state and federal government operations, and to private operations which are related to USDI activities. In addition, the parameters of the proposed EROS system are defined,* an illustration is presented of the sensitivity of benefits to resolution and frequency of observation, and certain criteria are presented for obtaining data (sun angle, etc.).

An important part of the report is Appendix A which contains a collection of estimates which are based on interviews, primarily with USDI personnel. Estimates are cited of benefits from 30 applications. These estimates are presented as a function of ground resolution and/or frequency of observation. In the body of the report these applications and

*A pictorial format which is the equivalent of 9"x9" hard-copy simultaneous imagery in two spectral bands covering 100x100 miles with 100-foot ground resolution. Coverage is $\pm 50^\circ$ latitude, 17-day frequency of observation.

benefit estimates are then arranged in a matrix format where the columns correspond to major USDI task areas: water, energy, environmental hazards, human resources and support, land, and food and timber. The rows of the matrix correspond to the level of activity to which particular applications apply: objective definition, applied research, planning, government operations, and private operations. The benefits to USDI accrue mostly in the research and planning areas.

Appendix B is a summary table where 69 applications are allocated among 10 USDI user agencies (without benefit estimates). Appendix C presents a method for calculating sun angle.

SUMMARY OF FINDINGS

- USDI would realize about $70 million in annual gross benefits from EROS imagery.
- Total annual gross benefits to government and private operations (including USDI benefits) are estimated to be about $538 million annually.
- It was not found possible to develop a suitable general questionnaire to obtain reliable benefit estimates.
- At the time of writing it was found impractical to develop cost estimates for allocation against gross benefits because the data processing and dissemination activity is not defined.

DOCUMENT CONCLUSIONS

- A massive centralized data processing activity is required to exploit EROS capabilities. There should be no manual processing or human interpretation.

DOCUMENT RECOMMENDATIONS

- A study should be made which examines in depth one or more of the "mature" applications which have immediate economic leverage. (For example, applications providing benefits to farmers producing on Bureau

of Reclamation irrigated lands are more "mature" than those which aid a research geologist.) This study should be a complete cost-benefit study with particular emphasis on the data-processing and interpretation system.

- The role of the EROS Program Office should be continued and strengthened within USDI as a communications medium among the other Bureaus.

STRONG POINTS

1. The benefit estimates are based on the opinions and judgments of knowledgeable USDI officials who are very familiar with the potential applications.
2. The credibility of the estimates is enhanced by reference to ongoing expenditures or other economic indicators.

WEAK POINTS

1. There is no cost information.
2. There is little comparison to alternative systems.

KEY WORDS

EROS, Space, Sensors, Systems, Mapping, User Education, Cost-Benefit Study.

DOCUMENT NO. 5

Planning Research Corporation. A STUDY OF THE ECONOMIC BENEFITS AND IMPLICATIONS OF SPACE STATION OPERATIONS. PRC R-1218. January 1968.
Volume I. Summary. 41 pp.
Volume II. Cost/Benefit Methodology. 69 pp.
Volume III. Case Studies. 258 pp.
Project Manager: Allen H. Muir

CONTRACTING AGENCY

The document was prepared for the National Aeronautics and Space Administration.

PURPOSE OF THE DOCUMENT

To develop a comprehensive and consistent methodology for the definition of satellite information gathering and dissemination systems and the economic evaluation of such systems.

NATURE OF CONTENTS

The general and specific areas of application for satellite-derived data which were analyzed in this report are listed below, with those five applications which were subjected to intensive case studies designated by asterisks:

Agriculture:	1. Crop inventory and yield - rice*
	2. Survey for new agricultural land
	3. Crop stress - wheat rust*
Natural Disaster:	4. Forest fire detection
Forestry:	5. Diseases and infestation of forests
Oceanography:	6. Increased harvest of marine life*
	7. Iceberg-dangers monitoring
	8. Improved nautical charting
	9. Economic ship routing by monitoring sea state

Health:	10.	Solid-waste detection and management
	11.	Animal disease detection
	12.	Air pollution monitoring
	13.	Water pollution monitoring
	14.	Minimization of malaria by low-water control*
Hydrology:	15.	Water sources monitoring for power generation efficiency*
Geology:	16.	Survey geological features for fuels and minerals
	17.	Monitor erosion, silting, etc.
Government Operations:	18.	Survey land for better tax assessment
Geography:	19.	Multiple benefits from improved mapping
Search and Rescue:	20.	Rapid location of distressed vehicles and personnel
Resource Management:	21.	Soil survey.

All candidate applications listed above (selected from a preliminary list of 234 possible applications) show identifiable potential benefits which are possible beginning in the early 1970's. Benefits were calculated over a 20-year period, 1970-1989. Noneconomic benefits are cited for the malaria case study, i.e., 50,000 lives and 6 billion sick days saved.

Most of the report is devoted to intensive cost-benefit case studies of the five selected applications. Each case study is devoted to a specific application within a more general candidate area (e.g., wheat rust control as a particular case of agricultural-stress applications). For each case, user needs for information are defined, a simple system synthesis is performed, and primary (direct) benefits are estimated. Considerable attention is also devoted to economic multipliers by which the total impact of the primary benefits on secondary sectors of the economy is assessed. Results of the specific case studies are extrapolated to cover other applications on a nationwide and worldwide basis. Of these five case studies, the cost of possible alternative systems was calculated for all but number 14, Minimization of Malaria. The other

sixteen applications are also analyzed although not through the method of intensive cost-benefit case study.

