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REPORT NO. 74-2002-10-2

THE ECONOMIC VALUE OF REMOTE SENSING BY SATELLITE: AN ERTS OVERVIEW AND THE VALUE OF CONTINUITY OF SERVICE

VOLUME II

SOURCE DOCUMENT

Prepared for the
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NOTE OF TRANSMITTAL

This Source Document is prepared for the Office of the Administrator, National Aeronautics and Space Administration, under Article I.C.1 of Contract NASW-2580. It contains data which back up summary statements of Volume I. Material contained in this source volume is further backed up by detailed analysis documented in Volumes III to X of this report. The interested reader is referred to these documents for substantiation of all data presented herein.

The data presented in this volume are based upon the best information available at the time of preparation. This includes a survey of existing studies. Four case studies, two in agriculture and one each in water use and land use are discussed in this summary. Others are discussed in the supporting volumes (Volumes III through X). Throughout the analysis, a conservative viewpoint has been maintained. Nonetheless, there are, of course, uncertainties associated with any projection of future economic benefits, and these data should be used only with this understanding.

ECON acknowledges the contributions of John Andrews, Alan Donziger, George Hazelrigg, Klaus Heiss, Francis Sand, and Peter Stevenson, who authored this volume.

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ABSTRACT

Since the launch of the Earth Resources Technology Satellite (ERTS-1) in July 1972, over 300 NASA-approved scientific investigations using ERTS data have been conducted or are ongoing. These investigations serve to define a lower limit of the technical capability of Earth Resource Survey (ERS) satellites. This report addresses the economic value of an ERS system with a technical capability similar to ERTS, allowing, however, for increased coverage obtained through the use of multiple active satellites in orbit. The economic value of an ERS system is obtained by aggregating non-overlapping benefits derived from a variety of specific Resource Management Functions (RMFs). The economic value of added remote sensing in each RMF is obtained either by an in-depth economic analysis performed by ECON or by other economic assessments which ECON believes are valid. The benefits are classified into eight Resource Management Areas and nine Resource Management Activities. A further division of benefits is made into the categories of equal capability, increased capability and new capability.

This volume provides a detailed breakdown of the benefits summarized in Volume I and establishes a methodology for their estimation. In addition, a description of the ECON case studies in agriculture, water use and land cover is presented. A description of the current ERTS system and of the costs for a projected ERS system is given in Chapter 1.

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1. THE ERTS PROGRAM AND ERS PROGRAM COSTS

The Earth Resources Technology Satellite (ERTS) Program is part of the Earth Resources Survey Program (ERSP) which also includes the continued analysis of Skylab Earth Resources Experiment Package (EREP) data and the Earth Resources Aircraft Program (ERAP). The stated purpose of the ERTS Program is "to conduct experiments in the interpretation and utilization of earth resources survey data from space." This program includes ERTS-1, a satellite launched on July 23, 1972 and still in operation, a backup satellite, ERTS-B, and over 300 NASA-approved scientific investigations.

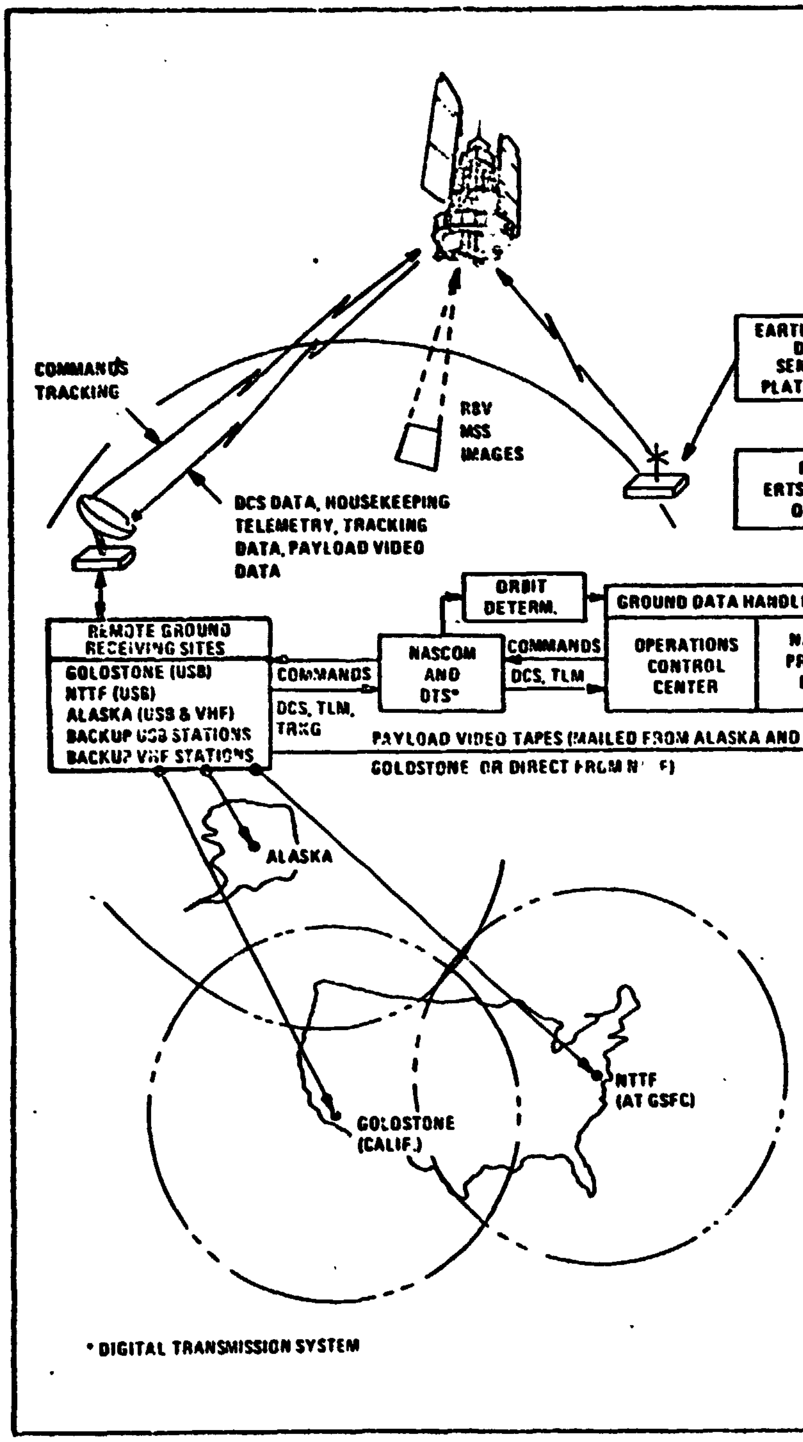
The discussion of costs and benefits in the present study is not limited to the ERTS Program, nor does it include all of the ERS programs. Rather, costs and benefits are investigated for a potential system for earth resources observation from space using satellites with capabilities similar to those of ERTS-1. Such a system is what is meant by an "ERS system" in this report.

1.1 The ERTS System

The current national (United States) ERS system, built around the ERTS satellites, is made up of the following components: (1) the satellites; (2) some 150 ground-based data collection platforms (DCPs); (3) three data acquisition facilities; (4) an operations control center (OCC) and (5) the NASA Data Processing Facility (NDPF). These components are described in the above order, and the whole system is diagramed in Figure 1.1.

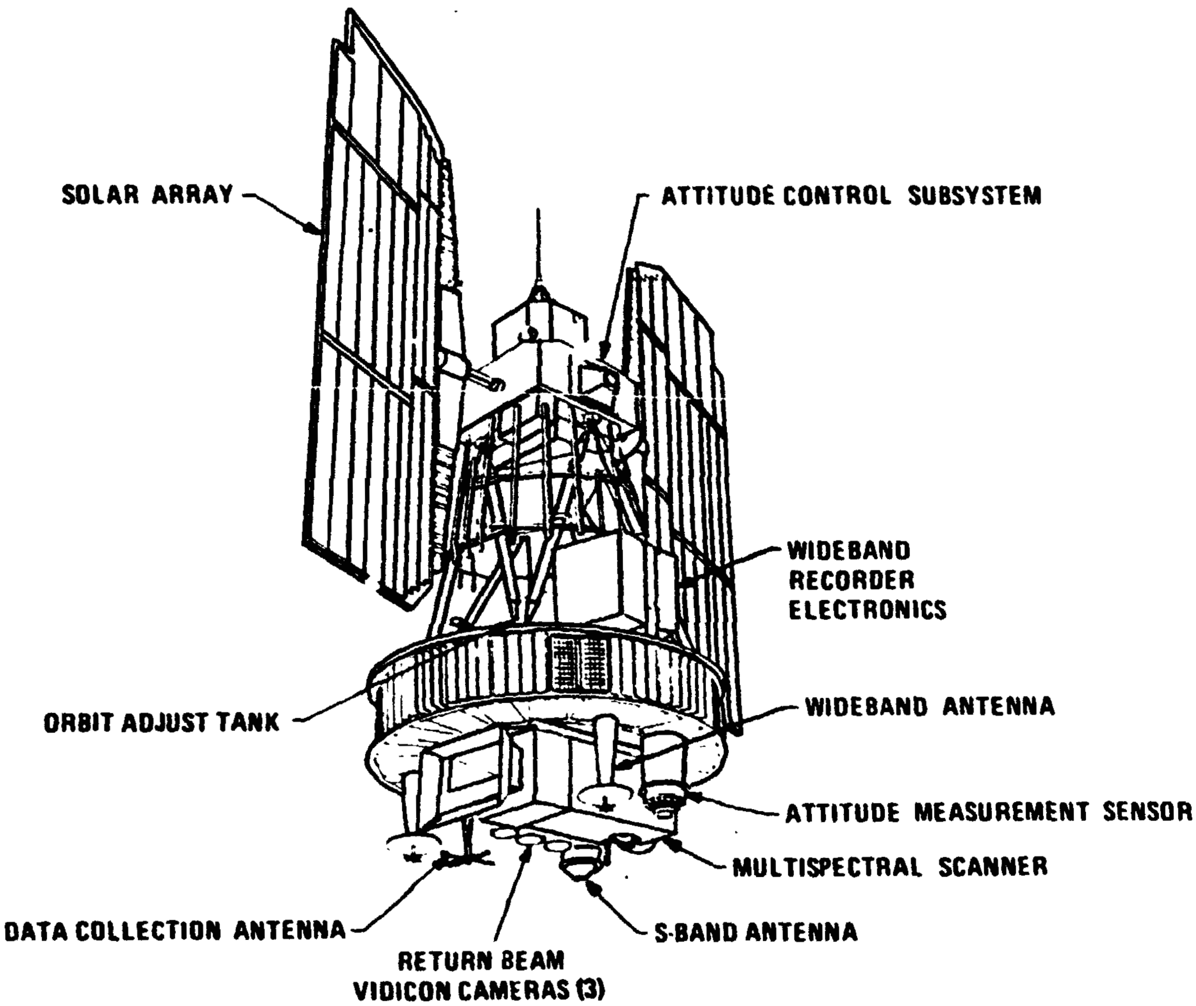
1.1.1 The ERTS Satellite

The ERTS spacecraft is shown in Figure 1.2. It has a mass of 891 kg (1965 pounds) and flies in a polar, retrograde orbit, the parameters of which are given in Table 1.1. The spacecraft makes about 14 orbits a day, collecting image data over a swath of earth 185 km (100 nautical miles) wide. The image data collected are cut to form frames covering about 34,000 square km (10,000 square nautical miles) each. Potentially the ERTS orbit provides global image coverage every 18 days for all latitudes from 80 degrees N to 80 degrees S. Images are not collected over the entire world during every 18-day period, however, primarily because of limitations in data acquisition and processing capacity. Complete coverage of the North American continent can be obtained, but only selected strips over portions of the orbit track are



Source: Final Report-Evaluation of Benefits and System Features of an Earth Resources Satellite Operational System (ERSOS), Appendix B, Phase I, Detailed Application Results, Dynatrend, Incorporated, Burlington, Massachusetts, August 31, 1973.

Figure 1.1 Overall ERTS System



Source: Same as Figure 1.1

Figure 1.2 Earth Resources Technology Satellite Configuration

imaged in the rest of the world. These strips, amounting to about 26,000 km per day, are chosen according to investigator requirements and forecasts of cloud cover.

The payload carried by ERTS includes imaging sensors, wide band video tape recorders, and a communications system (which is not part of the remote sensing experiment). The

Table 1.1 Nominal ERTS-1 Orbital Parameters	
Orbit Parameter	**Nominal Value**
Orbital Altitude	910 km
Inclination	99.092 deg
Period	103.267 min
Eccentricity	0
Local Time at Descending Node (Equatorial Crossing)	9:30 am
Coverage Cycle Duration	18 days (251 revolutions)
Distance Between Adjacent Ground Tracks	159.38 km

imaging sensors are two types -- camera and scanner. A three-camera return beam vidicon (RBV) provides images of an 185-by-185 km (100-by-100 nautical mi.) square area in three different spectral bands: green, red, and near infrared. These bands can be superimposed to yield "false color" images. Imaging of the scanning type (sweeping) is provided by the multispectral scanner subsystem (MSS), which operates in four spectral bands: green, red, and two near infrared bands. The MSS sweeping path is perpendicular to the orbital track. Table 1.2 gives the characteristics of the imaging sensors. The video tape recorders are provided so that images obtained when the satellite is out of the receiving range of the data acquisition facilities can be stored for later transmission. The communications system mentioned as a payload item is a relay system which collects information from the ground-based DCPs and passes it on to NASA ground stations for delivery to the users.

The RBV cameras of the ERTS-1 system have not provided images since shortly after launch because of an electrical anomaly. A malfunction resulted in the early failure of

Table 1.2 ERTS Imaging Sensor Characteristics

3 - Camera Return Beam Vidicon (RBV)

	Camera 1	Camera 2	Camera 3
Resolution, at max. scene contrast, TV lines	4500	4500	3400
Spectral bands, millimicrons	475-575	580-680	690-830
Video bandwidth, MHz	4	4	4
Time between picture sets, seconds	25	25	25

Multispectral Scanner (MSS)

	Band 1	Band 2	Band 3	Band 4	Band 5*
Resolution element, meters from 910 km	80	80	80	80	215
Spectral bands, millimicrons	500-600	600-700	700-800	800-1100	10400-12600
Video bandwidth, KHz	42.9	42.9	42.9	42.9	42.9

* MSS Band 5 is an option for satellites after ERTS-B only

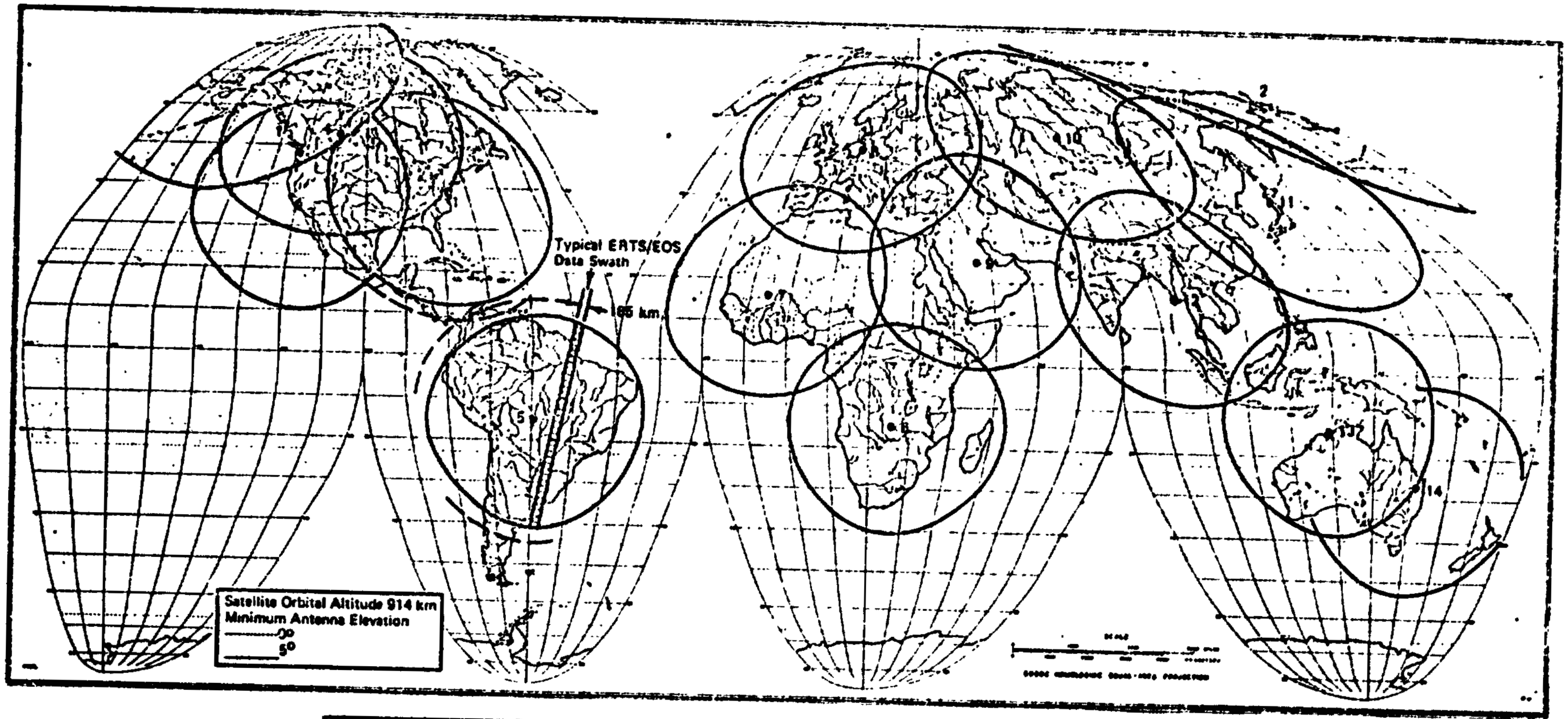
one of the video tape recorders, while the other tape recorder functioned until March, 1973, when it also experienced an anomaly. Complete failure of the second tape recorder occurred in 1974. Thus, ERTS-1 can presently obtain images only within the receiving range of the ground stations; however, images are still provided for nearly all of the North American continent (see Figure 1.3).

1.1.2 The Ground-Based Data Collection Platforms

The DCPs take automatic measurements of several quantities including stream flow, snow depth, soil moisture, and volcanic activity, generally in remote locations. The data are relayed through the satellite to NASA ground stations and are often used to provide ground truth to augment the remote-sensed image data.

1.1.3 The Data Acquisition Facilities

Three national data acquisition facilities are located in the United States - at Fairbanks, Alaska, at Goldstone, California, and at Greenbelt, Maryland. As of May, 1974,



Existing Stations				New Stations					
Sta No.	Host Nation	Approx. Location Longitude	Approx. Location Latitude	Sta No.	Approx. Location Longitude	Approx. Location Latitude	Sta No.	Approx. Location Longitude	Approx. Location Latitude
1	U.S.A.	77W	39N	6	27E	15S	11	142E	42N
2	U.S.A.	149W	64N	7	4W	16N	12	98E	16N
3	U.S.A.	117W	36N	8	13E	52N	13	130E	13S
4	Canada	106W	53N	9	48E	25N	14	154E	27S
5	Brazil	57N	16S	10	84E	56N			

Figure 1.3 Five Existing and Nine New Data Acquisition Stations Provide Global Coverage for ERTS Satellites [Beilock, See Footnote on Page [i-7].

there were two operating ground stations outside the United States: one in Canada at Prince Albert, Saskatchewan; and one in Brazil. Two more stations are under construction: one in Italy, and one in Canada. Each data receiving system includes an antenna able to track the satellite over a large range, with elevation down to about 5 degrees. This permits data reception over an area of about 23 million square km. The five receiving stations now in operation provide the capability of ERTS data reception over all of North America and most of South America. A total of fourteen ERS data receiving stations would suffice to provide reception for nearly the entire land area of the world (except Antarctica). Figure 1.3 illustrates proposed station locations.*

1.1.4 The Operations Control Center (OCC)

The OCC is located at Goddard Space Flight Center in Greenbelt, Maryland, together with the NDPF. The OCC functions include overall system scheduling, command communications with the satellite, and monitoring and evaluation of orbital operations.

1.1.5 The NASA Data Processing Facility (NDPF)

The data received from the satellite at the data acquisition facilities go to the NDPF for processing. The output of this processing is of two kinds -- hard copy prints and transparencies, and computer compatible tapes. Several steps are required to obtain these products from raw satellite data. Some of the important steps include geometric correction and radiometric calibration. For many applications, color composites are desirable, combining several spectral bands represented by colors chosen to facilitate interpretation. For other applications, greatest accuracy is obtained by analyzing the data in the digital form from which the images are derived. These data are accessible on computer compatible tapes provided for automatic data processing. The NDPF includes a storage and retrieval system for all data and provides for delivery of output products to the Department of Interior's Earth Resources Observation Systems Data Center at Sioux Falls, South Dakota. At this point, the data are in the public domain and copies are available for purchase by anyone. NASA also sends data directly from the NDPF to the ERTS-1 investigators located in 43 states, the District of Columbia, 31 foreign nations, and two international organizations.

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* Beilock, Milton M. *Systems for Acquisition, Processing, and Dissemination of Earth Resources Satellite Data*, for the UN Outer Space Div., New York, Dec., 1974.

1.2 ERTS Program Costs

To date more than $420 million has been spent in the ERSP and related supporting research and technology. Of this amount, NASA has provided over $414 million and the Department of Interior has contributed over $6 million. Funding has also come from the Department of Agriculture, NOAA and the Environmental Protection Agency. Table 1.3 gives a breakdown of the identifiable sunk costs. Included in the sunk costs are the costs of major ground facilities, including data acquisition stations at Alaska and California, the NDPF and the EROS Data Center, which will most likely continue to be useful well beyond the ERTS Program.

1.3 Projected ERS Costs

Cost projections for the elements of an ERS system are strongly dependent upon the technical capabilities of the system desired. The costs for a system with capabilities similar to ERTS are given in Table 1.4*. The particular

Table 1.3 Cost of the Earth Resources Program

Program Element	Cost to Date, * $ million	Cost at Completion, $ million
ERTS Satellites (A and B)	170.4	187.8
MSS Thermal IR	0.8	6.8
ERTS Launch Vehicles	8.9	8.9
ERAP	(86.9)	**
Skylab EREP Sensors	64.1	64.1
EREP Investigations	5.0	11.3
Support Research and Technology	(77.8)	***

* Through FY 1974
** $16-million per year forecasted beyond FY 1974
*** $14-million per year forecasted beyond FY 1974

Source of Data: NASA, Jan. 1974

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* Costs are for Mission Configuration 3 in Earth Resources Survey (ERS) Operational System Study Final Report, Review Copy, September, 1973, Goddard Space Flight Center, Greenbelt, Maryland.

Table 1.4 Phased Program Costs for a One Satellite System Over a Five-Year Period

Program Components	Program Costs, $ millions (1973)								
	1975	1976	1977	1978	1979	1980	1981	1982	TOTAL
INVESTMENT COST									
Spacecraft	2.7	10.7	10.8	10.7	2.0	2.0	0.5		39.4
Payload (Sensors)	5.6	11.4	2.8						19.8
Operations Control Center (OCC)		2.4	1.6						4.0
Data Processing Facilities (DPF)		3.4	2.2						5.6
Tracking & Data Aquisition System (TDAS)	0.3	6.7	6.6						13.6
Launch Vehicle			6.4		6.4		6.3		19.1
TOTAL INVESTMENT COST	8.6	34.6	30.4	10.7	8.4	2.0	6.8		101.5
OPERATIONS COST									
Operations Control Center (OCC)			1.1	2.3	2.2	2.2	2.2	2.2	12.2
Data Processing Facilities (DPF)			0.3	0.8	0.8	0.8	0.8	0.8	4.3
Tracking & Data Aquisition System (TDAS)			0.8	2.1	2.1	2.1	2.1	2.1	11.3
TOTAL OPERATIONS COST			2.2	5.2	5.1	5.1	5.1	5.1	27.8
TOTAL INVESTMENT & OPS	8.6	34.6	32.5	15.9	13.5	7.1	11.9	5.1	129.3
NASA CIVIL SERVICE COSTS	0.6	2.3	2.1	1.0	0.9	0.5	0.8	0.3	8.5
GRAND TOTAL	9.2	36.9	34.7	16.9	14.4	7.6	12.7	5.4	137.8

Source: Earth Resources Survey (ERS) Operational System Study Final Report system costed carries two sensors, a Panchromatic Return Beam Vidicon and a Multispectral Scanner. In addition, the satellite carries two wide band video tape recorders to provide for coverage outside the range of the ground receiving stations. There are two tracking and data acquisition stations and the data processing is all digital. A two-year satellite lifetime is assumed.

The time phased investment and operations costs given in Table 1.4 correspond to a five and one-half year operating period. Costs for each major hardware element are shown separately, together with NASA Civil Service Cost. Based upon the data in Table 1.4, the time phased costs for a sixteen and one-half year program have been projected as shown in Table 1.5. In addition, cost projections were made for satellite systems employing two simultaneously active satellites in orbit and three simultaneously active satellites in orbit. Summary costs for a one-, two- and three-satellite system program extending over a sixteen and one-half year period are shown in Table 1.6 for a two-year lifetime satellite.

The following assumptions lead to the cost figures of Table 1.6:

(1) A two-year satellite lifetime.

(2) A sixteen and one-half year program (1977-1993).

(3) Costs incurred up to data on tapes at a ground receiving station are included.

(4) The one-satellite case requires nine satellites operating over 16 years; the two-satellite case requires 18 satellites operating over 16 years; the three-satellite case requires 27 satellites operating over 16 years.

(5) All investment costs are assumed to be incurred as shown in Tables 1.5, 1.7, and 1.8.

Comparing Tables 1.4 and 1.5 as a basis for the numbers in Table 1.6 it is seen that the sixteen and one-half year program would involve three identical procurement cycles for spacecrafts and payloads, and launch vehicles are procured as required. In the cases of two-satellite and three satellite systems, the values for these cost items were scaled by 2 or 3, respectively, accounting for learning effects. Operations costs for the one-satellite system were simply extended from the

Table 1.5 Phased ERS Program Costs for a One-Satellite System and a 16.5-Year Program

Program Components	Project Costs, $ millions (1973)																				
Years:	1975	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	Total
Spacecraft	2.7	10.7	10.8	10.7	2.0	2.0	0.5														39.4
							2.7	10.7	10.8	10.7	2.0	2.0	0.5								39.4
													2.7	10.7	10.8	10.7	2.0	2.0	.5		39.4
Payload	5.6	11.4	2.8				5.6	11.4	2.8				5.6	11.4	2.8						59.4
OCC		2.4	1.6																		4.0
DPF		3.4	2.2																		5.6
TDAS	0.3	6.7	6.6																		13.6
Launch Vehicle			6.4		6.4		6.4		6.4		6.4		6.4		6.4		6.4		6.4		57.6
Total Investment. Costs	8.6	34.6	30.4	10.7	8.4	2.0	15.2	22.1	20.0	10.7	8.4	2.0	15.2	22.1	20.0	10.7	8.4	2.0	6.9		258.4
OCC			1.1	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2		
DPF			0.3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		
TDAS			0.8	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1		
Total Operations Cost			2.2	5.2	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1		83.9
NASA Civil Service Costs	0.6	2.3	2.1	1.0	0.9	0.5	1.4	2.6	2.1	1.0	0.9	0.5	1.4	2.6	2.1	1.0	0.9	0.5	0.8		25.5
Total Program Costs	9.2	36.9	34.7	16.9	14.4	7.6	21.7	29.8	27.2	16.8	14.4	7.6	21.7	29.8	27.2	16.8	14.4	7.6	12.8		368.0

Table 1.6 Total Program Costs* for an ERS Satellite System 1977-1993

Program Components	Program Costs, $ millions (1973)		
No. Active Satellites	1**	2***	3***
Investment Costs	258	494	645
Operation Costs	84	117	150
Civil Service Costs	26	40	58
Total Costs	368	621	853
Annual Program Cost (10% Discount Rate)	27.3	45.6	61.9

* Exclusive of Data Processing Costs

** See Table 1.5 and Volume VI, Land Use Land Cover Case Study, for further documentation back-up

*** ECON estimates based upon NASA GSFC data

values given in Table 1.4. For the two- and three-satellite systems, judgments were made concerning the extent to which the various components of cost would be impacted by two or three satellites orbiting at one time. Tables 1.7 and 1.8 present the cost estimates for the two- or three-satellite systems. The scaling factors assumed are provided in Table 1.9.

The cost annuities shown in Table 1.6 are the yearly cost equivalents of the total program costs at a 10 percent discount rate. These numbers are derived by taking the investment, operations and civil service costs distributed as shown in the backup Tables 1.5, 1.7 and 1.8. The costs given in Table 1.6 are estimates based upon NASA GSFC data for a one-satellite system. Thus, the estimates given in columns two and three of this table represent upper bounds of costs for these systems since these systems would probably incorporate cost-saving changes; for example, a five-year satellite lifetime, data relay satellites, MSS only, etc.

Table 1.7 Phased Program Costs for a Two-Satellite System and a 16.5 Year Program

Program Components	Program Costs, $ millions (1973)																				
Year	1975	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	Total
Spacecraft	4.4	18.4	18.6	18.4	4.0	4.0	1.0														68.8
							4.4	18.4	18.6	18.4	4.0	4.0	1.0								68.8
													4.4	18.4	18.6	18.4	4.0	4.0	1.0		68.8
Payload	11.2	22.8	5.6				11.2	22.8	5.6				11.2	22.8	5.6						118.8
OCC		2.4	1.6																		4.0
DPF		3.4	2.2																		5.6
TDAS	0.3	6.7	6.6																		13.6
Launch Vehicle			12.8		12.8		12.8		12.8		12.8		12.8		12.8		12.8		12.8		115.2
Total Investment Costs	15.9	53.7	47.4	18.4	16.8	4.0	29.4	41.2	37.0	18.4	16.8	4.0	29.4	41.2	37.0	18.4	16.8	4.0	13.8		4[illegible].6
OCC			1.6	3.4	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3		
DPF			0.5	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3		
TDAS			1.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5		
Total Operations Cost			3.1	7.2	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1		116.8
NASA Civil Service Costs	1.1	3.7	3.5	1.9	1.6	0.7	2.5	3.4	3.1	1.9	1.6	0.7	2.5	3.4	3.1	1.9	1.6	0.7	1.4		40.3
Total Program Costs	17.0	57.4	54.0	27.5	25.5	11.8	39.0	51.7	47.2	27.4	25.5	11.8	39.0	51.7	47.2	27.4	25.5	11.8	22.3		620.7

Table 1.8 Phased program Costs for a Three-Satellite System and a 16.5 - Year Program

Program Components	Project Costs, $ millions (1973																				
Years:	1975	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	Total
Spacecraft	4.1	24.1	24.1	24.1	6.0	6.0	1.5														90.2
							4.1	24.1	24.1	24.1	6.0	6.0	1.5								90.2
													4.1	24.1	24.1	24.1	6.0	6.0	1.5		90.2
Payload (Sensors)	16.8	34.2	8.4				16.8	34.2	8.4				16.8	34.2	8.4						178.2
OCC		2.4	1.6																		4.0
DPF		3.4	2.2																		5.6
TDAS	0.3	6.7	6.6																		13.6
Launch Vehicle			19.2		19.2		19.2		19.2		19.2		19.2		19.2		19.2		19.2		172.8
Total Investment Costs	21.4	70.9	62.4	24.1	25.2	6.0	41.6	58.3	52.0	24.1	25.2	6.0	41.6	58.3	52.0	24.1	25.2	6.0	20.7		645
OCC			2.2	4.5	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3		
DPF			0.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8		
TDAS			1.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0		
Total Operations Costs			3.9	9.3	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1		150
NASA Civil Service Cost	1.7	5.2	2.8	2.7	2.3	1.0	3.6	5.0	4.6	2.7	2.0	1.0	3.6	5.0	4.6	2.7	2.3	1.0	2.0		58
Total Program Cost	23.1	76.0	69.1	36.1	36.6	16.1	54.3	72.4	65.7	35.9	36.3	16.1	54.3	72.4	65.7	35.9	36.6	16.1	31.8		853

2. A METHODOLOGY FOR ESTIMATING ERS BENEFITS

The only tangible products of an ERS system are hard copy photographic prints, computer compatible digital tapes, and data collected by earth-based data collection platforms (DCPs) which are relayed to ground stations by a space-based data collection system (DCS). These products have little intrinsic economic value, but derive their value from the uses to which they are put as information. One way of analyzing the value of this information is based on the concepts of supply and demand, which are the natural major descriptors of a market economy.

Knowledge of the supply of and the demand for any commodity permits determination of its value, and this principle can be applied to informational products as well as to any others. The required knowledge of supply consists of the relationship of two variables--cost and output level--from a producer's point of view. Similarly, the required knowledge of demand is the relationship of the price charged and the quantity purchased, from a consumer's point of view.

Section 2.1 develops these ideas on the conceptual level, including their consequences for the value of informational products. Section 2.2 presents the practical methodology based on this conceptual foundation, and explains how it is used in the present study. Section 2.3 discusses the problem of "distributional benefits," and the final section of this chapter, 2.4, treats the important subject of the requirements for the realization of the potential economic benefits.

2.1 Economic Value -- Supply of and Demand for Information

It is necessary to estimate the demand for Earth Resources Survey (ERS) services. This is extremely difficult to do. First, an ERS system involves new technologies and uses, many of which cannot be predicted with confidence. Any estimation procedure will be guilty of many sins of omission since it is unrealistic to think that one can foresee all the important potentials of a new technology. Second, many of the benefits of an ERS system impact so-called public goods, for which a market does not really exist. A public good is usually characterized in either of two ways: if one individual consumes it, then others can also consume it at essentially no increase in supply costs, or if one individual consumes it, it is almost impossible to prevent others from consuming it. Estimating the benefits of public goods presents difficulties even for systems that already exist. Notwithstanding these difficulties, estimates of the potential demand for ERS services can still be made.

The essential ideas can be stated as follows. The gross value of a product is just what a user would be willing to pay for it. But when one is concerned with value to the nation as a whole, a net value concept is required, to account for the costs to the producer of making the product available. The net value of a product is thus the difference between the amount a user would be willing to pay for it and its production cost. In applying these concepts to important cases, a complexity arises immediately. Both the users' willingness to pay (demand) and the producers' cost of supplying a unit of some product depend on (among other things) the amount of the product that has already been produced. For example, whatever the users of ERTS images are willing to pay to meet their minimal data requirements, they are not likely to continue to pay at that rate for more images.

To quantify relationships like these, it is useful to define *demand curves* and *supply curves*.

Figure 2.1 represents a typical demand curve for a given commodity. The vertical axis represents the price per unit of the commodity, while the horizontal axis represents the number of units consumed. A point (Q,P) on the curve is interpreted to mean that when Q units are consumed, there are users who would be willing to pay price P for the next unit produced. The properties of the curve depend upon the users' resources, tastes, preferences, and needs, and the availability of substitute products.