SUMMARY OF FINDINGS

- A total of about $60 billion in annual benefits may be realized through an operational earth observation satellite system operating in the time interval 1970-1989 (based on extrapolations from the 21 applications noted above). These are allocated as follows:

Agricultural Stress	$27,000 million
Agricultural Inventory/Yield	11,340 million
Forestry	9 million
Hydrology	373 million
Health	17,872 million
Oceanography	1,576 million
Natural Disasters	645 million
Search and Rescue	57 million
Government Operations	202 million
Geophysics	42 million
Geography	114 million

- Costs are small compared to benefits as exemplified by the findings of the following specific cases which were analyzed (costs and benefits over the time period 1970-1989 are cited in incremental millions of dollars discounted at 6 percent to 1970):

Application	Pro-rata System Costs*	Total Net Benefit	Cost of Alternative Aircraft System
1. Adjustment of Rice Yield	6	530	9
2. Wheat Rust Control	6	6029	12
3. Increased Yield of Tuna	7	3125	506
4. Reservoir Management	6	834	18
5. Malaria Control	5	1603	**

*Exclusive of space flight subsystem costs.

**Well in excess of all except application 3.

DOCUMENT CONCLUSIONS

- The cost-benefit studies clearly support the economic feasibility of satellite-assisted information systems.
- Development of the current (1968) state of the art will allow a system to be operational in the early 1970's if an R&D program is undertaken immediately.
- Case studies are required in the depth undertaken in PRC R-1218 to evaluate the technical and economic feasibility of an operational system.
- Commonality of equipment tends to be high for multiple applications.

DOCUMENT RECOMMENDATIONS

- A second, deeper iteration of a few cases should be carried out to provide firmer support to the operational concepts, to establish realistic R&D requirements, and to quantify additional socioeconomic impacts.
- Cost/benefit techniques should be extended to justify and manage space and space-related R&D having potential socioeconomic impacts.

STRONG POINTS

1. Comprehensive development of analytical methodology.
2. Well written report.

WEAK POINTS

1. Rigorous methodology is linked by undocumented and not always indisputable assumptions.
2. Cost-benefit calculations are not subjected to sensitivity analysis.
3. Order-of-magnitude estimates of billion-dollar benefits are quoted as univalues and not in terms of ranges of values.
4. Many unrealistic observations, statements, and assumptions are presented in descriptive material on potential applications.
5. Many extrapolations of findings appear to be tenuous.

KEY WORDS

Socioeconomic Trends, Cost-Benefit Study, Hydroelectric, Rice, Wheat Rust, Fishing, Malaria, Sensors, Orbital Parameters, Earth-Orbital, Forestry, Oceanography, Diseases, Wastes, Animals, Air Pollution, Water Pollution, Geology, Minerals, Mapping, Rescue, Geophysics, Geography.

DOCUMENT NO. 6

General Electric Company, Missile and Space Division. FINAL REPORT ON THE SPACE/OCEANOGRAPHIC STUDY. March 1968. 167 pp.
Project Manager: E. Ludwick

CONTRACTING AGENCY

The evaluation was prepared for the National Council on Marine Resources and Engineering Development.

PURPOSE OF THE DOCUMENT

To define the nature of useful oceanographic information which can be collected via satellite and to define the characteristics of satellite systems to collect this information. The information requirements are based on national policy as stated in the Marine Resources and Engineering Development Act of 1966. This policy has four basic goals:

1. Protection of health and property
2. Enhancement of commence, transportation, and national security
3. Rehabilitation of commercial fisheries
4. Increased utilization of (ocean) resources.

NATURE OF CONTENTS

The report contains a survey of existing information, a description of space/oceanography systems applications, and an evaluation of postulated systems. It describes particular applications relative to the basic goals and lists ocean phenomena which might be observed to implement these applications. The required quality of each observation is specified and satellite systems are synthesized to provide the specified data. System cost estimates are generated for these systems and the methodology is developed to evaluate space oceanographic systems.

SUMMARY OF FINDINGS

- Relative to the national policy noted above, the basic economic needs (worldwide as well as U.S.) which may be fulfilled by satellite systems pertain to:

1. Improvements in forecasting weather and ocean conditions
2. Enhancement of commerce and ocean shipping
3. Increased harvest from the sea.

- To meet these needs, four types of measurements are desired which may be obtained via satellite:

1. Sea-surface temperature
2. Wave characteristics
3. Phenomena which are related to the presence of fish
4. Ice/water interface.

- Within the existing state of the art the maximum system effectiveness relative to observations is 0.71 (on a scale 0 to 1). This is due to the degradation of observation capability due to darkness, cloud cover, etc.

- The maximum potential observation effectiveness was calculated for several exemplar systems. For example, a single, 3-sensor satellite will provide 0.28 effectiveness (at an annual cost of $42 million) and a system which employs two 6-sensor satellites will provide 0.69 effectiveness —almost the theoretical maximum for ocean applications—(at an annual cost of $108 million).

- The largest benefits cited are found for monitoring in order to maintain national quotas for fish catches. U.S. benefits for this application are estimated to range from $74 million to $215 million annually with corresponding global benefits of $900 million to $2 billion.

DOCUMENT CONCLUSIONS

- There are a number of data requirements concerning the ocean surface which can be satisfied through remote sensing by space-borne sensors.

- Significant technological and developmental effort has been and is being directed toward advancement of space oceanography.
- The state of the art in sensor technology is such that feasible systems may be postulated for space oceanographic applications.
- Utilization of space oceanographic systems can provide unique practical benefits.
- Continuing technical and investigative effort is required.

DOCUMENT RECOMMENDATIONS

- In general, the recommendations are for additional technical effort in satellite development and system definition to provide an operational capability in the 1970 "time period" and to continue these efforts to attain increased capabilities as time goes on.

STRONG POINTS

1. Expert, clear, and precise synthesis of space ocean technology, with an especially competent description of sensors.
2. Precise, elegant, and meaningful evaluation of oceanographic space systems including development and use of an imaginative, but realistic, system-effectiveness model.
3. Competent evaluation of system costs.
4. Clear documentation of all statements, quoted facts, and figures.
5. Well thought-out recommendations.
6. Readable report.