The particular prices marked on the vertical axis (P_1, P_i, and P_e) represent the price that could be obtained for the first unit, the price that could be obtained for the i th unit, and the existing price, respectively. It is assumed that all units (totalling Q_e) are actually sold at price P_e. Since the units up to and including $Q_e - 1$ are sold for less than the users would be willing to pay, part of the gross value (willingness to pay) is realized by the users. This part is called the "consumer surplus" and is measured by the shaded area of Figure 2.1. Another component of the gross value of the product may be realized by the producer. To analyze this component, the "supply curve" is constructed as shown in Figure 2.2.

The supply curve plots the cost of the next unit produced (called marginal cost) as a function of the total number of units already produced. In a competitive environment the quantity produced is determined by the condition that the selling price equals the marginal cost of production, so that the point of intersection of the supply and demand curves represents the actual state of affairs. Thus the producer obtains total revenues of P times Q, the product of the price per unit and the

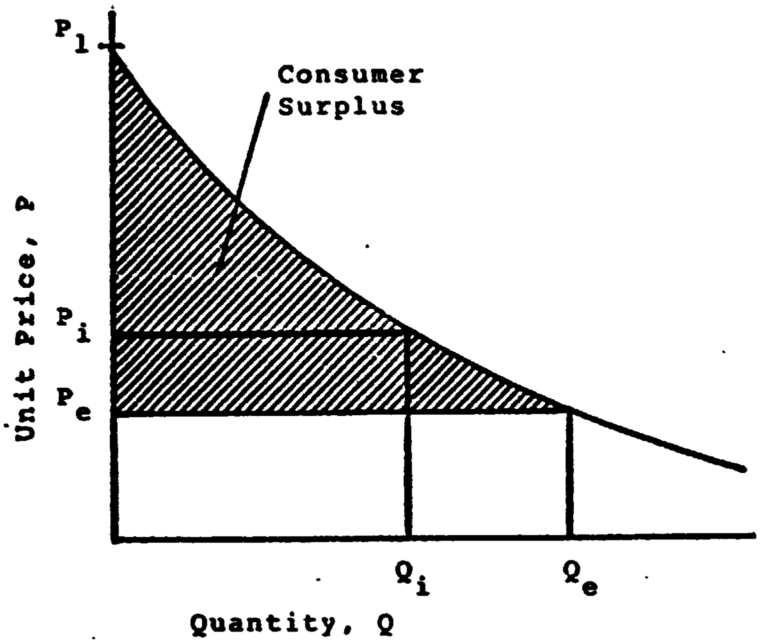

Figure 2.1 A Typical Demand Curve

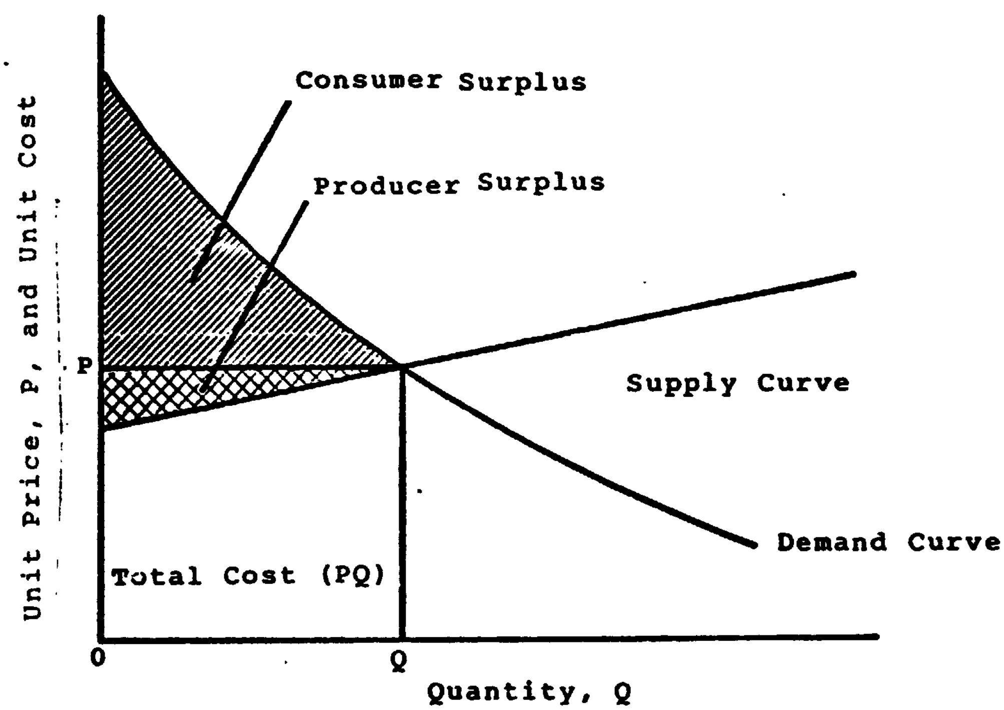

Figure 2.2 Typical Supply and Demand Curves for a Commodity

total number of units produced. This total revenue is the area of the rectangle in Figure 2.2 with vertices (0,0), (Q,0), (Q,P), and (0,P). The area of the part of this rectangle below the supply curve is the producers' cost of providing Q units, so that the shaded part of the rectangle is the part of the gross value of the product which is realized by the producers. The area enclosed by the vertical axis, the supply curve, and the demand curve represents the *net* economic value of the product.

In applying these value concepts to the determination of benefits of improvements in products or substitution of new products for old ones, one is concerned with the *change* in the net economic value due to the improvement or substitution. Such a change is reflected in a change in the supply curve, the demand curve, or both.

2.1.1 Known Demand Structure

If the change affects cost factors without affecting the qualities determining user valuation of the product, the supply curve shows a change, while the demand curve does not. This happens, for instance, when a lower-cost process is employed in making a product of unchanged specifications. Figure 2.3 portrays the associated change in net value--the *benefit* of the improvement or substitution.

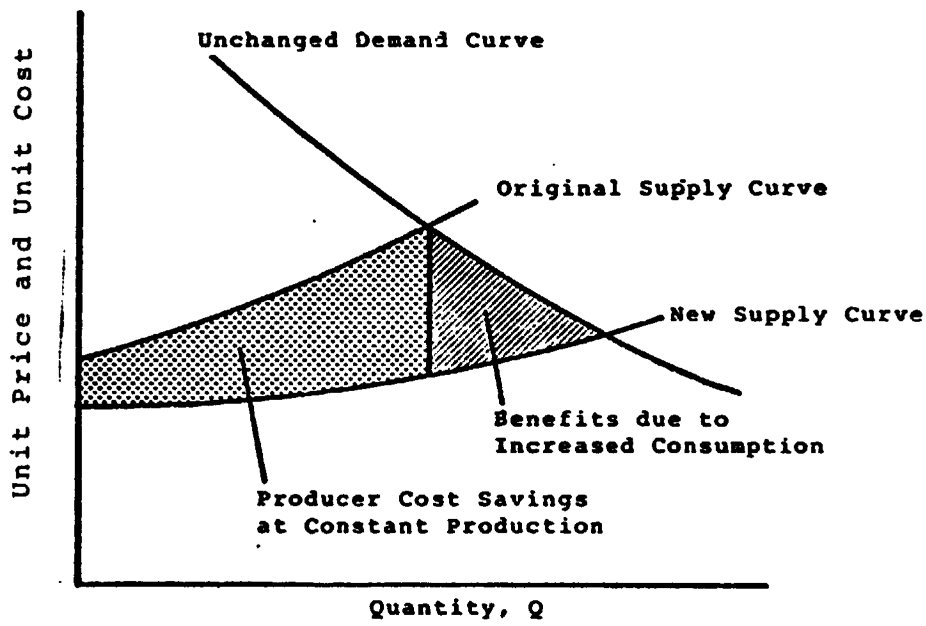

Figure 2.3 The Benefit of a Change in Cost Factors

In the case where the marginal cost of production is independent of the quantity already produced, the supply curves are both horizontal lines, completely specified by that marginal cost. Since the marginal cost is the selling price of the product, the benefit can be obtained simply from knowledge of the demand curve and the original and new prices. In Figure 2.4, such a situation is diagrammed with the benefit indicated by the shaded area. Part of the benefit, represented by the area to the left of the vertical dotted line, can be determined without knowledge of the shape of the demand curve. That part of the benefit is given by $(P_1 - P_2) \times Q_1$, and is simply the cost saving (realized in this case by the consumers) for the quantity of the product produced at the original price. Regardless of the details of the demand curve, this cost savings benefit is a lower bound for the total benefit due to the price reduction.

For calculation of the remainder of the benefit, represented by the triangular area to the right in Figure 2.4, some knowledge of the structure of demand is required. In some cases, particularly when the price change is small, the knowledge can be obtained directly. Users can be asked, for example, how much more of a product they would purchase if the price were lower.

Sometimes it is possible to predict with considerable

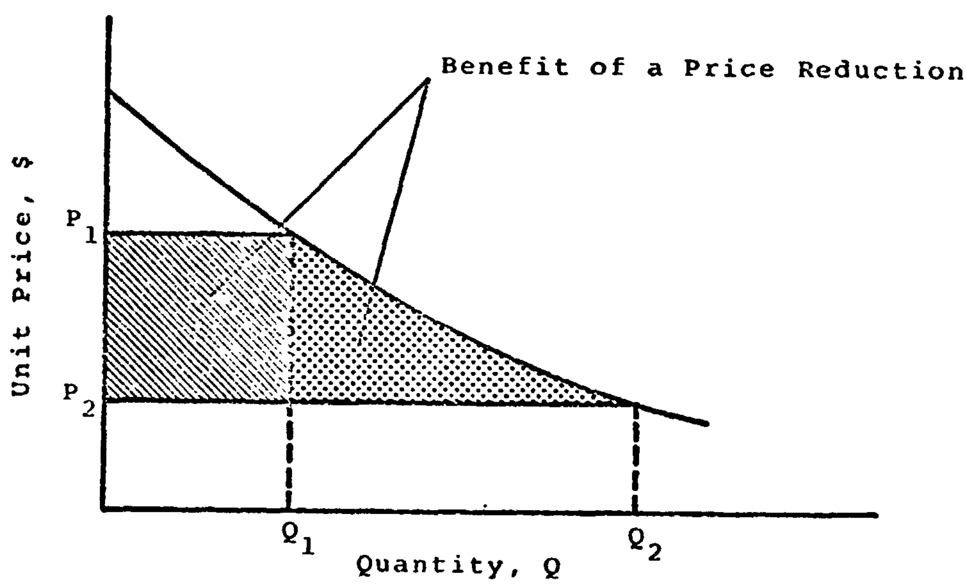

Figure 2.4 Benefit of a Price Change when Marginal Cost is Independent of Level of Production

confidence that the demand will follow one of several familiar patterns. One of these patterns is called "perfectly inelastic demand". In this case, the total quantity purchased does not increase with the reduction in price. Then the demand curve is vertical and the *total* benefit is just $(P_1 - P_2) \times Q$. This is often the situation when the demand is institutionalized. As an example in the context of informational products, a government agency directed by law to obtain maps of a particular region will not be likely to invest in more maps in response to a lower unit price. Another common pattern is called "unit-elastic demand." In this case, the total amount of money spent on the product by the buyers is the same at the higher or the lower price. This implies that the demand curve has a hyperbolic shape and is described by the formula $PQ = \text{constant}$. Unit elastic demand also is often a good description of institutional buying behavior. For example, the United States Forest Service has targets on forest inventory cycles, but does not meet them under its current budget. If inventory procedures were made less costly, it is likely that the savings realized would be used for the "purchase" of more inventory activity, at least up to the point of meeting the target cycle times. In the course of the benefit estimates of this study, the unit elastic demand case occurs frequently. A simple formula gives the total benefit for this case when the price reduction is known; it is presented here. Figure 2.5 represents a unit elastic demand curve, with the consequences of a price reduction. The new price is a fraction f of the old price, and because of the unit elasticity, the new quantity is the old quantity divided by f. The total benefit B represented by the shaded area, is easily calculated by integration, as follows:

$$B = PQ \int_{fP}^{P} \frac{dy}{y} = PQ\ [\ln(P) - \ln(fP)]$$

$$= -\,PQ\ \ln(f)$$

where ln refers to the natural logarithm. In application, one often determines the part of the benefit corresponding to production level Q first. If this part of the benefit is denoted B_1, then since $B_1 = PQ(1-f)$, the total benefit can be written

$$B = B_1\ \left[\frac{-\ln(f)}{1-f}\right],$$

and the remaining part of the benefit, denoted B_2, is given by

$$B_2 = B - B_1 = B_1\ \left[\frac{-\ln(f)}{1-f} - 1\right]$$

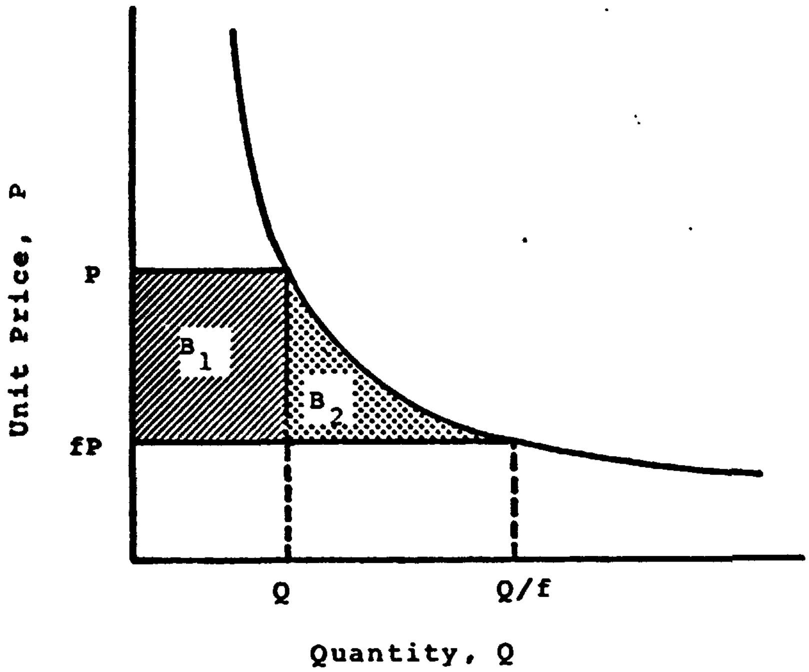

Figure 2.5 The Equal Capability and New Capability Benefits When Demand Is Unit Elastic

2.1.2 Unknown Demand Structure

So far the discussion has considered the impact of a cost change only in markets that already exist. However, a new technology will often lead to changes in addition to those in the costs and quantities of goods being produced at the time of implementation. One of the major problems involved in the analysis of new technologies is the tendency to create new markets and needs. Although the estimation problem is much more difficult, the conceptual framework is similar to the one for the case where a market already exists. One postulates the existence of a demand for the new product and the economic benefit is the area between the supply curve for the new product and the demand curve for the new product.

The numerical estimation of the demand curve can be based on an analysis of the needs or objectives of the potential users of the new product. When the product is a form of information, two important general principles guide this analysis. First, the need for information arises in the course of production or acquisition of other products, for which supply and demand analysis may be feasible. Second, the economic benefit of information is in making decisions relating to those products, by which is meant committing economic resources in one way rather than in another. Thus, information has economic value to a user only if it permits him to make a better decision than he could in its absence. In view of these two principles, the determination of a given users's demand for information requires an analysis of (1) his decision alternatives and their consequences and (2) the value of the products in the market he is operating in.

An excellent example of the interactions under discussion here is the situation with respect to winter wheat, which Kansas farmers generally use as a cover crop to be plowed under in the spring. The increased price of wheat due to the Russian grain deal, however, has recently led several farmers to harvest their wheat instead. An informational product of importance here is the forecast of the current crop yield. Illustrating the first principle above, need for this information arises within the context of the wheat market, for which supply and demand analysis is feasible and productive. Second, the farmers use information of this type in making decisions on whether to harvest the winter wheat or to plow it under. Consequently, to estimate how much a farmer would be willing to pay for crop yield forecasts of a given quality, it is necessary to determine how he would use the forecast in making his harvest-or-plow decision and what profits he can look forward to after making the decision.

It is important to consider whether a farmer's increased profits constitute a benefit to the nation as a whole, and if so, how much. In this regard it is clear that good decisions made by farmers are also good for consumers. If, in fact, there exists a potential shortage of wheat, this can result in higher wheat prices. By harvesting his wheat crop rather than plowing it under, the farmer can take advantage of the higher price and, at the same time, keep the price from going even higher by adding his wheat to the total wheat supply.

2.1.3 The Attributes of Information

In the analyses of the present study, the subject is often the substitution of information derived from one source for information derived from another. For example, sometimes consideration is given to the direct substitution of ERTS frames for aerial photographs. A more intricate case is the substitution of statistics such as rangeland condition assessments gathered with the aid of ERS data products for similar statistics gathered entirely by conventional means. Whenever value comparisons are made between information derived from different data sources, consideration must be given to the *attributes* of information which determine its usefulness in decision making, and hence its economic value. These attributes are both economic and technical in nature and are five in number:

1. *Cost* - Cost is an economic attribute of information, affecting its value directly. Information that costs as much as or more than its contribution to good decision making is of zero economic value.

2. *Accuracy* - Accuracy is a technical attribute of information that expresses the extent to which data (inputs to information) are correctly interpreted. Information loses value as its accuracy is decreased. As some point, information substitutes take over and the information loses all economic value.