WEAK POINTS

1. Somewhat inconclusive discussion of the economic benefits of space oceanography.
2. Lack of an up-to-date statistical base used in the discussion of ocean fishing, off-shore petroleum and minerals search and exploitation, and ocean transport.
3. Reticence in the discussion of nontechnical and noneconomic global problems.

KEY WORDS

Space, Oceanography, Sea, Sea Food, Fishing, Sensors, Satellites, Effectiveness, Cost-Benefit Study.

DOCUMENT NO. 7

Mathematica. COST BENEFIT STUDY OF THE EARTH RESOURCES OBSERVATION SATELLITE SYSTEM: GRAZING LAND MANAGEMENT. (GLM) By Charles R. Frank, Jr. and Klaus-Peter Heiss. September 1968. 86 pp.

CONTRACTING AGENCY

The document was prepared for the Astro Electronics Division of RCA.

PURPOSE OF THE DOCUMENT

To present a cost-benefit analysis of U.S. grazing land management.

NATURE OF CONTENTS

The document contains an in-depth, detailed analysis of one general application of EROS*, general descriptions of the theory of measuring costs and benefits, and a review of current practices in grazing-land management. Three sources of satellite-derived benefits are postulated:

1. Savings relative to the cost of obtaining aerial photographs
2. Improved management through accurate prediction of grazing land conditions
3. Forecasts of forage growth.

Although these estimates are well supported philosophically, they are based only on the assumption of small percentage improvements over current practices. Costs for the satellite system are cited but without supporting cost analyses. The report also contains appendices on technical factors and cost effectiveness, methodology for measuring the value of the forage resource, and a discussion of discounting to present value.

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*EROS sensor data is taken to be multispectral television pictures with 100- to 200-foot resolution and 15 to 20 observations per year, not allowing for cloud cover.

SUMMARY OF FINDINGS

- U.S. benefits will be small with initial EROS systems ($100 to $300 thousand annually) but will increase to about $2.6 million as the system attains better resolution and other technical capabilities.

- World benefits will be much greater since the world's grazing lands are 10 times the size of those in the United States.

DOCUMENT CONCLUSIONS

- U.S. benefits from grazing land management application will not cover the cost of EROS (which is stated to be $17 million annually).

- Future satellites, to be most useful, require a stereoscopic capability and observation capabilities in as many as 12 spectral bands.

DOCUMENT RECOMMENDATIONS

- A more intensive study should be undertaken *after experimental satellites have been launched* to obtain better estimates of the possible benefits to grazing land management. In this study a sample survey would be made of potential users such as USDI and Forest Service officials and individual livestock producers.

- The earliest satellites should be designed with two functions in mind: to serve high payoff applications and to perform applied research. The results of the applied research may be used in the choice of design for later flights.

- Economic analysis should be done on a continuing basis leading to thorough cost-benefit analysis as the performance capabilities of a satellite become better known. This analysis should be devoted to singling out the *most likely* high payoff uses. Thorough cost-benefit analysis may be useful in the next design stage—after data from experimental satellites becomes available.

STRONG POINTS

1. The topic of satellite application to GLM is thoroughly discussed.

2. An elegant theoretical analysis of potential benefits of the EROS system for one application.
3. Highly logical and practical recommendations.

WEAK POINTS

1. The conclusions and recommendations are not clearly expressed. It is difficult to distinguish which of the conclusions and recommendations apply to the GLM application and which apply to EROS applications in general.
2. System costs are not explicitly treated.
3. Failure to grasp the full potential of the EROS-type system.

KEY WORDS

Cost-Benefit Study, EROS, Satellites, Land Management, Economic Analysis, Livestock, Photos, Forecasting, Forage.

DOCUMENT NO. 8

Mathematica. COST BENEFIT STUDY OF THE EARTH RESOURCES OBSERVATION SATELLITE SYSTEM: ESTUARINE AND COASTAL MANAGEMENT. By Edward J. Greenblat and Klaus-Peter Heiss. June 1969. 81 pp.

CONTRACTING AGENCY

The study was conducted for the Astro Electronics Division of RCA, Princeton, N.J.

PURPOSE OF THE DOCUMENT

To investigate applications and provide an analysis of possible economic benefits of the EROS system* in estuarine and coastal areas.

NATURE OF CONTENTS

A significant portion of the report is devoted to defining the nature of estuaries and to describing their importance. The nature of government authority over the estuarine zone is also defined in detail. A brief (inconclusive) section is also devoted to possible EROS applications in the estuarine zone.

In the section of the report that is devoted to measuring the economic benefit of EROS, the extent of U.S. and world estuarine areas are defined. The only benefit which is actually estimated is related to the savings which would accrue if satellite-derived data could replace data which would otherwise be gathered by conventional methods. An appendix is devoted to technical factors and cost-effectiveness of ERS.

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*"EROS is a Department of the Interior program for the utilization of space-craft technology in resources surveying and management. There is no EROS satellite as such. The satellites referred to are those of NASA's ERTS project. The first of these, ERTS-A, will carry three multispectral television cameras as its basic sensor. The term EROS is used for convenience only." It is implicitly assumed, however, that ground resolution of 100 to 200 feet is now available.

In the discussions, frequent reference is made to the Mathematica GLM study, Document No. 7. The cost-benefit methodology which was developed in the GLM report was applied in this study.

SUMMARY OF FINDINGS

- Seven of the ten largest metropolitan areas in the world border on estuaries. This has resulted in extreme changes in the estuarine environment—including pollution—which has diminished the value of the estuaries for other uses.

- In addition to being an important human industrial habitat, estuaries and marshlands are a primary base of living ocean resources.

- In the U.S., there is no government agency that has overall cognizance for estuarine management although many have responsibilities in the area. The interest of the Corps of Engineers appears to dominate.

- EROS satellites might be used to identify areas of marine growth and sources of nutrients and possibly to provide information relative to non-living resources in addition to monitoring pollution.

- It is difficult to calculate the probable marginal economic benefits to be derived from additions to currently available information.

- About 500 thousand square miles would have to be observed periodically in a national estuarine program. Only part of this is being observed currently on a systematic basis.

- Near-term U.S. gross benefits of about $600 thousand annually would increase to perhaps $21 million annually in 10 years as satellite performance increases and as the survey program becomes broader and more intensive. These benefits are savings which would accrue as satellite surveys replace aircraft surveys and as the scope and frequency of surveys increase over the next 10 years.

DOCUMENT CONCLUSIONS

- Estuarine and coastal applications do not justify, by themselves or in combination with grazing land applications (Document No. 7), the cost of an EROS system.

- The policy of designing satellite systems for early high pay-off may not be the best, since, at present, pay-offs are uncertain.
- The results derived from applied research, based on early EROS systems, may be used in the choice of design for later operational satellite systems.
- The most appropriate model for EROS-type design decisions is an uncertainty model in which information obtained in an early stage of the program provides inputs for the following design stage.

DOCUMENT RECOMMENDATIONS

- Isolate applications with a high "expected value" payoff.
- Design early EROS-type satellite systems for higher pay-off application and for applied research.
- In the design, consider trading off "better-information-later" for early but risky commercial pay-off.

STRONG POINTS

1. Well-documented descriptions of estuarine and coastal areas of the United States.
2. Elegant treatment of economic benefit analysis.
3. Logical conclusions.
4. Well written report.
5. Good bibliography.

WEAK POINTS

1. System costs are not explicitly treated.
2. Report is difficult to read because of poor organization and printing.
3. Lack of sufficient data to investigate the potential of ERS over a wide range of applications.

KEY WORDS

Cost-Benefit Study, EROS, Satellites, System Analysis, Estuaries, Sea Coast, Management, Ecosystems, Life Forms, Environmental Factors, Economic Values, Satellite Applications, Surveying, Fish.

DOCUMENT NO. 9

Planning Research Corporation. A SYSTEMS ANALYSIS OF APPLICATIONS OF EARTH ORBITAL SPACE TECHNOLOGY TO SELECTED CASES IN WATER MANAGEMENT AND AGRICULTURE. PRC R-1224. November 1969.
Volume I. Technical Summary. 51 pp.
Volume II. Technical Report (including separate Appendix volume). 853 pp.
Project Managers: Allen H. Muir and John F. Magnotti.

CONTRACTING AGENCY

The report was prepared for NASA in partial fulfillment of a request by the Bureau of the Budget.

PURPOSE OF THE DOCUMENT

To formulate and evaluate feasible future operational system concepts for applying satellite-based remote sensing to improve the management of specific water resources and agricultural activities.

NATURE OF CONTENTS

The document contains cost-benefit case studies for three ERS applications. These are in-depth studies which are supported by statistics and extensive analytical modeling to determine user requirements, system characteristics, benefits, and costs. Scenarios are used extensively in the modeling and for illustrative purposes.

The specific applications studied are: (1) water management of the Columbia River Basin to increase benefits from hydropower generation, irrigation, flood control, navigation, and recreation; (2) management of wheat crop yield and inventory control for the United States; and (3) early detection and control of wheat-rust fungi to increase the wheat yield in the United States.

The benefits estimated for the Pacific Northwest are extrapolated separately to major river basins in the rest of the United States (allowing for individual basin characteristics), and estimated for the rest of the world using broader assumptions. The potential benefits from wheat crop yield and inventory management are estimated for the United States (considering worldwide production) and then extrapolated to potential world benefits. Similarly, wheat rust control benefits are estimated for U.S. farmers and extrapolated to the rest of the world.

The estimated total cost of the conceptualized system is compared with the estimated potential benefits from each application. Benefits and costs of the space-assisted information system are compared to benefits and costs of an aircraft-assisted information system as well as of selected non-information alternatives.

SUMMARY OF FINDINGS

- If the multi-purpose satellite system specified in the report ". . . were employed and used to manage the three systems studied in this report, the discounted 20-year net benefit to the United States would be approximately $9.6 billion. If world benefits can be realized they would add about $50 billion [over the 20-year period]."

- The cost of a satellite-assisted system, which is estimated to be about $2.5 billion over the 20-year program period, could be supported by the benefits from any one of the three applications.

- Total U.S. annual benefits from water management are:

Hydroelectric Power	$94 million
Irrigation	282 million
Flood Control	306 million
Recreation and Navigation	6.5 million

- Annual U.S. gross benefits from wheat-crop management will be about $214 million to the potential user groups which were studied.

- Annual U.S. gross benefits to farmers from wheat-rust control could approach $146 million.

- Mission performance capability would be severely degraded if ERTS satellites were substituted for the recommended satellite configuration (Advanced System I). Degradation would be on the order of 75 to 90 percent from the wheat rust and hydrology applications and from 10 to 75 percent for the wheat inventory/yield application.

DOCUMENT CONCLUSIONS

- A satellite-assisted information system for water management, wheat-crop management, and wheat-rust control is technically feasibly and could, if research and development is adequately supported, be operational by the mid or late 1970's.

- The information system conceptualized in the study could provide substantial benefits to different groups of users. Although alternative systems may be less expensive for some specific applications, the total costs for a multi-purpose satellite-assisted system are expected to be considerably less than the sum of benefits to the various user groups. The anticipated water management benefits in the Pacific Northwest alone would be sufficient to pay for the entire satellite-assisted information system. Benefit from other applications studied would then be obtained essentially without significant additional costs.