3. *Completeness* - Completeness is a technical attribute of information that expresses its degree of fulfilment of the total information requirement. For example, in the context of timber harvest management net growth of timber for an entire National Forest is less complete than the same information given by location within the forest.

4. *Dependability* - Dependability is a technical attribute of information that relates to its consistency from sample to sample. If information is not dependable, then even when it is inexpensive, accurate, complete, and timely, its economic value may be lessened.

5. *Timeliness* - Timeliness is a technical attribute of information that relates to its period of availability. Information that is available after a decision is made is of little value to the decision maker.

In order for certain information to have increased economic value over alternative information, at least one of its attributes must be improved. Information with the same technical attributes but lower cost, for example, has the value of cost savings. Other information may have the same or higher cost but, because of improved technical attributes, allows improved decisions to be made, thus obtaining added value.

In comparing information prepared using ERS satellite data with information prepared using high-altitude aircraft images, attribute differences are typically found in cost, completeness, timeliness and sometimes accuracy. The higher resolution of aircraft images may result in greater accuracy, but the cost is higher. But in some situations the information requirement is such that satellite images provide greater accuracy. For instance, when information is required on the location and shape of large geological structures (as in oil exploration), or in the areal extent of particular earth phenomena (such as forest vegetation or ocean coverage), the synoptic viewpoint provided through the satellite's altitude results in greater accuracy than can be obtained by means of aircraft. In the case of timeliness of information, the satellite may have an advantage for most routine information collecting activities, but it cannot be rerouted to fill an immediate need for coverage of an area it passed over two days ago, whereas an aircraft *could* be dispatched to the site.

It would be a mistake to limit the evaluation of ERS satellite information to an assessment of its ability to meet specifications established before it was available. This is because specifications on the requirements for information and on its attributes have no absolute validity; they are, at most, valid in connection with a particular method of using the information in decision making. In the final analysis, the only information *requirement* is the answer to the question, "What is the right decision?" For example, in the case of timber harvest management, this question takes the form, "How much timber (if any) should be cut from each location?" The standard methods of making this decision call for information on annual timber growth, removals, and mortality, obtained through statistical sampling procedures. As part of standard procedures, accuracy specifications have been developed for the measurements (actually estimates) of these three quantities. When considering the possible benefit that can be attributed to ERS satellite information, it is not sufficient to ask whether the satellite data alone can be used to make estimates of the quantities within the specifications already established. A better question is whether the whole sampling procedure can be modified to include satellite data, as well as data collected conventionally, but in a manner designed to complement the satellite data. The accuracy targets of the new sampling procedure would be stated for the output information, not for the measurements made from the satellite data tapes.

Thus, the analysis of the attributes of information is not applied to the input information of the sampling process, but to its output. However, the expanded question *still* may fail to locate significant benefits of new information. The timber harvesting decision is made primarily on the basis of the single quantity -- annual addition to timber. The three components of this quantity are growth, removals, and mortality. If it is possible to measure the annual addition by a procedure that does not depend on precise measurements of the components, a benefit may be thereby achieved. Frequent satellite coverage suggests alternative procedures for making the desired estimate -- such as by taking the difference of volume estimates made at different times. If satellite data can be used in such a procedure to improve efficiency of harvest management, a benefit is achievable whether or not benefits can be achieved in the other ways discussed above.

The timber management case is a very simple example of a phenomenon that occurs in connection with many other resource management functions. The general principle suggested by this example is that the use of satellite data can always be viewed as part of a multi-stage statistical sampling procedure, and the best use of the satellite data to provide information to support a given management function depends on designing the entire sampling procedure with the management function in mind.

2.2 The Practical Methodology

To assure comprehensiveness and precision, and to assist in the organization of data for the present study, the benefit estimates are carried out for individual resource management functions (RMF). The RMFs are classified on two levels. At the highest level, the classification system defines eight resource management areas. At the next level, each resource management area is divided into nine resource management activities. Finally, the RMFs themselves are selected to focus on distinguishable functions within the activities. The classification system is all-inclusive through the first two levels. The resource management areas form a comprehensive (and mutually exclusive) list of earth resources, while the resource management activities are comprehensive, and, are ordered according to the sequence in which they are ordinarily performed. Tables 4.1 and 4.2 in chapter 4 list all of the areas, activities, and functions of the resource management classification system.

Within a given RMF the procedure is to estimate benefits of three types, which are: (1) equal capability benefits; (2) increased capability benefits; and (3) new capability benefits. These three types correspond to the properties of the demand curves discussed in section 2.1. Each RMF is involved with the production of some economic commodity. For example, RMF 1.1.3 (Domestic Soil Surveys) involves the publication of statistical information, while RMF 3.4.1 (Management of Water-Impoundment Systems - for Power Generation) involves the production of electrical power. Whatever the product associated with the RMF, whether informational or otherwise, the demand for that product is investigated for the benefit estimation. In the cases where some quantity of the product is presently being produced, or will be soon because of statutory requirements, equal capability benefits are estimated. The equal capability benefits (shaded area left of the dotted line in Figure 2.4) consists of the cost savings due to ERS information for the quantity of the product presently produced. When the demand curve is considered to be (or is approximated as) unit elastic, the increased capability benefit is calculated. It consists of the benefit due to the increased production of the same product made possible by the lower cost of production. New capability benefits are calculated when analysis of potential users' decision processes and their economic consequences have been accomplished, so that the needed demand curve information can be estimated. In most cases this analysis requires in-depth case studies. The case studies prepared by ECON to support the present analysis of ERS system benefits are discussed in Chapter 3 while those of other authors which provided useful results are treated in Chapter 4.

In the above discussion, the assumed supply curve is horizontal, describing a situation in which the marginal cost of production is independent of the amount already produced. There is a reason for this use of a horizontal supply curve. Over the long run it is to be expected that industry supply curves will tend to be flat since the existence of a producer surplus will serve to attract new producers who will enter the market so long as the costs of entry are less than the producer surplus that can be earned. For the case of government it is to be hoped that pricing is based on incremental cost and that no producer surplus exists. This stems from the assumption that the government will not try to make a profit from its services, but rather that it tries to maximize the benefits of those services to society and its members.

For most commodities, the shape of the demand curve is not known accurately. However, for the programs of the federal government, the two special cases of perfectly inelastic demand (equal capability benefits alone) and unit elastic demand (benefit calculation assumes equal budget) are most important.

2.3 ERS Benefits from Improved Distribution

Many people find it difficult to believe that an improvement in information can result in an economic gain to the nation as a whole, even though the quantity of goods and services produced remains the same. It can indeed be shown that society may be made better off by a change in the distribution of a fixed quantity of goods. To the extent that better information allows a better distribution of these goods among people, or among countries, then this information has improved society's well-being.

If for example, two countries, I and II are potential trading partners in the agricultural sector, "information" concerning each others' crops would be necessarily exchanged before trade was commenced. To be a bit more definite, suppose Country I grows soybeans while Country II grows wheat exclusively. The situation prior to trade may be represented by the production-consumption table:

Table 2.1 Pre-trade Pattern of Crop Production-Consumption

	Soybeans	Wheat	Consumption
Country I	X	O	X
Country II	O	Y	Y
Production	X	Y	X + Y

Following the trade agreement, there might be no change in production in this simplified model, but consumption changes as Table 2.2 shows.

In the conventional language of the economist each country's consumption preferences may be expressed by an Indifference Curve (Figure 2.6). The country is indifferent between any of the soybeans-wheat consumption patterns represented by points on the curve I, such as point B or D. Implicitly, the country also considers point C as preferable to point A because both the quantity of wheat and the quantity of soybeans increase in moving from A to C. Putting these two concepts together, the country is said to possess an indifference map (Figure 2.7). Although indifferent between any two points on a member of the family of curves, the country prefers to be on a curve which is further from the origin (e.g., III is preferred over II).

Figure 2.8 presents indifference curves for Countries I and II on the same graph with the origin for Country I at the upper right and the origin for Country II at the lower left. The interior of the rectangle consists of exactly those points representing possible distributions of the fixed quantities of wheat and soybeans between Countries I and II. Points toward the left represent distributions in which Country I consumes more wheat and Country II consumes less, while points toward the right represent distributions in which Country II consumes more of the wheat. Similarly vertical differences represent the consumption of soybeans. Points toward the top of the rectangle represent distributions in which Country II consumes more soybeans while Country I consumes less, while points toward the bottom represent distributions in which Country I consumes more of the soybeans.

Table 2.2 Post-trade Pattern of Crop Production-Consumption

	Soybeans	Wheat	Consumption
Country I	X - S	W	X - S + W
Country II	S	Y - W	Y + S - W
Production	X	Y	X + Y

In figure 2.8, the pre-trade situation is represented by point A with Country I having most of the soybeans and Country II having most of the wheat. After exchanging crop information, they trade with each other and move to a point such as B. Since each country is on a higher indifference curve at B, they are both better off even though the total quantity produced of each crop has not changed.

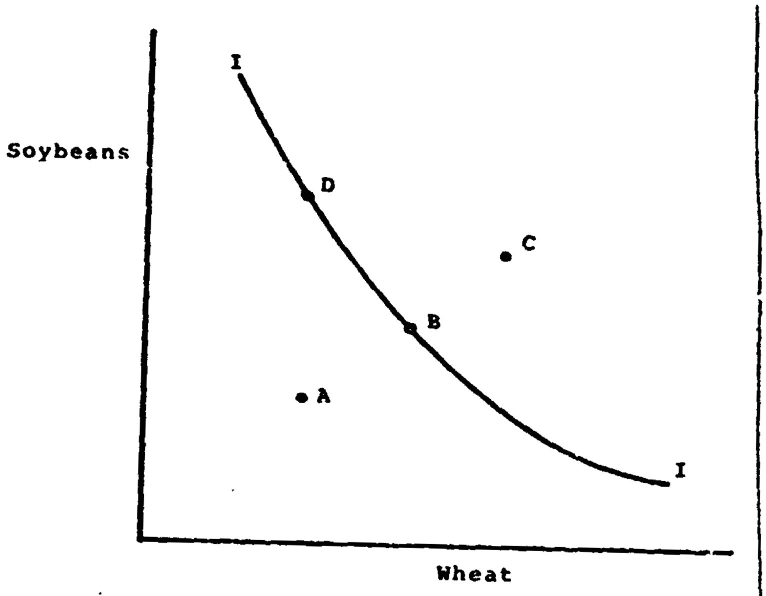

Figure 2.6 An Indifference Curve

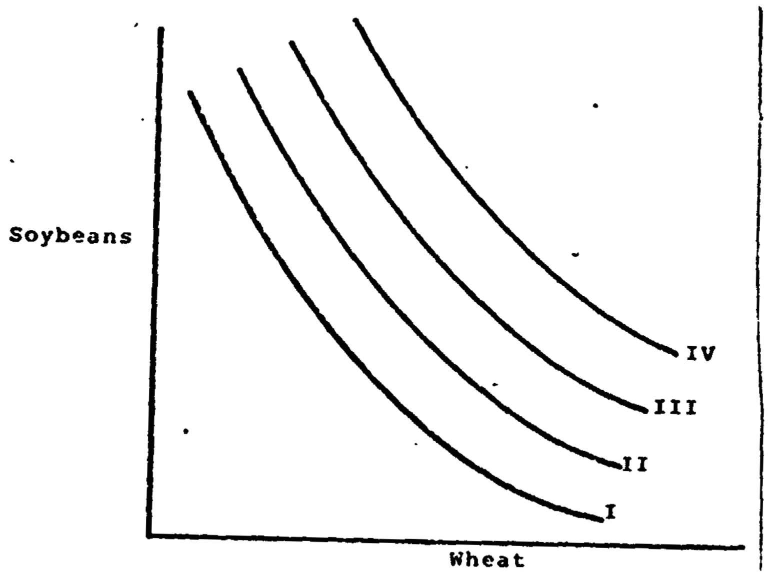

Figure 2.7 An Indifference Map

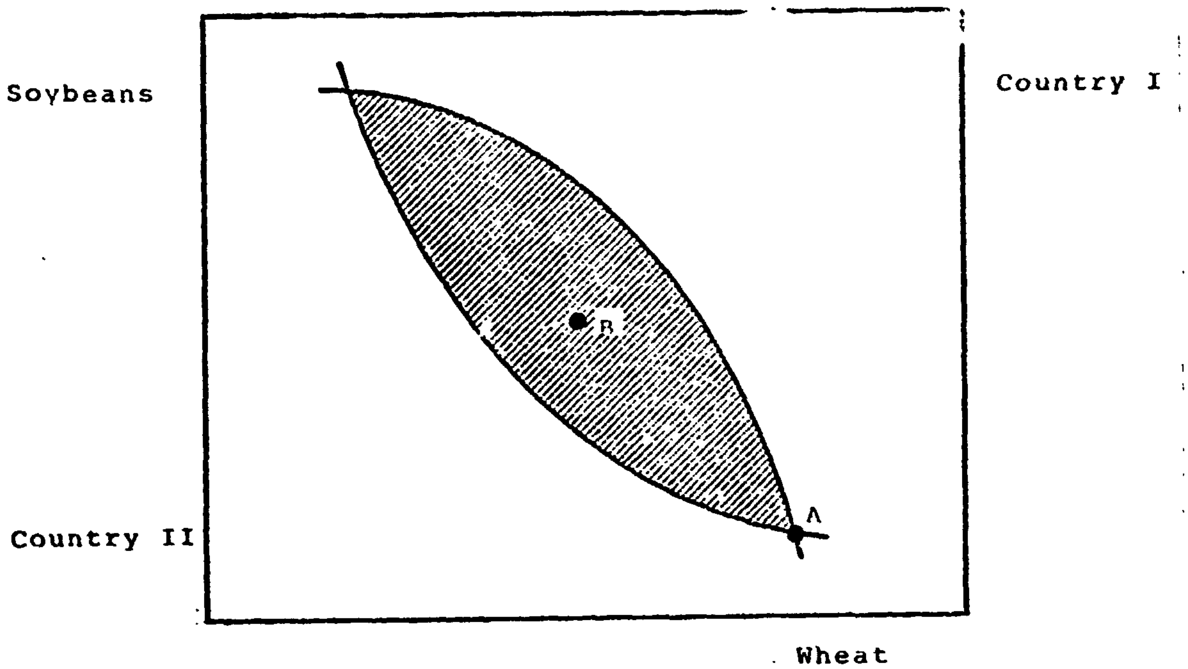

Figure 2.8 Two Individual Indifference Curves--
The Benefits from Trade

Many resource situations are very similar to the wheat/soybean situation discussed above. For example, the consumption of wheat is a process in which the alternatives are to eat the wheat today or to store it for future consumption. The extent to which wheat is stored is a function of its price with expected higher prices resulting in more storage. The wheat futures market consists of a group of individuals who make decisions to buy (store) or sell (release to consumption) wheat. They will buy wheat in the spot market if they believe that the price of wheat will increase, for example, due to a small wheat crop, and sell if they believe that the price will fall (due to a large crop). The consumers are a group of individuals with money that they can trade for wheat. Better crop yield information allows *both* the future investors and the consumers to achieve a better state of trade. This benefit of achieving a better state of trade is entirely independent of changes in production, but it is a very real economic benefit to both parties.

2.4 The Realization of ERS Benefits

The Earth Resources Survey Program has, to date, focused on the requirements of the scientific community. This community has a broad requirement for data with objectives primarily oriented toward a better understanding of man's total environment; that is, all the resources that affect man's existence on planet Earth. Clearly, man's present understanding of these resources is very limited: it is not known how much of each resource exists, where it exists, what its use implies, and so on. In the past, this information was not necessary. But as world population increases and the Earth is strained to provide a comfortable life for everyone, a better understanding of Earth resources and timely information on the present state of these resources becomes vital.

Knowledge of the quantity and distribution of a resource is information which, in itself, has potential economic value to all people. However, as discussed in section 2.1 and 2.2, it is not the knowledge itself that produces the economic value: the economic value depends on new or different actions based upon this knowledge. These actions are taken by individuals who manage or deal with resources--they are not taken, in general, by the scientists who are studying the resources. Thus, before the benefits of a remote-sensing Earth resources satellite system of any sort can be realized, there must be a transition of focus from the scientific community to the user or resource manager community. This is not to say that scientists must reduce or cease their involvement or that the satellite system must become non-responsive to the scientist's needs. The scientists very well might increase their activity level as this transition occurs. But they will certainly become more responsive to the needs of the users.

The evolutionary process from development of scientific theory through verification, application and transferral to the user community is a natural and proper process. It involves a variety of individuals with different talents and specialties from scientist to engineer to economist to manager. To proceed smoothly and efficiently requires careful planning and a continuity of effort.

Where we stand today in this evolutionary process depends, of course, on the particular resource management function under consideration. In many applications, scientific theories are themselves only in a very formative or embryonic state. In other areas, applications of remote-sensed data are already in use by managers.

The type of research required at each step in the implementation process has its own special peculiarities. Consider, for example, the application of information by a farmer who must decide whether or not to spray his fields to protect against a particular type of insect. Clearly, if he knows that there is no danger of infestation, he will not spray, and he will spray if there is a definite indication of danger. But levels of information between these limits carry a degree of uncertainty which represents a source of disbenefits. If the farmer sprays when he does not have to, he loses the cost of spraying and if he does not spray when he should have he suffers loss of crops. Uncertainty in the information available can be interpreted as meaning that at least some farmers will make the wrong decision.

In order to apply remote-sensed data to this management function, it is first necessary to establish a method for measuring the danger of insect infestation. Can insect larvae be detected? Can insect damage be detected? Can the spread of insect infestation be monitored? These questions require research on identifying, quantifying and monitoring events present in the data and, indeed, much research of this type is ongoing. However, recognizing insect infestations in one ERS image does not mean that a technique is ready for application.

The next step is to verify that the technique produces valid results under varying conditions, across a sizable set of images. Now it is necessary to address questions pertaining to the reliability and dependability of the information derived. What is the detection rate? What is the false alarm rate? What is the accuracy of the information derived?

Given that a technical capability which satisfies these requirements can be developed, it is then necessary to provide for the application of this capability to the management functions. In the example cited, this means primarily that satellite and ancillary data must be collected, analyzed and the resultant information must be distributed to the farmer on a timely basis. Then, if the farmer has confidence in the information, he will act accordingly.

Several important points are made in the above example. First, it is not adequate to occasionally detect a phenomenon, given that it is in the data; it must be detected and supplied to the user with at least some minimal dependability. Second, low reliability or false alarms can severely degrade the value of the information. Third, the user is interested in information directly applicable to his management function, not data. Fourth, the information must be supplied on a timely basis and, fifth, the user must have confidence that the information is correct.

In light of these requirements, it is understandable that the major transition from scientific investigation to user application of earth resources satellite data has not yet occurred. The purpose of this section is to quantify the requirements necessary for this transition to take place and to establish a methodology for establishing the value of maintaining continuity of satellite services.

2.4.1 Data Processing and Distribution

Satellite imaging instruments gather primary (thermal IR) and reflected radiation, filter these radiations into various spectral bands and measure the radiation intensity radiance on an image element-by-element (pixel-by-pixel) basis. These data are then converted into a digital data stream interspersed with identifiers, frame sync and line sync data, and other data and transmitted to a ground receiving station. The data received by the ground station are referred to as raw data and, as such, they present no interpretable information. The raw data are next processed to the extent of decoding the received bit stream, computing the appropriate radiances and providing a spatial correlation of image data to geometrical location in an image. The resulting data comprise the least complex or lowest level of information obtainable from the satellite system.

It is now important to distinguish between data and information in the economic sense. Information is knowledge upon which decisions can be based: for example, there is a 75% chance of insect infestation in a particular field. Data are the substance from which information is created. Information derives from processing data in models and algorithms, both primary data and ancillary or supporting data, and it can be characterized in the economic sense by the attributes discussed in section 2.1, which distinguish economically "good" information from economically "bad" information. Also, it is worth noting that what constitutes information for one decision function may only be data for another. For example, a thematic map maker may want to know which image pixels contain wheat and which do not. To him a simple yes-no identification is information. But to a statistician who is trying to compute acreage of wheat crops, this is only data. And one step further, wheat acreage information is only data in the determination of a wheat yield forecast.

From the initial point that remote-sensed data become low level information, repetition of data retrieval, higher level processing and mixing with other data lead to higher and higher levels of information. At each point that information results, that information has economic value if and only if it is economically good information and it is used to influence an action which has an associated economic worth. Thus, if an earth resources satellite system is to provide benefits to users, it must produce economically good information for use in actions which have associated economic worth. Data contained on an ERTS image which delineate areas of insect infestation, for example, are of no value to the farmer unless they are processed into information indicating the need for action and distributed to the farmer on a timely basis.

The processing of data into appropriate information and its subsequent distribution on a timely basis is a problem of considerable magnitude. First, it is necessary to know what information is required for various actions. In many areas of important economic application, for example, in agriculture, a comprehensive list of desired information products does not exist. Nor is it necessarily appropriate to construct such a list at the present time, as the list must obviously be based on a set of capabilities many of which are yet undefined and more scientific investigation may be required even to obtain a comprehensive list of potential applications.

The second problem, having established a list of desired information goals, is to formulate algorithms, that is, data processing procedures, for obtaining these information products. Now the engineering particulars of the satellite system become important. The ERTS multispectral scanner, for example, produces image data at the rate of about one million pixels per second. And ERTS is only a first-generation experimental satellite. It is not at all inconceivable that later generation satellites or even ERTS-like systems using multiple satellites could produce image data at the rate of ten million to perhaps one billion pixels per second. Indeed, the potential benefits of remote sensing increase substantially with both increased resolution and frequency of coverage thus arguing for higher data rates.

In terms of modern high speed digital computer technology and near-term projections of this technology, it is impractical to think in terms of meeting the earth resources data processing requirements using general purpose computers. However, a technology does exist that can meet these requirements. It is the technology of "pipeline" computers. As opposed to a general purpose computer which operates on individual data blocks by applying generalized sequences of programmed instructions which may operate repetitively on the stored data, pipeline computers pass the data block sequence once through a set of programmed instructions.

Programming of a pipeline computer is limited in two ways. First, not all mathematical manipulations can be performed on a pipeline computer; and second, programming changes are limited by the hardware limitations of the device. Thus, one must have a fairly well formulated algorithm of the proper form in advance of procuring a pipeline computer. Until the information requirements are well established and algorithms and models fully developed and tested, so that procurement of adequate computing hardware can be accomplished, the needs of users requiring fast service must go largely unfulfilled.

The third problem arises from the question of who should have the responsibility to obtain and distribute information. For example, should the Department of Agriculture be the agency responsible for agricultural information? If so, to what level of quality, detail, timeliness, et cetera? Where the government does not provide adequate service, private industry might very well find profit incentives to act as either a supplier of information or, may exploit the information themselves. The problem of responsibility leads also to the problem of information interchange between agencies, especially where information outputs depend on many data inputs of widely different sorts. This interaction is shown schematically in Figure 2.9. It should be noted that a third dimension also exists, but is not shown on this figure: that of time. As data are processed into higher and higher levels of information, time is consumed by ancillary data collection, interagency communications and the computational procedures. Distribution to the user can also be a time consuming process. Yet for the information to be useful, the entire process leading to information in the hands of the user must be set up to occur on a timely basis.

Now the first time that a user is given new or better information, he cannot be expected to immediately begin to use that information, let alone use it in an optimal way. The example of weather forecasting serves to make the point. If the local weather announcer stated that a major breakthrough had occurred and from now on all weather forecasts would be 100% correct, this improvement in information should clearly affect the actions of nearly everyone. And yet, probably only the actions of a very few people will be affected during the next day or the next few days. It will not be until people believe

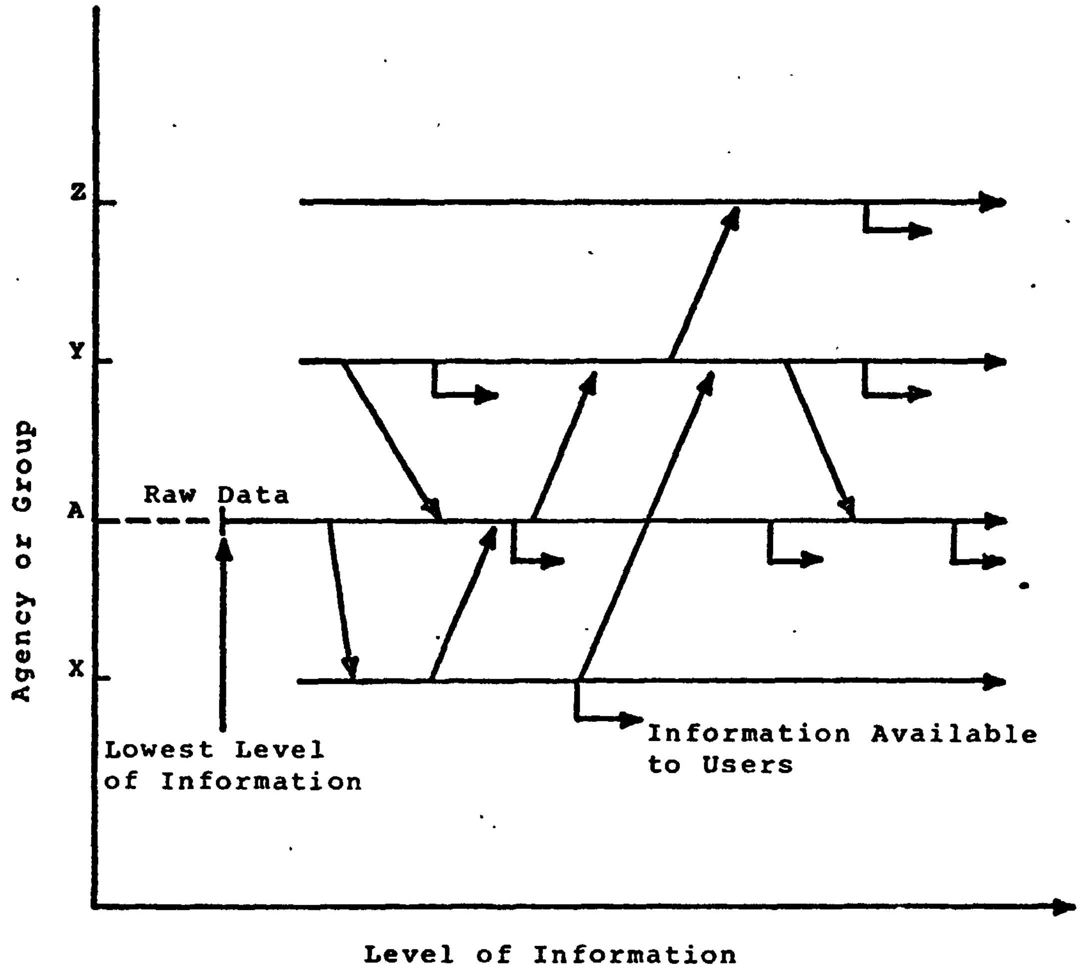

Figure 2.9 Schematic of Information Processing and Interchange Between Agencies or Groups

the new forecasts that they will actually adjust their actions accordingly. This takes time. In the case of something as overt as a change to 100% accurate weather forecasting, it is not unreasonable to think in terms of the adjustment taking on the order of months to occur. For something far less overt, such as an improvement in crop yield forecasts by, say, 3% on a monthly (rather than daily) basis, the period of adjustment could take on the order of years. This process of acceptance of new or better information can, in fact, be modeled as a problem in the statistics of perception probabilities.

2.4.2 The Value of Continuity of ERS Service

This section deals with the economic benefits foregone in the event of a one-year gap or a two-year gap in ERS coverage providing at least the capabilities of an ERTS system. The benefits foregone can be expressed as the sum of two parts, the value of a continuing benefit stream beyond ERTS-B and the value of continuity of service in providing a more rapid build-up rate of the benefit stream prior to and during the ERTS-B mission, and this in turn depends largely on the projected future of ERS systems. Thus, the mere assurance of a follow-on program beyond ERTS-B can and probably will affect the benefits derived directly from an ERS program.

At the moment, NASA is committed to launch the ERTS-B satellite, tentatively in February 1975. If ERTS-B fails to orbit and function properly, there is, of course, no backup satellite and ERS services will be interrupted. There exist, no doubt, many individuals and groups whose interest in the ERS Program is dampened by this uncertainty.

In this analysis, we assume that ERTS-B is successfully launched and activated as scheduled. The satellite is expected to last for two years, and there is every reason to believe that it will, but no guarantee that this is the case. In any event, ERS users face even greater uncertainty beyond ERTS-B: Will there exist a satellite to take over the ERS data-gathering function when ERTS-B fails? Will it be successfully launched and activated? What happens if it fails? What comes after it?

In principle, a program of phased growth of some sort should interest the largest number of users. First, it is recognized that the ERTS satellite is a first-generation, R & D experimental vehicle. But its potential usefulness, capabilities and reliability are now demonstrated. An abrupt advance to a more sophisticated ERS satellite without continuing the ERTS Program is fraught with uncertainties that could very easily overshadow its improved capabilities in the short-term. Thus, independent of the sophistication of the second-generation ERS system, there is value to a continuation of the ERTS Program, even into an overlap period. Second, it is clear that, until the risk of interruption of ERS service is removed, many potential users will choose not to make use of ERS data.

The effect of risk on a rational investor is a quantity that can be measured. It is well established that most individuals will pay, that is, forego profits, to reduce risk. For example, most people are not averse to obtaining as little as $1.03 or $1.04 for a guaranteed short-term investment of $1.00. However, this would certainly be unacceptable if there were a 50% chance of getting $0 back. In the latter case, a rational person would not invest $1.00 unless, with 50% probability, more than $2.00 were returned (but with 50% probability of zero return). Conservative or risk averse individuals will insist on substantially more than $2.00 return even on a very short-term investment particularly if the $1.00 constitutes a large portion of his net worth. The amount beyond $2.00 required to entice the individual into the venture is a measure of his cost of risk or, conversely, a measure or what the individual is willing to pay to reduce risk. Most successful investors are quite risk averse.

At the present time, the ERS Program contains a great deal of risk to the potential user. Will the program continue? Will there be gaps in service? Will the nature of the service change drastically? These risks impose a perceived cost on present and potential users that cause them to exercise this new (ERS) capability in only a very cautious and limited manner, thus foregoing many of its potential benefits. Elimination of gaps in ERS services will certainly reduce this risk and thus increase the benefit stream. Only a long-term commitment to continuity of service can create an environment in which full realization of the ERS potential as reported in this study will be possible.

It is necessary to take a brief look at where remote-sensing of Earth resources stands today and what factors can influence the rate at which the ERS benefit stream matures. The ERTS investigations to date have focused on a scientific evaluation of the general capabilities of an ERTS-type satellite. Can wheat, corn, rice, etc. be recognized? Can acreage be measured and to what accuracy? Can snow and clouds be differentiated? Can forest insect infestations be observed? Some transfer from scientific investigation to the user has occurred, but it is minimal *compared to the ultimate potential*. Part of the reason for this is the sequence of events that must transpire before this transfer can be accomplished.

First, after establishing scientific feasibility of an activity, for example, obtaining wheat acreage from an image, it is necessary to validate the results across many images, of many different areas, under differing meteorological conditions.

A new set of questions, operational questions, must be answered. How dependable is the ERS system for this activity? With what reliability can wheat be recognized? What is the false alarm rate? How can recognition based on spectral signatures be extended to areas with little or no on-ground observations? It may be possible to observe some phenomenon 100% of the time when it occurs but, because there may be a high false alarm rate, there is no guarantee that there is any associated economic value.

Second, given that validation of an activity is complete, it is next necessary to provide for the application of the activity to meet the needs of a user. For example, given that wheat acreage could be measured over a large area, dependably, reliably, accurately, these data must still be put into some useful context. To the farmer, this may mean biweekly estimates of wheat crop production yield and acreage. Thus, ERS data must be combined with other supporting data (it may very well be that the ERS data are the "supporting" data), processed into the information that the farmer needs and distributed to him on a timely basis. Because of the magnitude of this problem, improved wheat crop forecasts cannot come about over night after the launch of an ERTS satellite. Appropriate government agencies must set up new operations to handle the new, better and greater volume of data. Often, this will involve interagency cooperation, for example, between USDA and NOAA.* It will also frequently involve a considerable expansion of computer and other data processing facilities.

It is important to remember that providing for information dissemination is an important component of the *application* process. The best information on wheat crop acreage and yield is of no value to the farmer after he has harvested and sold his crop--or plowed it under.

The above two steps, validation and application, are sequential and come only after scientific and technical feasibility has been demonstrated. Clearly, these steps can require two-to-five years or more for various activities depending upon the scope, complexity and difficulties encountered. Yet, when they are complete, the benefit still does not emerge immediately, "off the shelf."

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* To obtain this interagency cooperation there exists the Interagency Coordinating Committee Earth Resources Survey Program.

The last step is transferral to the user. Again, this is a process that takes time. Assume that USDA is suddenly able for example, using an ERS system, to improve its annual wheat crop forecasts by, say, 2% (a reduction in expected error by 2% of the established expected error in any month). One could expect that farmers would take advantage of this improved information, but not immediately. First, the farmer must become aware that an improvement has indeed occurred and learn to make full use of the improved information. He has to gain confidence in the information.

In summation of the above qualitative analysis, it is apparent that anywhere from two to maybe ten years will pass before some major operational applications of ERS data are providing significant benefits. It is also apparent that this process is deterred somewhat by a present lack of a firm, long-term commitment to continuity of ERS satellite services, especially by a potential, imminent gap in service following the useful lifetime of the ERTS-B satellite.

Two distinct catgeories of Earth-resources activities are complemented with ERS information: mapping and monitoring. Mapping activities are those which include the use of ERS information in an open loop decision process.* ERS and other data are combined to provide timely information for a decision. Follow-up on the decision is then exclusive of the ERS system. A peculiar aspect of a mapping application from the user's point of view lies in the *risk* associated with the use of the ERS system. Many mapping applications are such as to permit the user to wait until the satellite has collected adequate data for his application before making any investment. His investment may, in fact, come as late as the time at which he actually has the ERS data in his hands. Furthermore, since there is no need to follow-up on his subsequent decisions using ERS data, he has now essentially eliminated all elements of risk associated with the data collection process. It remains only for him to process the data that he has in hand.

Figure 2.10 shows the above process schematically. Since the user does not begin his investment until after the satellite has completed (or nearly completed) the required data collection, the time of satellite failure, interruptions in service, what comes next, etc., are all largely irrelevant to him. He has eliminated, by merely waiting for the appropriate time to invest, the risks associated with continuity of service.

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* Not to be confused with map making.