- The benefit-cost ratios are sufficiently promising to suggest the need for intensification of the research efforts leading toward a possible future operational satellite-assisted information system. Since the first series of dedicated earth resources research satellites, designated Earth Resources Technology Satellites (ERTS), are scheduled to be in orbit in 1972, the timing of future decisions on the development of possible future operational systems should be closely coordinated with the ERTS program as it evolves.

- Intensified research and development in the earth-based science models; in user decision models; in data storage, retrieval, and processing; and in remote sensors is needed. In particular, the development should include interpretive and predictive models which are based on

physical phenomena appropriate to a selected earth activity and which are structured to make effective use of the emerging capabilities of multispectral remote sensing.

DOCUMENT RECOMMENDATIONS

- None, except those which can be drawn from the conclusions.

STRONG POINTS

1. An excellent, well-organized document.
2. Text is supported by well-reasoned appendices.
3. Valid findings at the prefeasibility level of analysis.
4. Intelligent presentation of values of potential benefits over a 20-year timeframe.
5. Well reasoned and supported conclusions.
6. Areas where specific action can be taken are outlined in the conclusions.

WEAK POINTS

1. Derivation of univalue maximum benefits only—lack of discussion of ranges of values.
2. Rigorous chains of analyses are interrupted by doubtful assumptions.
3. Some of the benefits cited in the wheat-management case are based on speculation as to the use of predictive information.
4. While the need to develop predictive models is cited in the conclusions, the degradation which might result from the lack of such models is not estimated.

KEY WORDS

System Analysis, Earth Orbital, Water Management, Agriculture, Sensors, Models, Hydrology, Cost-Benefit Study, Wheat, Wheat Rust, Pacific Northwest, Columbia River Basin, Rivers, Hydroelectric, Irrigation, Flood Control, Navigation, Recreation.

DOCUMENT NO. 10

Summer Study on Space Applications, National Academy of Sciences, National Research Council, Division of Engineering. USEFUL APPLICATIONS OF EARTH-ORIENTED SATELLITES. January 1969.

Study Chairman: Dr. W. Deming Lewis

Report of the Central Review Committee. 34 pp.

Summaries of Panel Reports. 92 pp.

Panel 1. Forestry-Agriculture-Geography. 69 pp.

Chairman: R. Keith Arnold

Panel 2. Geology. 65 pp.

Chairman: Ron J. P. Lyon

Panel 3. Hydrology. 73 pp.

Chairman: Paul Bock

Panel 4.* Meteorology. 73 pp.

Chairman: Verner E. Suami

Panel 5. Oceanography. 104 pp.

Chairman: Gifford C. Ewing

Panel 6.* Sensors and Data Systems. 85 pp.

Chairman: David A. Landgrebe

Panel 7.* Points-to-Point Communication. 149 pp.

Chairman: Richard B. Marsten

Panel 8.* Systems for Remote-Sensing Information and Distribution. 91 pp.

Chairman: Arthur G. Anderson

Panel 9.* Point-to-Point Communications. 172 pp.

Chairman: Cole A. Armstrong

Panel 10.* Broadcasting. 121 pp.

Chairman: Wilbur L. Pritchard

Panel 11.* Navigation and Traffic Control. 85 pp.

Chairman: P. C. Sandretto

Panel 12.** Economic Analysis

Chairman: James B. Hobbs

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*These reports were not reviewed since the contents were not pertinent to the five earth resources disciplines included in the scope of INTERPLAN's work.

**Report not received.

Panel 13. Geodesy and Cartography. 45 pp.
Chairman: Frederick J. Doyle

CONTRACTING AGENCY

The study was undertaken at the request of NASA.

PURPOSE OF THE DOCUMENT

To report the findings of a study group which was convened to determine the probable future usefulness of satellites in practical earth-oriented applications and to examine the economic factors involved.

NATURE OF CONTENTS

In the reports reviewed, the problem areas of the world are discussed in relation to the specific disciplines being considered by the separate panels. In general, there are comprehensive discussions of the interrelationship between potential users, applications, general observables, and desired frequency of observation. There are also discussions of potential economic benefits, and a comprehensive cost analysis is presented for first-generation systems.

Emphasis was placed on the development of system concepts for performing earth observations in the various disciplines and the identification of problem areas which will require further work in order to achieve the ultimately desired capabilities.

While emphasis is placed on space systems, the role of aircraft in the total program is also delineated as well as the requirements for land and ocean surface systems.

The report of the Central Review Committee of the Study and the Summaries of Panel Reports contain a series of observations on the ERS Program in general and on those factors leading to common-use systems. Social and economic influences and international concerns are also addressed. A series of general recommendations are made relative to the conduct of the total ERS Program.

SUMMARY OF FINDINGS

- In general, a two-pronged approach is necessary to achieve the desired operational capability in the disciplines of Forestry-Agriculture-Geography and Hydrology. This involves (1) deployment of state-of-the-art satellites within three or four years and (2) immediate initiation of long-term R&D leading to systems which will provide complete operational capability in 10 to 15 years. The long-term systems would contain improved sensing and also would feature advanced data systems to make full use of the observations.

- The state of the art of oceanography relative to the development and use of space-oceanographic systems probably lags that of the other disciplines. The first oceanographic satellites will be heavily dependent on surface equipment (such as buoys) to achieve capability.

- Total cost for a 7-year operational program (of first-generation systems) is about $1 billion if separate systems are used to serve each discipline (Forestry-Agriculture-Geography, Geology, Hydrology, Meteorology, and Oceanography). Savings of about $83 million over this time period would result from a common use approach using three satellite types (Earth Resources, Data-Collecting Relay, and Meteorological) and an aircraft radar system to augment the satellites in serving the geology discipline.

- The state of the art of satellite design now allows more complex satellites with consequent savings in data processing on the surface.