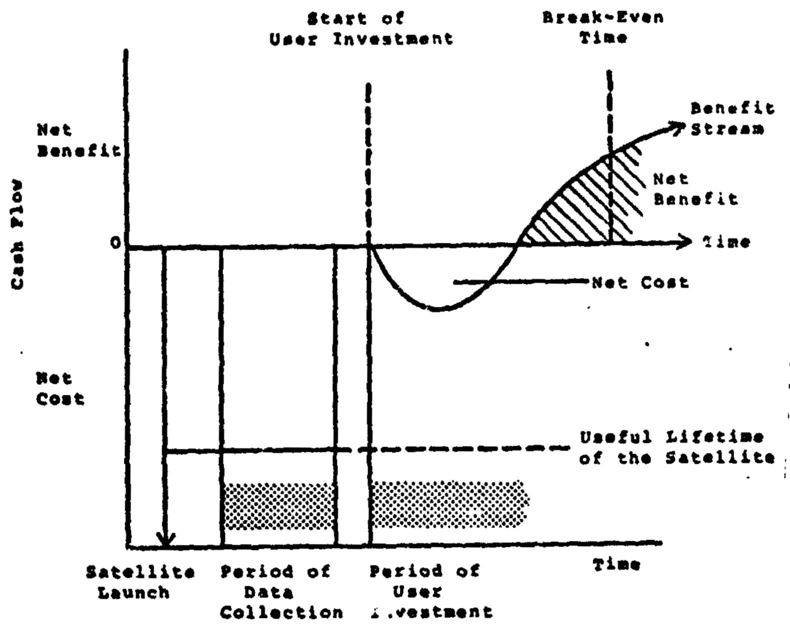

Figure 2.10 Scenario of User Involvement in an ERS *Mapping* Application

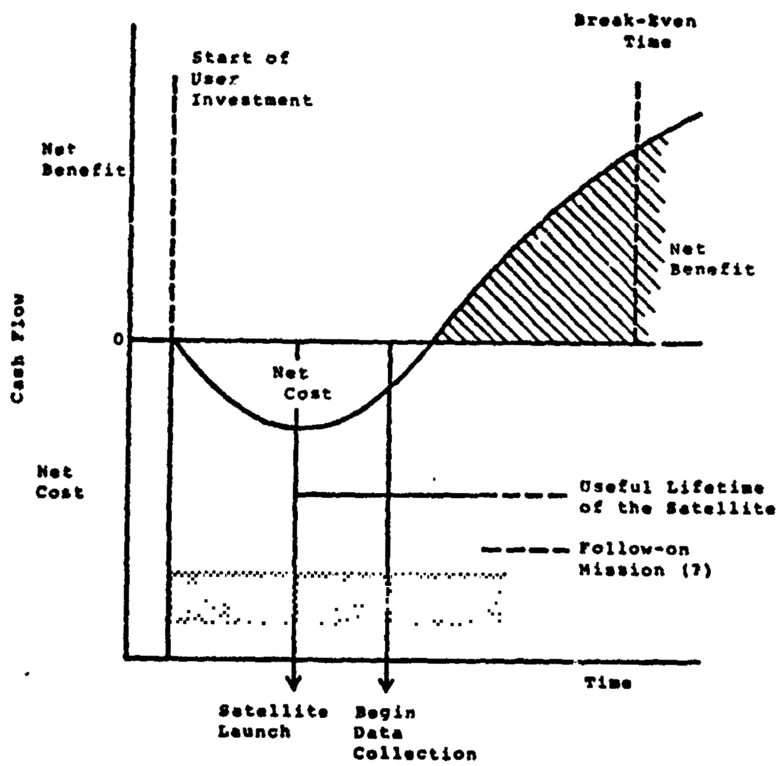

Figure 2.11 Scenario of User Involvement in a *Monitoring* Application

Monitoring applications are substantially different from the above point of view. Monitoring decisions are made on the basis of data presented at a variety of points in time. The effects of previous decisions are evaluated using new satellite data in a closed-loop process and future decisions derive their bases from the effect of (monitored) previous decisions. Here, the investment must be made *in anticipation* of satellite data - often even before satellite launch - to insure an operational application capability early in the mission. Figure 2.11 details the monitoring application. It is now generally impossible for the user to protect himself against the uncertainties of the satellite launch and deployment, and the useful lifetime of the satellite. Furthermore, monitoring applications typically involve larger initial investments and have a longer time to break even. Thus the user often cannot help but to be concerned over potential interruptions in service and the nature of the follow-on program. Almost all large-benefit ERS applications are monitoring applications.

Monitoring applications comprise two types of information gathering requirements:

(1) *Complete area coverage requirement:* This requirement is typical of land use planning functions. The requirement in this case is to cover, with assurance, a total, contiguous area (a state, a drainage basin, an estuary). Under this requirement the incidence of cloud cover is an important and limiting factor in determining total system configuration (space, aircraft, ground). The economic issues arising from this requirement are addressed comprehensively in the land cover case study (Volume VI, Part II).

(2) *Sampling of observations for national, regional or worldwide estimation requirements:* Requirements of this type are typical for purposes of national, regional or worldwide crop inventorying and forecasting purposes, among others. In this application requirement all that is necessary is an assurance that enough statistically valid observations are made from each subregion, often "floating" sample observations, to allow a statistically significant regional, national or worldwide

measurement, inventory or forecast. Under this requirement cloud cover poses no major problems to observations from space in the United States in the main application areas.

The above discussion provides the basis for an assessment of the value of continuity of ERS service. The assessment is presented in Volume I, Section 4.1.

3. KEY FINDINGS OF ECON CASE STUDIES

In this chapter the relevant case studies performed by ECON are summarized. These include two case study reports on agriculture (under Contract NASW-2558), one ad hoc case study on water management, and a land cover cost effectiveness study of ERS systems (under Contract NASW-2558).

3.1 Case Study on the Value of Improved (ERS) Information Based on Domestic Distribution Effects of U.S. Agriculture Crops (Wheat)

In this case study the theory necessary to evaluate improvements in the *measuring* system used to produce grain crop harvest forecasts is developed. Crop forecasts are used by a variety of agents in an economy for consumption and production planning. Two classes of agents of particular importance are singled out: farmers (in their planning decisions process) and inventory holders (in determining how much to hold). Of these, in turn, the uses of better information by the second group are likely to generate the larger share of benefits. In addition, it turns out that the way in which a theory of inventory determination leads to a value of information is somewhat simpler than that required to incorporate producer decisions. In this case study, only the benefits derived from improved inventory decisions are considered.

This is not the same thing as considering only benefits to inventory holders. Quite the contrary is the case of the economic system studied most closely, the competitive market system. The tendency of competition to eliminate super-normal profits causes the benefits of improved information to be transmitted to those buying and selling from inventory holders. In our model, because production decisions are considered as fixed, this means that only distribution benefits to consumers of wheat, either directly, as in cereal and bread, or indirectly in the form of meat, are included.

Actually, very little grain can be said to be consumed "directly," since milling and baking are necessary to produce bread, breakfast cereal, noodles, etc. The use of grain as an input to some further production process is considered to be "consumption," as distinguished from storage. Since the demanders of wheat from the inventory system include such producers, some of what is labelled "consumption benefits" will actually occur in the form of increased producers' surpluses (rents), although, again, in a market system competition tends to lead to a further passing along of such gains to ultimate consumers.

The "objective" form of the benefits derivable from better information is taken to be a smoothing of the flow of consumption. In a market system this corresponds to more stable prices. The value attributable to reduced variability of the grain consumption flow derives from the phenomenon of diminishing marginal valuation, the tendency for increments of a good to be more highly valued when little is available, and less highly valued when a great deal is available.

Although there is a world grain market, and our theoretical model applies as well to that system as to a single national market, in applying our analysis we chose to confine attention to the benefits generated for U.S. residents arising from improvements in *forecasting* U. S. harvests of wheat. (Note that one could sensibly consider the benefits generated for world residents from better forecasting of U.S. wheat harvests, or benefits for U.S. residents from better measurements of world wheat harvests. The same methods apply, although different econometric problems would be encountered.) The concentration on the United States was influenced in part by the obvious concern U.S. policymakers will have for benefits within the country, and in part by the availability of reasonably good data with which to estimate crucial parameters for this system.

For similar reasons, the modeling effort is directed at inventory determination in a market system. Crop estimates are, obviously, produced and used in economies organized in other ways. Indeed, the active intervention of the U.S. government in the domestic market system means that even in the United States the market model has not been the appropriate one for many periods. However, at the present, the competitive market mechanism dominates the determination of grain inventories in the United States. This is fortunate, since modeling the political determination of inventories poses more difficult problems.

3.1.1 Overview of Case Study

The layman understands well that information can be valuable, but that the value to one individual may be at the expense of another. The football defense based on a knowledge of the other team's signals is sure to be a good one, but that gain due to better information comes at the expense of the offense. On the other hand, some information, such as the timing of the crest of a flood, is clearly of general social value. In the case study, first an informal discussion of the value of more accurate crop forecasts is presented with an attempt to isolate the concepts subsequently incorporated into the formal model.

The "better" information gained from data obtained by advanced technology methods does not lend itself immediately to better forecasts. The remote sensing devices and associated data processing systems produce data which may allow for improved accuracy of measurement of such phenomena as planted acreage, crop stress, harvested acreage, etc. This information is then used to produce forecasts by incorporation into a forecasting model. There is a tendency to equate shortcomings of forecasts with shortcomings of input information or data, but the first may arise through bad forecasting models and through the sheer randomness of events occurring through the time between forecast and outcome. Then the model of crop forecasting used in the study is described. The notion of "ideal forecast" at a point in time is introduced. This is the forecast which could be constructed on the basis of perfect information about the things which are knowable at that time. The *measurement error* component of a forecast is assumed to arise from imperfect perception of the "state" of nature, when the measurement is made. Measurement improvements result in better estimates of ideal forecasts.

Information may be improved in another way as well, by reducing the lag between the date of measurement and the availability of the resulting information in the form of a forecast. The framework established in the case study (Volume III) makes it easy to keep track of this aspect of information quality, which seems likely to be an important one in the application to satellite systems.

Next, the way is shown in which better information in the guise of improved forecasts has socially valued effects as transmitted through improved inventory decisions. The important point is established that the value of information depends upon the rule by which such transmissions take place. If the *use* of information is not appropriate, "improved" information may be valueless. Using a one-nation world, a measure of the value of information and a theory of the nation's incorporation of information into inventory decisions are developed.

The nation's choices are taken to be optimizing behavior. With only minor modification, however, the general form of the problem can be used to describe that of inventory determination in a market system. Whereas one could simply assume an objective function for the nation depending upon the monthly grain consumption, it is necessary to derive a social objective function. One can use the area under the demand curve to represent the dollar value of any specified quantity of grain consumed. The benefits of an improved information system are taken to be measured by the expected value of annual grain consumption (by month) less storage costs. This is set out in Section 4 of the case study (Volume III) in detail.

While the inventory decisions could be derived from the optimizing behavior, the rule by which forecasts influence inventories in a market system must be determined from profit-maximizing behavior of many competitive inventory holders. Competitive inventory holders earn profits by the capital gains on their stocks. If the increase in price from period to period is large enough to compensate for storage and interest costs they hold additional inventories. If the price increase expected is too little, inventory holders sell off their stocks. The price is determined by the amount made available to consumers, which is the sum of heldover inventories and current-period harvests, less inventories carried forward. Thus in order to predict prices, inventory holders must predict their own future decisions. The way in which this system can be closed is then shown. Along the way futures markets are introduced to coordinate the expectations of inventory holders as a group.

A full theory of the relationship between information as translated into forecasts and competitive inventories is developed. All of the pieces are then put together in an empirical application, calculating the value of improved information in the case of the U.S. wheat market. Most of the required parameters are estimated with reasonable confidence. *An exception is the current and prospective degree of accuracy of measurement systems*. The final estimated results are therefore presented in parametric form.

The accuracy of current agricultural crop forecasts was estimated with the assistance of published results such as the Goddard Task Force on ERTS*. For a single crop, winter wheat, the accuracy of USDA-SRS forecasts of the total U.S. crop is about ±14% at 5 months and +2.10% at 0 month forecast lag.

The performance of USDA for the years 1969-1972 is shown in Figure 3.1. However, all of these accuracy numbers refer to *annual* crop estimates. The errors include measure-

* D. B. Wood. The Use of the Earth Resources Technology Satellite (ERTS) for Crop Production Forecasts, Draft of Final Report, Goddard Space Flight Center, July 2, 1974

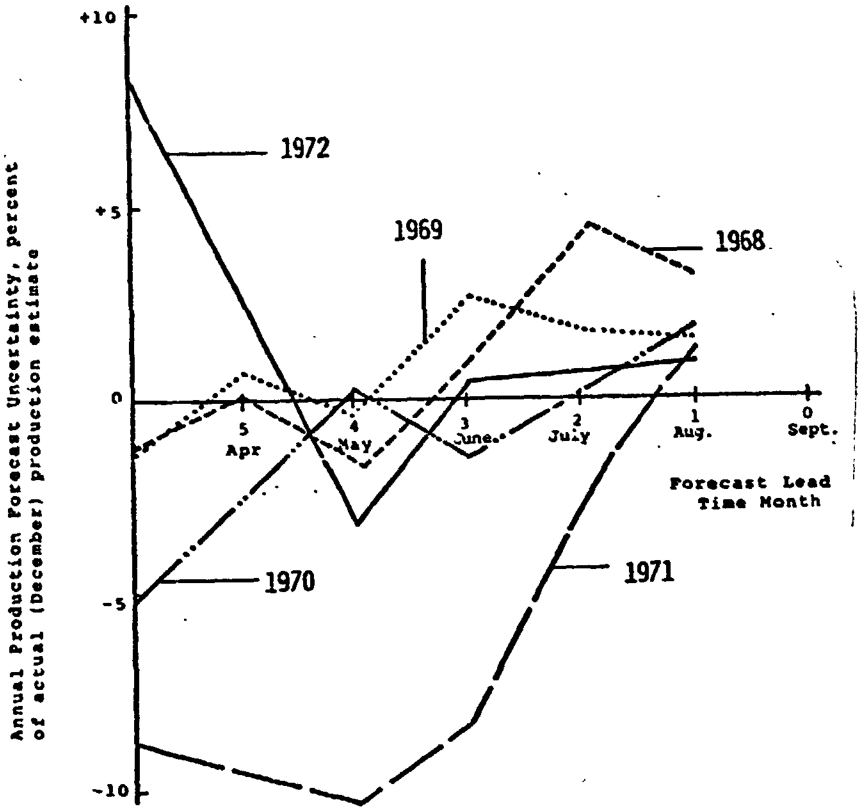

Figure 3.1 Published USDA - SRS Forecast Accuracy
Winter Wheat -- Total U. S. Crop

ment errors, errors due to the time lag between measurement and publication of estimate, and nature's randomness before the actual harvest.

However, taking USDA estimates at *completed harvest* (for winter wheat) and accepting the *December estimate* of USDA of the same calendar year as completely accurate (i.e., ignoring the fact that one never really knows precisely the crop of any year), the measurement errors of USDA crop estimates at completion of the U.S. harvest season are still 2.2% for winter wheat and 4.4% for spring wheat. In order to achieve these measurement accuracies for the *annual* harvest, much larger measurement errors are implied for the harvest as it comes onto the market.

Each crop is harvested over several months. Crop-specific *monthly* harvest patterns based on 1969 USDA data have been taken by ECON as typical of the crop. The task force on agricultural forecasting estimated that at *completed harvest*, ERTS type systems can *improve* USDA estimated by 50-70%. Furthermore, ERS systems can observe fields throughout the growing season. *Whenever* the harvest occurs, the measurement accuracy of ERS systems at *completed* harvest in any one major region should be the same, irrespective of whether the harvest occurs in May, June, or August. This is so since the sample size (numbers of pixels in any crop area) is potentially unlimited. Thus, even with *no* improvement by the ERS beyond the actual USDA crop estimate accuracies at completed *annual* harvest substantial improvement can be expected from ERS systems in terms of better month-by-month harvest estimates, and this improvement will have *economic* value. A 4.4% ERS crop measurement accuracy *at harvest* for spring wheat in 1969 would imply a reduction of the monthly harvest measurement error from approximately 16% to 4.4%, an improvement substantially larger than 50%. A 2.2% accuracy of ERS crop measurement accuracy *at harvest* for winter wheat in 1969 would allow a potential reduction of monthly harvest measurement from 8% to 2.2%, again an improvement substantially more than 50%. It is likely that thorough statistical analysis will yield similar improvements for other years.

The current accuracies of crop estimates for winter and spring wheat are not precisely known except for the range of numbers just given. For ERS systems, divergent claims are made, ranging from "no improvement" of USDA *annual* estimate accuracies to 50-70% improvement as claimed by the task force on agricultural forecasting.

Given these divergent technical claims for purposes of this analysis and to arrive at the basic estimate of ERS benefits, it is assumed* that *monthly* harvest estimate errors can be reduced for winter wheat from 7.5% to 3.75% in spite of the likely potential of ERS systems to achieve 2.2% accuracy; and for spring wheat from 15.8% to 7.9% instead of 4.4% ERS potential accuracy. The ranges of likely economic benefits resulting from such improvements in accuracy of the estimates are listed in Table 3.1 at a 95% confidence level. The calculations are based only on the benefits resulting from improved information on the U.S. wheat crop.

Table 3.1 indicates how this particular measurement improvement would be affected by various changes in the underlying parameters. Although the range noted there is large, this is the result of including for comparison purposes a parameter value used in other studies (that of the elasticity of demand) which is replaced by new econometric work.

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* To the extent that the pattern of monthly harvesting departs from the 1969 wheat crop pattern, the economic benefits of an ERS system in agricultural forecasting will also be affected.