- Benefits to agriculture and forestry may be of the order of magnitude of $15-22 million annually to the U.S. and $44-81 million annually worldwide, taking into consideration only one limited aspect of the potential economic benefits—that of improvements in data systems.

DOCUMENT CONCLUSIONS

- The benefits from space application are expected to be larger than most of the study participants had originally believed, and certainly larger than the costs of achieving them. However, an extensive, coherent,

and selective program will be required to achieve these benefits. Also, the funding of the present space-applications program is too small by a factor of 2 or 3 when compared to the substantial opportunities that could be realized if financial support were increased by this amount.

- It will be desirable for NASA to continue its technical leadership beyond the R&D stage into a phase of pilot operation. Potential user agencies should participate in this work.

- Imaginative organizational and political innovation is important for suggesting patterns for international space applications.

- To prevent crowding of the geosynchronous orbit, international agreement may be required.

- User education of large numbers of people in business, industry, and the U.S. government agencies will be essential.

- The use of manned vehicles, per se, does not at present appear necessary or economically desirable for the operation of the various space-applications systems.

DOCUMENT RECOMMENDATIONS

- Greater emphasis should be given in future programs and activities to earth satellite programs with promise of beneficial applications.

- Funding should be at the $200-300 million per year level.

- NASA should take the responsibility for involving potential users in the experimental program.

- NASA and the Department of State should continue to develop a favorable international climate for ERS.

- Support of sensor-signature R&D should be increased.

STRONG POINTS

1. Well presented summaries and detailed views of some 200 experts from business, industry, and the academic world.

2. Constitutes a general encyclopedia on the state of the art of earth-oriented satellites.

WEAK POINTS

1. There are numerous generalities and omissions (unavoidable when presenting consensus views of approximately 200 individuals).

KEY WORDS

Satellites, Forestry, Agriculture, Geography, Geology, Hydrology, Meteorology, Oceanography, Sensors, System Analysis, Communications, Remote-Sensing, Broadcasting, Navigation, Traffic Control, Geodesy, Cartography.

APPENDIX C

SUGGESTED APPROACH TO DEVELOPMENT OF AN ERS SYSTEM EFFECTIVENESS AND R&D DECISION MODEL

The core suggestion which emerged from this study (Section 3, pages 72-78; Section 4, pages 80-82) is that an ERS system effectiveness and R&D decision model should be developed in the near future in order to provide a quantitative framework for integrating the findings of past and future studies on the costs, benefits, and technological requirements of the ERS system.

Since INTERPLAN considers that development of such a model is of significance to all future work, this Appendix is included (1) to describe and discuss briefly the fundamental relationships which INTERPLAN feels can be used to express the cost-benefit effectiveness of the ERS system and (2) to suggest an approach toward development of a model which appears to INTERPLAN to be one which will result in the most practical ERS R&D planning tool.

TERMINOLOGY

The terminology used in this Appendix to describe the chain of information requirements (benefits, predictions, measurements, sensors) which link the benefits from an application to sensor measuring capabilities is taken from the PRC R-1224 study. In this terminology the *benefits* from an application result from using a number of *predictions* which have been made on earth resources and meteorological (and earth physics) conditions (e.g., crop vigor, streamflow, sea state) as a basis for taking action. Formulation of the *predictions*, in turn, depends on obtaining information from *measurements* of earth resources and meteorological (and earth physics) phenomena (e.g., rainfall, plant temperature, soil moisture). The quality of the measurements and predictions (and, hence, the magnitude of benefits which will be realized) depends, in turn, upon the degree to which specific sensor measuring capabilities are developed.

CHARACTERISTICS OF THE MODEL

It is felt that the final R&D decision model should be a mathematical expression of the relationships between ERS system benefits (from major user applications) and R&D costs (for developing specific technological capabilities) which is described in such a way that the cost-benefit effectiveness of the ERS system can be optimized subject to the foreseeable R&D budget and certain realistic constraints on R&D planning activities.

In a cursory review of the literature over 30 methods for evaluating and selecting R&D projects were located. However, these methods are all designed to attain the objectives of profit-oriented firms or the military and, hence, none of them appears to be readily adaptable to the rather specialized objectives of the ERS R&D programming effort. In addition, while most of the methods examined define in precise mathematical language the intricacies of various aspects of R&D problems and offer imaginative solutions, INTERPLAN feels, for the most part, that the models suggested in the literature require data which is either not usually available at the prefeasibility level or, if available, generally cannot be supplied with the precision implied.

Therefore, in an effort to evolve a practical tool designed specifically for ERS program use, it is visualized that initially a static model would be described where the values specified would represent the estimated program costs and benefits discounted to present worth. Subsequently, the model would be refined (to the degree that required values can be estimated) to include dynamic considerations such as changes in the size of benefits to be realized across time, development time-frames for specified levels of technological capability (and the time versus R&D cost interaction), changes in the size of the expected R&D budget with time, and the like. Constraints would then be imposed on the dynamic model which, at a minimum, would (1) permit the *a priori* selection of certain applications which, for non-economic reasons, should be included in the system, (2) control the timing of total benefits over the life of the ERS program, (3) place maximum and minimum limits on the number of technological capabilities being developed, and (4) permit the total operational cost of the program to be limited.

THE STATIC MODEL

The mathematical relationship between major elements of a static model upon which the dynamic model would be based are briefly described below. Only a brief description of the static model is given here in order to present INTERPLAN's understanding of the basic ERS cost-benefit relationships. As discussed in more detail later in this Appendix, it is felt that attempts should first be made to quantify the relationships described in the static model before an attempt is made to incorporate dynamic considerations.

It is premised that the objective of the static model is to isolate those technologies which, when developed to a specified capability level, will optimize the benefits from the ERS system of applications at a cost equal to the foreseeable R&D budget.

Benefit Relationships

In the course of this study, benefit estimates were analyzed for a broad spectrum of applications which postulate the acquisition of the same, better, and new information from satellite observations.

The benefits, B, to be optimized, therefore, are

$$B_i = B_{Si} + B_{Bi} + B_{Ni} \quad ,$$

where

B_i = Total, net*, discounted benefits ($)
B_{Si} = Cost savings from *same* information applications
B_{Bi} = Added value from *better* information applications
B_{Ni} = Absolute value from *new* information applications

for $i = 1 \ldots n$ applications.

Although the components of B_i represent different kinds of economic values, the initial objective will be to maximize

$$\sum_{i=1}^{n} B_i$$

irrespective of these intrinsic differences. At some later time, if desired,

*Benefit to user less user's own cost.

the relative importance of different kinds of benefits to the program could be introduced by appropriately weighting the B_{Si}, B_{Bi}, and B_{Ni}.

Now
$$B_i = \sum_{j=1}^{m} P_{ij} \cdot S_{ij} \quad , \tag{1}$$

where

P = the predictions upon which user decisions are taken (see Note 1)

S = the significance of each prediction to realization of the total benefit

for j = 1 . . . m predictions.

Further,
$$P_{ij} = \sum_{k=1}^{r} M_{ijk} \cdot W_{ijk} \quad , \tag{2}$$

where

M = the measurements which are required to formulate each prediction

W = the weight given to each measurement to express its importance in obtaining a "perfect" prediction (see Note 2)

for k = 1 . . . r measurements.

Each measurement can, of course, be made at various levels of precision depending upon the technological capability which has been developed. That is, the quality of each M_k (and related payoffs) is a function of the level, l, of technological development. If, say, three levels of technological development are considered for each measurement, there will be three sets of payoffs associated with each M_{ijk}: $(M_{ijk1} \cdot D_{ijk1})$, $(M_{ijk2} \cdot D_{ijk2})$, and $(M_{ijk3} \cdot D_{ijk3})$ where D represents the degree to which the value of the measurement is degraded due to the less-than-perfect measuring capability for l = 1, 2, 3 capability levels.

Cost Relationships

Regarding the cost aspects of the model, two major cost elements can be identified: (a) R&D cost and (b) operational cost. Since only R&D costs are germane to the initial solution, only R&D costs are considered in the static model, although an optional constraint on total operating costs would be included. Operational costs would be computed after systems of applications are isolated (based on R&D cost effectiveness) by considering

the requirements of each application relative to the frequency of observations, coverage, etc., and the costs resulting from the potential use of ancillary information sources such as buoy-satellite combinations. The sum of R&D costs and operational costs can then be used to express the resulting cost-benefit effectiveness of the total ERS program.

If C_{k1} is considered to be the R&D cost for developing a specific measurement capability, then the expression

$$\sum_{k=1}^{r} C_{k1}$$

(where 1 = 1, 2, or 3) can be set equal to the foreseeable R&D budget and the most cost-effective R&D budget allocation determined by isolating the set of M_{k1} with the largest total payoff.

Inputs and Outputs

INPUTS. For operation of the model, values would have to be quantified and assigned to the following variables for each user decision model (application) considered:

1. B_i, the benefit to be attained for implementation of each application
2. S_{ij}, the significance of each prediction to realization of the benefit (assuming that "perfect" predictions can be obtained)
3. W_{ijk}, the weight each measurement has relative to obtaining "perfect" predictions
4. D_{ijk1}, the degree to which the value (or payoff) of each measurement will be degraded if less-than-perfect measuring capability is attained
5. C_{k1}, the R&D cost for developing a specified level of measurement capability
6. Foreseeable R&D budget.

OUTPUTS. It is suggested that the output of the static model be arranged to yield:

1. A list of the optimum system of applications
2. Total benefits to be realized:

a. from the system of applications
b. from each application
c. from each application as a fraction of the total potential payoff of the application

3. Measuring capabilities required and the level of technological capability to be developed
4. Required sensors
5. Operational parameters such as coverage, frequency of observations, ancillary information sources, and the like
6. Operational costs to satisfy the requirements of 5 above.

SUGGESTED APPROACH

The following sequential approach to development of the model is suggested in an effort to insure that the final result will be a practical planning tool for ERS R&D guidance:

(1.) Develop and complete the mathematical description of the static model described above including development of a program to isolate the optimum set of measurements and measuring capabilities. (It is anticipated that a linear programming approach would be used initially.) After completing the mathematical development, formats of required data inputs would be prepared for use in polling experts for quantification of inputs.

(2.) Test the model on the system of four applications described in the GE study, using the quantitative relationships between benefits, predictions, measurements and sensors, and the operational costs which were developed in the study. Expert judgment would be sought to obtain R&D cost estimates. At this stage the effect of alternative and/or ancillary information sources (such as buoy-satellite combinations) would be introduced into the description of the model and tested using the GE data on these measurements.

As was discussed in the body of the report, the GE study emphasized expressing the quantitative relationships between sensors, measurements and predictions and the overall effectiveness of the system in attaining the objectives of the applications. The estimation of benefits was pursued in much less detail. Therefore, while the quantitative relationships developed

in the GE report can be used at an early stage to test the functioning of the model, the results with respect to cost-benefit effectiveness could not be considered valid unless further work were undertaken to improve upon some of the benefits estimated.