Table 3.1 The Value of Reducing Measurement Error Based on Goddard Task Force Results on ERTS: Wheat Crop

Price Elasticity for Wheat Demand a/	Benefits in millions of 1973 dollars associated with α, 95% confidence limit for percentage error in monthly harvest measurement		
	7.92% g/	10%	15.84% h/
1. -.065 b/	95.1	151.7	380.4
2. -.10 c/	61.8	98.6	247.2
3. -.25 d/	24.8	39.5	99.2
4. -.50 e/	12.4	19.7	49.6
5. -0.75 f/	8.2	13.2	32.8

a. United States domestic demand for all wheat, except as noted.

b. The authors of Vol. III, Part II have estimated this value for "human purposes" (food) elasticity of demand for wheat.

c. EarthSat estimate in recent report to U.S. Department of the Interior.

d. 50% reduction in the basic estimate, No. 4: for sensitivity analysis.

e. The basic estimate obtained by the authors for the price elasticity of unconditional demand for wheat (1971 data).

f. 50% increase in the basic estimate, No. 4: for sensitivity analysis.

g. α derived from 2.2% error in annual harvest (May crop measurement error for Winter Wheat).

h. α derived from 4.4% error in annual harvest (September crop measurement error for Spring Wheat).

Taking into account the wide range of estimated elasticities, and the previously noted 95% confidence limit of benefits calculated for each elasticity and each percentage error, we find that the U.S. gains annually from the ERS improvement of wheat crop information:

- 8.2 - 95.1 million dollars for Winter wheat
- 32.8 - 380.4 million dollars for Spring wheat

To achieve a narrower range of plausible distribution benefits using round numbers, we would suggest adopting a single median value of 10% monthly measurement error with a range of elasticities from -.50 to -.10 which leads to potential annual ERS benefits of:

- 19.7 - 98.6 million dollars

3.1.2 Informal Discussion of the Value of Accurate Forecasts

The subject of the value of information is a broad one and usually concerns the current value of certain measurable quantities. An ERS space system is expected to provide more accurate information about the current status of different agricultural crops, which will enable one to predict with greater accuracy the quantity of those crops that will emerge from the farm at specified times in the future. Information of this kind may be distinguished at least for practical purposes from information about new technologies, which in principle might never be revealed at all.

A forecast of the future is expressable, explicitly or implicitly in the form of a probability distribution. Such a distribution may be thought of as representing the degree of certainty of a person's beliefs about the future.

Of course, a forecast is usually summarized by a single number: the wheat harvest forecast for the year 1975 will be a number such as 2,000 million bushels. This number is the mean of the distribution of harvests characterizing the belief of the person making the forecast. Equivalently, one may think of the beliefs as characterized by this number plus a distribution of errors, the various deviations between the 2,000 million bushels forecast and what the forecaster anticipates will actually occur. Corresponding to this *subjective distribution* is an *observable distribution* (in principle) of deviations between the forecast and what is known to have occurred after the fact. These observable quantities are what are normally referred to as "forecast error." The subjective distributuion is the one relevant for decision-making. For the most part the term forecast error is used to refer to both concepts, refering to the distinction only where confusion may otherwise result. It is assumed that such distributuions are completely determined by specification of mean and variance; sometimes these are treated as Gaussian normal.

Forecasting error variance expresses the degree of uncertainty, which may arise from two sorts of sources. First, one may not have a very good idea of what the state of the world is now or has been in the past. For example, one may have only a crude thermometer available to assist us to forecast the afternoon temperature. Second, there may be events which are genuinely random, or may be treated as such, which will occur between now and the time point to which the forecast is directed, which make it impossible to know the future with certainty, no matter how clear the picture of the present state of affairs: no matter how accurate the knowledge of the starting point of the roulette ball, one may not be able to narrow the forecast error on its ultimate stopping point. (The example illustrates the ambiguity of the distinction. Presumably if one *really* understood the roulette wheel and could calculate well enough, one could improve the forecast.) The "information" here is directed toward reducing the variance due to the first source. Improved information allows one to make more accurate forecasts, expressible as a reduction in the dispersion of a subjective distribution of forecast quantities before the fact and, correspondingly, a reduction in the dispersion experienced by forecast error (deviation between forecast and actual quantities) after the fact. Such a reduction might be achieved by obtaining from the farmer precise information about the amount of wheat he plans to plant in June 1974. While, before the harvest, the uncertainty about the outcome resulting from weather variability remains, the information about the planting allows one to construct a guess about the resulting outcome in September which is more accurate than the guess in the absence of the information. The degree to which an estimate is improved can be expressed by a reduction in the variance of the subjective distribution and of the forecast errors.

The value of information thus depends upon the value of good forecasts. In the remainder of this section a discussion is presented why forecasts are valuable and to whom. This will form the basis for the formal theory used in the case study measurements.

3.1.3 The Meaning of the Value of Forecasts

When one speaks of the value of forecasts one must distinguish carefully between value to the entire economy and the value to a single individual. It is often possible for an individual to reap large gains from a possession of knowledge of greater accuracy than that possessed by others. This is illustrated by the example of a price prediction, say of a painting by Rembrandt which is to come up at auction in September, 1974, and which is now on the market for purchase in January, 1974. Knowing exactly what the Rembrandt will sell for 8 months hence, one can make a certain decision now what price it is worth paying. The accurate forecast of the future allows one to make with certainty a gain now. However, should the information lead one to decide to buy the painting now, in January, the effect is to shift the profit obtained by the difference between the selling price now and that 8 months hence, but at the most of an equivalent gain in the hand of someone else who might have purchased the painting. The opportunity would obviously have been lost to the former were the information about the price to rule in September available generally instead of available to one person alone.*

In this illustrative case one sees that the sole effect of improved information in the hands of a single individual is to alter the incidence of a gain from one person to another. Presumably the ultimate purchaser of the Rembrandt in September would have ended up holding the painting in any case, and the only effect of improved informaion is to place the gain in the hands of one person rather than in someone else's hands. It is usual in applied welfare economics, although not always justifiable, to equate equivalent dollar amounts of gains by one person with the same amount of gains by someone else. In this case there has been a private gain offset by an equivalent loss from the improved information about the price of the Rembrandt in September, 1974. Though there have been possibly large changes in private wealth as a result of this information one can say, loosely speaking, there is no social gain whatsoever.

This distinction between private gain and social gain may be even more dramatically illustrated by pointing out the possible advantage to an individual of misinformation in the hands of others. Thus, if one person wishes to purchase a piece of property it may be greatly to his advantage that

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* It would be desirable to have different terms for the various meanings of the word "information" occurring in this study. Strictly speaking, the word is intended to refer to an estimate of some observable quantity, such as the number of acres planted in wheat. In this sense, a forecast is not "information," at least given the current development of normal human perceptions. It seems rather pedantic, however, to enforce this distinction throughout the text; hopefully no confusion will result from this usage.

everyone else in the world thinks it highly likely that a major highway is going to be built across that property, even though he knows with certainty that this is not the case. Even though other people may be caused by the misinformation to make various bad choices, that person stands potentially to make a substantial gain. Again the crucial point for estimating private gain is the degree of inequality or asymmetry of information in the hands of different individuals. In this illustrative case it should be clear that there is in no sense a possible social social gain to be had from the promulgation of misinformation, even though this might be greatly to one individual's private advantage.

3.1.4 Sources of Social Gain from Improved Forecasts

There are two broad sorts of social gain from a general reduction in crop forecasting error. First, by virtue of good forecasts of forthcoming crops a society is able to make improved allocative decisions. Both by making better timed disposition of inventories of available farm products, and by making planted quantities take into account anticipated harvests the society can optimize the flow of consumption over time. The underlying idea is that it is desirable to have a smooth flow of consumption of commodities, rather than an irregular one. This is the familiar principle that the value of increments to consumption of a good decreases as the quantity consumed increases: The value of an additional bushel of tomatoes in the presence of a large crop in August is much smaller than the value of an increment of a bushel in the middle of winter when few tomatoes are available.

Secondly, a reduction in the dispersion of the subjective distribution of forecast errors, i.e., an increase in the degree of certainty, may be valued in itself. One customarily assumes that economic agents prefer a certain outcome to situations in which the average of expected outcome is the same but with some variance. It is this value which is referred to when one speaks of individuals having risk aversion, the prevalence of which is suggested by such phenomena as insurance and portfolio diversification.

In this study only the gain of the first sort is considered: that arising from an ability to make decisions which are less likely after the fact to have proved incorrect. The value of reduced undertainty *per se* will be ignored. In the context of models to follow of behavior of agents in markets under uncertainties, this assumption that uncertainty *per se* is not a source of loss of value will be embodied in the assumption that agents act to maximize expected monetary profits.

3.1.5 Measurement of Inventory Adjustment Gains Only

Within the class of allocative gains we further restrict our attention to those resulting from improved inventory choices. There are two reasons for this. The first is that in the case of wheat, the crop to which our analysis is applied empirically, the possibility for significantly adjusting production within the crop year appears limited. This means that we are guessing that the size of the gain from this source is small relative to that available from the inventory improvements. It would, r doubt, be most desirable to test this guess by carrying out the analysis and measurements, which brings us to the second reason for starting with a concentration on inventories. The analysis of this problem is simpler than that of the case of endogenous supply decisions. Since the chain of reasoning and calculations trace in the study is already rather long, there is a great advantage in resisting the further complication. At the same time, while our expectation was fulfilled that it is possible to obtain highly convincing econometric estimates of demand parameters, there is every reason to expect great difficulty in estimating supply parameters. Thus both reasons of theoretical complexity and estimation problems reinforce our preference on grounds of expected relative potential gain for considering the pure inventory adjustment model. The integrated systems effects of improved (ERS) information in U.S. Agriculture will be examined in the second case study.

3.1.6 The Distribution of Gains from Improved Information

It may be thought that the gainers and losers from the production of new and better information are affected by the way in which the new information is introduced into the system, and this indeed appears to be the case. Clearly from our discussion of the possibilities for private gain from asymmetry of information above, it should be clear that the particular agents to whom new information is first communicated tend potentially to reap large personal benefits, exactly how large is a matter which appears rather difficult to settle.

An example might be made of a discovery by a corporation of large deposits of some mineral. This discovery will be reported to the general public on a specified date in the future; in the meantime it is of extraordinary value to an insider who may be able to capture enormous speculative gains, much as our Rembrandt purchaser was able to in the earlier illustration. By the same token it is clear that it is possible to introduce information in some ways which is actually harmful to individuals, at least in the *ex post* sense. In this case, for example, thie individual who sells his stock in the company which has discovered the large mineral deposit after the fact will certainly be less well off than he would have been had all of the information become available on the date in the future when it was to be made generally public.

Of course even information in the hands of a stock market insider is transmitted at least partially to the general public via the very process by which that individual capitalizes on his advantage, in this case through the resulting increase in the price of the stock of the corporation in question due to his purchases. In this way information in the hands of the insider is related to decisions of other people by their observation of the market price of the stock.

Similarly in the case of improved forecasting the potential for speculative gains in the hands of individuals in possession of improved information are obvious distributional consequences, shifting gains from one group to another. Here too the information would in part be made available to the general public, at least in its crucial aspects, via the movements in price which would be generated by its possession in a single individual's hands. Just as in the case of the Rembrandt painting, however, the speculative gains may be entirely offset by speculative losses and the net social benefit might be zero or very small. The implications for social policy o. the precise method of releasing information therefore appear nontrivial.

At the opposite pole from the stock market insider archetype is the government statistical information made available in a carefully controlled way to an entire group of people at once. The ideal picture of this sort of information release is a report on our corporation with the large new mineral deposit appearing for the first time in a Sunday newspaper on which day the market in which the company's stock is traded is closed. Now we have no price changes occuring during a period in which information is asymmetrically distributed. Rather, the market opens on Monday morning with all of the agents in possession of the same new knowledge. Who gains and who loses? Paradoxically, in *ex post facto* sense, it would appear that there do exist possible losers from introduction of better information. Let us suppose, for example, that the information [illegible] an increase in the forthcoming supply of some crop. [illegible] holder of the stock of this commodity I had planned on Monday morning to sell my entire inventory on the market. The new information will cause the market price of this commodity to decline and I will therefore have been made worse off by its introduction. Again, for every such loser there is a corresponding gainer, and it is difficult to make a strong case for a particular distribution of such gains and losses without going into considerably greater detail along normative lines. There seems to be some normative advantage to avoiding extra gains and losses attributable to asymmetrical information, but it is not entirely clear that this is well grounded.

If we consider a more prior sense of gains and losses, and imagine that we can all choose whether the government should make available at some date in the future a particular report about forthcoming crops, we expect intuitively a preference for the system where this report is made. (Counter cases could be constructed, however.) On the other hand, if we imagine that the crop information is going to be made available to an insider, it is not at all hard to imagine our wishing rather that the information not be made available at all. It might be fruitful to examine in greater detail the difference between these two cases.

There is one important group of people who would be averse to the government's introducing a new statistical service, for example, and these are the people now engaged in producing information and marketing it. Obviously, such information producers are potentially hurt by the introduction of a new information source.

3.1.7 The Model of Forecasting Used in This Case Study

The construction of a forecast involves two main elements: *information* about what is the *current* status of various features of the world and a *model* of how the currently observable features influence the variable, that being the forecast. Suppose, to pose an illustrative example, we are interested in knowing into which of seven holes a pinball will roll at the end of its run down an inclined plane studded with the usual obstacles. Let us consider how a forecast is constructed.

3.1.7.1 Nature's Randomness

We start with a model of how the ball will roll starting from a given point with a given velocity. This model consists of the laws of motion and of knowledge about the positions and physical characteristics of the obstacles, by which it is possible to compute the path of the ball. Typically there will be unknown or imperfectly known elements of the physical system. Furthermore shocks may be anticipated from outside the system which will influence the path of the ball; the pinball machine may be located just above a subway tunnel. As a result, even if we know the starting point our physical model of the system that does not generally allow us to predict exactly the path of the ball. We might typically express our forecast of the final location of the ball in the form of a single number (e.g., "hole number 3"), but this normally is simply the central tendency of an implied probability distribution.

If we have precise knowledge of the position and velocity of the ball at a given point in time we can predict its position at any later time using this physical model, which is what we referred to above as a model of how the currently observable features (position and velocity) influence the variable (future position of the ball) being forecast. Because of what may be regarded as truly random aspects of the systems within which the ball is moving, our forecast itself must be in the form of a probability distribution, even though we may express it in the form of a single number. Furthermore, because of the cumulative nature of the random shocks through time, the dispersion of our forecast distribution of the positions of the ball is likely to increase as the distance into the future over which we are attempting to forecast increases. In looser and more commonplace language, long-term forecasts are "less accurate" than short-term forecasts owing to the greater intervention of random influences.

3.1.7.2 Measurement Errors

As was suggested above, there is in addition to nature's randomness, another source of "inaccuracy" of forecasts, associated with inadequacy of *information* about the current state of the system, in this case the current position and velocity of the ball. Let us suppose, for example, that these are obtained by the observer using a ruler on top of the glass cover of the pin-ball run and a stop watch. Assuming that the observer is capable of instantaneous calculation of the forecast once he is given position and velocity, he can convert his observation of these variables into a prediction at once. However, the procedure for obtaining position and velocity is itself subject to error, which we shall refer to as *sampling error* or *measurement error*. Measurement error would cause forecasts to be random variables, with some degree of dispersion, even if the model of the system were perfect and the system itself not subject to outside shocks. The dispersion or inaccuracy of actual forecasts is thus a compound of nature's randomness and measurement error.

This study is primarily concerned with the value of reducing the monthly *measurement* error in the construction of crop forecasts. It is clear that this is only a part of the source of dispersion in crop forecasts. However, even though variability due to nature's randomness is great, and there is correspondingly a large potential for improving forecasts by improvements in the model of the crop production system (e.g., by deeper understanding of the determinants of weather), we shall see that relatively small measurement errors are surprisingly costly. **AS A RESULT THERE ARE SUBSTANTIAL GAINS TO BE MADE BY REDUCING THE MEASUREMENT ERROR AT COMPLETED HARVEST (MONTHLY).**

3.1.7.3 Availability Lag of Information

There is a further way in which information can be improved, and one which may prove in the present application to be of greater importance than reduction in measurement error. This is the reduction in the time between the observation or measurement of the state of the system and the *availability* of the information for use in the form of a forecast. Such a reduction seems particularly likely in shifting from methods of sampling involving postal or telephonic cominucation of observations to a central calculating unit--as when field units report to the U.S.D.A. -- by an advanced technology method based on satellite observation, in which information is handled electronically as a matter of course at every stage.

We refer to the time elapsed between the actual observation of the state of the system and the production and transmission of a useful forecast based on that information as the *availability lag* associated with a forecasting procedure. This may be illustrated with our pinball machine. Suppose that the initial procedure involves measurements, using the ruler and stop-watch, which are then entered into a mechanical calculating machine to produce a forecast of the path of the ball. Imagine that the usual run of the ball lasts thirty seconds and that the measurements are made after ten seconds have elapsed, i.e., with twenty seconds remaining. By the time the calculation of a forecast has been made the ball is no longer at the point on which the forecast is based. The forecast, in other words, is constructed on the position and velocity of the ball at some time in the *past*. The longer is this lag the less useful is the forecast for two reasons. First, the longer the time which has elapsed, the less useful is the historical position and velocity of the ball as a predictor of its current position and velocity, because it has in the meantime been subject to nature's random shocks. Second, the longer is the delay, the less remains of the ball's path to be predicted. If the delay is long enough the forecast arrives after the ball has already reached the end of its run! The forecast is then of use only in checking the adequacy of the model of the system. It arrives too late to help the person wanting to place a bet on the final position of the ball.