(3.) Obtain from professionals estimates of the quantitative relationships between benefits, predictions, and measurements and the R&D cost estimates for developing specific capabilities (i.e., data input requirements) for at least the five highest payoff applications isolated in this study as listed below:

Application	Application Number	Report	Estimated Annual U.S. Benefits ($million)
1. Detecting fungi stresses in small grains	68, 69	PRC R-1224	230
2. Providing world wheat production forecasts	77	PRC R-1224	115
3. Expediting exploration of petroleum	39	Westinghouse	125
4. Improving forecasts of irrigation water availability	57, 58, 59	PRC R-1224 and Westinghouse	~300
5. Minimizing flood damage through improved water management	53	PRC R-1224	300

It is suggested that (a) information be obtained on these applications in approximately the order shown and (b) all information be obtained on one application before effort is expended on the next. The order in which applications are listed reflects INTERPLAN's opinion as to increasing difficulty of quantifying the required relationships and is based on the number of "predictions" and "measurements" involved, the quality of the data base available, and the presence (or absence) of requirements for user predictive submodels, i.e., the Moving Forecast Scale required in the PRC water management cases (4 and 5 above).

In general it is felt that the difficulties involved in quantifying cases 1 to 3 are broadly equivalent as are those of cases 4 and 5.

(4.) Input the data acquired in (3) above into the model. Run the model as data on each successive application is acquired to test the reasonableness and utility of the output.

(5.) Extend the mathematical description of the model to include dynamic considerations and those R&D constraints considered by NASA to be of most value in planning R&D activities. The dynamic parameters to be included in the model would be selected on the basis of the degree to which professionals consider that quantitative data can be obtained, or credibly estimated. After the mathematical model is defined, corresponding dynamic programming techniques would be evolved. Considering the probable complexity of the dynamic model, it is anticipated that simulation, rather than analytical techniques, will be used.

(6.) Obtain from professionals the required additional dynamic values on the applications evaluated in (3) above and input this information into the model to test the reasonableness and utility of the output.

(7.) Use data obtained from the ERTS series to update the values estimated previously. New budgetary information may also be at hand to further update the model values.

(8.) Input data from the remaining applications isolated in past and suggested supplementary work (see pages 79-81) as well as any new applications which may have been analyzed in the interim.

(9.) Update the values in the model as new information is acquired.

NOTES

1. The chain of information requirements for mapping applications proceed directly from *benefits* to *measurements* with no *prediction* requirements. Therefore, for these applications

$$B_i = \sum_{k=1}^{r} M_{ik} \cdot W_{ik} \qquad \text{(see Equation 2)}$$

2. It is noted that the S_{ij} of Equation 1 and the W_{ijk} of Equation 2 are probably not mutually independent, as assumed here. It is felt, however, that the decision as to whether or not an attempt is made to define these dependent functions should be based on the degree to which actual users are able to describe and evaluate the interdependencies.

APPENDIX D

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APPENDIX E

STATEMENT OF WORK

The Contractor will perform an analysis, review, and appraisal of cost-benefit analyses of the Earth Resources Survey Satellite System.

Under this contract the contractor shall provide the Earth Observations Programs Office of the Office of Space Science and Applications, NASA Headquarters, with an analysis, review, and appraisal of the cost-benefit studies previously conducted for Earth Resources Survey Satellite Systems.

In attempts to quantify the costs and the resulting benefits that will accrue from the survey of earth resources from space, several analyses have been made, by governmental and non-governmental agencies. These analyses, conducted independently of one another, have adopted different bases, assumptions, and technical and economic approaches. For this and perhaps other reasons, the results and conclusions of these analyses do not present a conformity of opinions. Therefore, it is difficult to assess the value of any individual analysis or to fully exploit the findings of these studies in conducting the Earth Resources Survey Program. Therefore in order to attempt a consolidation of opinions, the contractor shall exert its best efforts to accomplish the following:

1. Review cost-benefit studies, as directed by NASA, which relate to the economic benefits to be obtained from the Earth Resources Survey Satellite Systems. The studies to be reviewed will include, but not necessarily be limited to, studies conducted by the following organizations:*

IBM
Planning Research Corporation (2)
Cornell Aeronautical Laboratories (sic)**
General Electric Company
Westinghouse Electric Company
Mathematica

*The reports to be studied under this contract will be furnished by NASA.
**Cornell University, The Center for Aerial Photographic Studies.

2. Assess the extent to which these previous studies are adequate indicators of the expected cost-benefit effectiveness of future operational ERS.

3. Assess the value of these studies for directing R&D activities.

4. Indicate the appropriate nature of future economic studies in the ERS Program.

THE EPILOGUE

It is generally agreed that Spaceship Earth was launched about five billion years ago. Life first appeared on Planet Earth approximately three billion years ago. . . . Modern man emerged about fifty thousand years ago.

Informed conjecture on the solar energy still available and on the probability of cosmic accidents encourages us to believe that it should be possible—barring man made catastrophies—to sustain life on our planet for at least three million more years.

NAS Summer Study on Space Applications, page 74.

This is a report on the first steps of the world's most exhilarating search of the 1970's—how to apply space science to the solution of global problems, how to sustain life on our planet for three million more years. The time span examined in this study is a mere 30 years. However, the problems facing mankind between now and the year 2000 are formidable:

- A hungry world population of six billion
- Two hundred separate national governments with widely divergent political and social aspirations
- "Standing room only" on the earth, with consequent pressures to colonize the sea and the moon
- Man-made environmental degradation, including possible exhaustion of basic earth resources that may portend the extinction of life.

Unless the problems of the next 30 years are solved, hopes for the next 3 million years for our planet are futile.

The way to the solution may be through space. The studies reviewed in this document indicate that satellite-derived information should enable us to understand, at last, the true nature of our biosphere. This understanding may lead to the global management of earth's productive resources and the preservation of its environment. Earth-oriented satellites, operating in monitoring, command, and action postures, may become prime instruments for preserving and managing the earth as one system.

From this study INTERPLAN has learned that although the search to apply space science to the needs of this planet has barely begun, America's understanding of the economics and technology of space has reached such maturity that—given political opportunity and leadership—this understanding could be transformed, well before the year 2000, into benefits for all mankind.