The two aspects of improving the information base for forecasting are thus interrelated. The shorter is the availability lag the more valuable is any given reduction in measurement error.

3.1.7.4 The Crop Forecasting Problem

A rough analogy exists between the pinball forecasting problem and the idealized version of crop forecasting used in this study. We take time to be broken into discrete months. The problem of crop forecasting is not to follow a single ball through time but rather several balls in the form of *monthly* harvests. Let G_t (sometimes we shall write this equivalently as G(t)) denote the quantity of the grain of interest harvested during month t. This notation will be used throughout, although later, when exports are introduced, we shall let G_t stand for "effective harvest," or actual harvest less exports.

It is assumed that, on the basis of perfect information about conditions on the ground, numbers of acres planted in the specified grain in each of several geographical regions, visible conditions of ripeness, etc., forecasts can be constructed of the quantities to be harvested for each of a certain succession of coming months, using a model of how grains evolve over time as they mature. Such forecasts are subject to error due to nature's randomness. We speak of this *set* of ideal forecasts, which would be made in a given month on the basis of perfect information about what is in principle knowable in that month, as the *st te of the system*. The state of the system as of period t is denoted by S_t. S_t is a *vector* of ideal forecasts, its first component is S_t^t, a "forecast" of G_t; its second component is S_t^{t+1}, a forecast of G_{t+1}, etc.:

$$S_t = (S_t^t, S_t^{t+1}, \ldots, S_t^{t+M+1}) \quad . \tag{3.1.1}$$

Note that the superscript which identifies a component of S_t identifies the period for which an ideal forecast is being made.

Actual forecasts of crops are based not upon perfect information but upon measurements and samples of such quantities as acres under cultivation, height of stalks, etc. These are subject to sampling or measurement error. These errors, when the data are fed into the model which produces forecasts, result in deviation between the actual set of forecasts of monthly harvests and the ideal set of forecasts represented by S_t. Great simplification in our analysis is effected by regarding S_t *itself* as the object of measurement.

It is important to be clear about this device. When we speak of sampling or measurement error, we refer to an error of measurement of S_t, *not* directly to the underlying errors of measurement of acreage, growth, etc. Since such underlying errors translate directly into errors in estimation of S_t this analytical convenience does not affect the generality of the results. However, some caution must be exercised when we come to specification of a probability distribution of percentage errors in measurement of S_t, a distribution which need not be identical to that of percentage errors in any of the components from which forecasts are calculated.

A forecast based on month t information then, is here taken to be an *estimate* of S_t. Denote by $\hat{S}_t$ such an estimate. We shall assume that the measuring devices and procedures introduce an error ψ_t such that

$$\hat{S}_t = S_t + \psi_t. \tag{3.1.2}$$

The measurement error, ψ_t, is thus a vector, with components

$$(\psi_t^t, \psi_t^{t+1}, \ldots, \psi_t^{t+M+1}).$$

At this point we should explain the meaning of the parameter M which occurs in the specification of S_t. We refer to this parameter as the "maturation period", a name motivated by a simple model, whereby the grain harvested in any period must have been planted exactly M periods earlier. If we take the quantity planted as exogenously given, not endogenously determined, in this model it is not possible to forecast the harvest of any month more than M periods into the future on the basis of currently observable features of harvests, but this is not dependent upon an input of current information.

In fact, this simple model is only a very rough approximation to the case of wheat, the grain to which our analysis will be applied in this study. The number of months between planting and harvesting varies greatly with the type of wheat and the region of the country in which it is planted. There is no reason one could not take this into account in the model, allowing M to be itself a function of t. Rather than carry along this complication, however, we have chosen to work with a constant M. It can in any case always be interpreted as the maximum number of months into the future one can forecast harvests, with the forecast depending upon features at least in principle currently observable.

Under this interpretation we see that the last component of the measurement error vector in (3.1.2): ψ^{t+M+1}, will be identically zero. This is so because by definition of M the forecast of G_{t+M+1} cannot depend upon features observable at time t.

We have very nearly completed the description of the model of forecasting. It remains to put the availability lag back into the story. Let the symbol AL stand for availability lag. Then $\hat{S}_{t-AL}$ is the vector of forecasts available at time t. To be more precise, the components of $\hat{S}_{t-AL}$ referring to harvests occurring beyond month t are taken to be the forecasts available at time t. Thus, for example S_{23}^{26} would be the forecast of G_{26} available in month 25 if the availability lag were 2.

This model of forecasting is then used throughout the case study as documented in Volume III of this report.

3.1.8 Measurement Errors and Value of Information Due to Improvements in Measurement Capabilities

Available studies, such as that by Gunnelson, Dobson, and Pamperin* tend to focus on *forecast* error, which is a compound of Nature's variance and variance introduced by the measurement system. Statistics on forecast error contain, of course, some information constraining measurement error, but drawing implications from them requires very strong assumptions as to the underlying model. For our purposes these data are not suitable.

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* Gunnelson, G., W. D. Dobson, and S. Pamparin, "Analysis of the Accuracy of USDA Forecasts," *American Journal of Agricultural Economics*, November, 1972, pp. 639-645.

In their study of the value of improved statistical reporting, Hayami and Peterson encountered much the same sort of problem.* In their Table 1 (p. 125) they present data on "typical sampling error" in major U.S. farm commodities prepared by the Statistical Reporting Service, U.S. Department of Agriculture. The methods by which the U.S.D.A. calculated these statistics are not specified, nor are definitions of the usual sort provided. By making some assumptions, however, we can use these data as the basis for plausible illustrative values in exploring our own results. Again, we would stress that these figures should be regarded as far from well-established.

According to Hayami-Peterson, the U.S.D.A. as of the time of their writing, conducted their surveys with a goal of attaining an average *sampling* error of 2 percent. Hayami-Peterson's Table 1 indicates that this overall average performance corresponds to a sampling error of 2.1 percent for wheat. The error refers to *annual* harvests, and we may regard it as applying to a sum of twelve monthly harvests. Denote by μ the error in measuring the annual harvest, AH, and by μ_i the error in measuring H_i, the ideal forecast of the harvest in month i. Using "hats" (^) to denote measured quantities we have

$$(3.1.3) \qquad \hat{AH} = AH + \mu$$

$$\hat{H}_i = H_i + \mu_i$$

$$\hat{AH} = \sum_{i=1}^{12} \hat{H}_i$$

implying, if the measurement errors are independent,

$$(3.1.4) \qquad \alpha_{\mu}^2 = \sum_{i=1}^{12} \alpha_{\mu_i}^2$$

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* Hayami, Yujiro, and Willis Peterson, "Social Returns to Public Information Services: Statistical Reporting of U.S. Farm Commodities," *American Economic Review*, March 1972, pp. 119-130.

By our assumption,

$$(3.1.5) \qquad \alpha^2_{\mu_i} = \left(\frac{\alpha \bar{H}_i}{1.96}\right)^2$$

Interpreting "average sample error" as the ratio of the standard deviation of μ to AH, we have, from Hayami-Peterson

$$(3.1.6) \qquad \alpha^2_{\mu} = (2.1 \text{ AH})^2$$

Substituting into (3.1.6), we have

$$(3.1.7) \qquad \alpha = \frac{(1.96)(2.1)}{\sqrt{\sum_{i=1}^{12} h_i^2}}$$

where h_i refers to the fraction of the annual crop harvested in the i^{th} month. Using the percentage distribution of the wheat harvest as described previously the value of α can be calculated to be given by

$$(3.1.8) \qquad \hat{\alpha} = \frac{(1.96)(2.1)}{\sqrt{(.2964)}} = 7.559 \simeq 7.6\%$$

The Task Force on Agricultural Forecasting at Goddard attempts to assess likely improvements of ERS systems measuring crop acreage in perspective to present USDA performance. (See Figure 3.1 of this section.) Based on those results we may use the likely improvement in monthly measurement by 50% from α = 7.6 percent to α = 3.8 percent for winter wheat and from α = 15.75 percent to α = 7.9 percent for spring wheat as a convenient basis for sensitivity analysis of the results. Table 3.1 gives the value of this improvement (not including cost savings by USDA if new methods are introduced and, of course, not netting out additional measurement costs) under a variety of changes in the parameters of the model.

The results described in Table 3.1 indicate both the possibility of very substantial gains from reducing measurement errors in the crop forecasting system and the extreme sensitivity of the results to the values of current and potential measurement error variances.

Even relatively conservative assumptions (zero population growth, better current measurement, smaller percentage gain in accuracy) seem to suggest a rather substantial potential for gain from improved measurement accuracy. However, the great sensitivity of the results to variations in percentage accuracy, indicate that to obtain reliable estimates an effort must be made to discover more about current and potential measurement error.

At the same time the results described should make us sanguine about extending the measurements to other crops. The procedures generalize without any difficulty, and there is no obvious impediment to obtaining reasonably accurate measurements of all of the important parameters, with the exception, again, of the distributions of errors of measurement.

3.1.9 Data Sources Used in the Empirical Estimation of ERS Information Distribution Benefits

The following is a comprehensive list of the economic data sources used for this case study:

1. Chicago Board of Trade, *Statistical Annual* (1956-1972), henceforth SA.

2. Federal Reserve Board, *Federal Reserve Bulletin* (March 1963, February 1965, March 1966, March 1967), henceforth FRB.

3. --- *Business Statistics* (1971, 1973), henceforth BS.

4. --- and the Massachusetts Institute of Technology, *Quarterly Econometric Model* (January 1973), henceforth FMP.

5. U. S. Department of Agriculture, Economic Research Service, *Feed Statistics* (September 1967) and Supplement for 1971 (July 1972), henceforth FS.

6. --- *Food Grain Statistics*, henceforth FGS.

7. --- Supplement to *Food Grain Statistics* (1971), henceforth SFGS.

8. --- *Wheat Situation* (May 1973), henceforth WS.

9. U. S. Department of Agriculture Statistical Reporting Service, *Statistical Bulletin* 277 (January 1961), 387 (January 1967), and 503 (December 1972), henceforth SB.

10. --- *Cattle on Feed* (January 1973, January, 1974), henceforth COF.

The above references supplied the following information for this case study:

1. Quantities

Visible Supply of Grains (millions of bushels)
Monthly: SA

Total Stocks of Grains (millions of bushels)
Quarterly: SA

Domestic Disappearances of Corn, Grain Sorghum, Oats, and Barley (millions of bushels)
Quarterly: FS

Total Domestic Wheat Disappearance (millions of bushels)
1. July 1964 - June 1970, Quarterly: WS
2. July 1955 - June 1963, Semi-annually: FGS

Food and Industrial Disappearance of Wheat (millions of bushels)
1. July 1964 - June 1970, Quarterly: WS
2. July 1955 - June 1963, Semi-annually: FGS

Total Domestic Rye Disappearance (thousands of bushels)
1. July 1966 - June 1971, Quarterly: SFGS
2. July 1955 - June 1966, Semi-annually: FGS

Cattle and Calves on Feed in the States of Ohio, Indiana, Illinois, Minnesota, Iowa, Missouri, South Dakota, Nebraska, Kansas, Texas, Colorado, Arizona and California (thousands of head)
Quarterly: SB and COF

2. Prices

High and Low Futures Prices (pennies)
Monthly: SA

Average Price per Bushel of Number Three Barley at Minneapolis (dollars)
Monthly: FS

Average Price per Bushel of Number Three Yellow Corn at Chicago (dollars)
Monthly: FS

Average Price per Bushel of Number Two White Oats at Minneapolis (dollars)
Monthly: FS

Average Price per Hundred Pounds of Number Two Yellow Grain Sorghum at Kansas City (dollars)
Monthly: FS

Average Price per Bushel of Wheat at the Farm (dollars)
Monthly: SFGS

Average Price per Bushel of Number Two Rye in Minneapolis (dollars)
Monthly: SFGS and FGS

3. Other

Open Market Rate for Prime Commercial Paper, 4 to 6 Months Duration (points)
Monthly: FRB and BS

Gross National Product (billions of dollars)
Quarterly: FMP

Unemployment Rate (points)
Quarterly: FMP

Consumer Price Index (1958 = 1)
Quarterly: FMP

Population of the U.S. (millions of persons)
Quarterly: FMP

Consumer Price Index (1967 = 100)
Monthly: BS

3.1.10 Concluding Remarks on this Case Study

All of the calculations in Chapter 6 of the Case Study Report* were directed toward evaluating a reduction in measurement error. However, as our discussion of forecasting in general in Section 3.1.3 makes clear, the timeliness of information also importantly affects its value. This would be expressed in our model as reduced availability lag. This is an area in which satellite technology clearly promises substantial improvement, and it is one which may even have the potential for more substantial gains than found for measurement error reduction. Our estimates suggest rather substantial month to month variability in ideal forecasts, Nature's randomness. By reducing the availability lag by one month, we, in effect, eliminate one month's worth of variance. The value of this should be comparable to that of a similar reduction of variance due to measurement error improvement.

The components of this calculation are much the same as those assembled in Chapter 6 of the Case Study Report*. However, the formulae are more complex, owing to certain interactions among terms which take place when variance is reduced in this way. Programming and carrying out these calculations should be a high priority follow-up research item.

Other extensions of the research are suggested by a review of the results described in Chapter 6 of the Case Study Report* which comes at the end of a long and complex chain of reasoning and calculation. It is appropriate to consider here in summary fashion the links of the chain, to assess their strength, and to indicate how new ones can be added.

The basic logic of the model is simpler than its many details may lead one to believe. Grain production is taken to be exogenously given, but subject to random shocks obeying a (possibly complex) stationary stochastic law. Production in any period can be allocated to consumption (including use in the production of other goods) or additions to inventory. Inventories are determined by profit-seeking competitive agents, who base their decisions on forecasts of forthcoming grain harvests. In order to determine their current inventory levels, these agents must anticipate the future inventory levels as well as future harvests. They do this by assuming that all inventory

* See Vol. III, Part II of this report.

holders understand the underlying demand and marginal storage cost relationships, and hence they in effect look for a market clearing set of spot and future prices.

Given these facts, and having equipped ourselves with knowledge of the demand and marginal storage cost functions, we can describe the functional dependence of inventory decisions produced by the market system and forecast harvests. This being the case, we can determine the relationship between measurement errors, as leading to forecast errors, and the average amount of variability to be expected in the grain consumption flow. Variability is a source of disutility--marginal quantities of grain are more highly valued when consumption levels are low than when they are high, as reflected in the demand curve. Hence we can calculate the loss in value due to measurement error, and the gain due to its amelioration.

The weakest links in this chain are probably the early ones, for example, the very first one, which assumes grain production is exogenously given. We have argued in the text that a good case can be make for taking this assumption as a working hypothesis. Nevertheless, we should expect the results to be altered by the introduction of an endogenous production decision model of farmer behavior. That smoothing out of consumption and hence price movements over time is likely to have value to farmers should be obvious, given the history of the search for farm price stability. This will be done in the second agricultural case study, which actually confirms our basic results ($19.7 - $98.6 million per year).

The second link shows a related weakness in leaving out a set of decision makers. It was noted in the text that production is allocated not simply to consumption and inventory changes, but also to net exports, and in fact, the empirical parameters of a very simple model of export determination importantly influenced the numerical results, as summarized in Table 3.1. A final important group of agents is omitted at the third link at which it is assumed that grain inventories are determined by private entrepreneurs. In fact, certainly in the United States over the past twenty years, the government has been a major agency determining the quantity of grain in inventory.

How greatly the absence of these decision agents from the model affects the results is difficult to say. Surely, leaving out the dependence of production on prices causes our procedures to understate the value of improved information. On the other hand, the fact that farmers must make their planting decisions several months before harvesting leads us to guess that the additional benefit which will be found upon incorporating production to the model will be small relative to that attributed here to improved inventory decisions.

Again the results of the second agricultural case study do take these effects into account and confirm broadly the results of this case study.

The direction in which the results are biased by our naive treatment of the export sector appears indeterminate. One could estimate the gain to the rest of the world attributable to improved inventory choices in the United States alone, and this would be expected to add to the total benefit. On the other hand, the extent to which the export sector acts to dampen the variance of domestic consumption arising from variance in domestic production is too cursorily treated here to give a reliable indication of the results of a more careful study. Perhaps more important than these effects will be the consequences of more accurate forecasting of world-wide production. Since net exports can be treated as negative harvests in the U.S., and since world production will greatly influence net exports, the ability to predict world production has implications for even domestic inventory allocation improvement much like those studied here. (A whole-world model, on the other hand, is in principle simpler again, since there are no net exports.)

The policy of the U.S. government was, at least in large measure, directed toward price stabilization of grains over the past three or four decades. Insofar as the government is completely successful in this effort, the role of the private inventory holder is superseded, and speculative inventories will not be held. This would clearly affect the analysis in a major way, presumably in the direction of reducing the value of improved information, except, perhaps, as it determines the government's decisions. The most recent experience, of high grain prices, has temporarily, at least, taken the government out of the grain inventory business, and the broad outlines of the competitive model appear to hold.

Extending this model to production decisions by competitive farmers is not likely to involve more than complication in the form of higher order difference equations, etc. While the computational problems this can pose can be formidable, we would not anticipate major theoretical difficulties. The more challenging task is incorporating government and export sectors, particularly the former. The problems one can anticipate in the case of international demand are partly, again, those of sorting out the interactions of competitive producers and inventory holders. The behavior of governments enters in the determination of international movements of grain (as the famous Russian wheat deal made abundantly clear), as well as into the nominally "government" sphere already alluded to, and it is in modeling the behavior of the important political actors, including the major agencies, that exceedingly interesting and possibly intractable problems lie.

3.2 The Integrated Impact of Improved (ERS) Information on U.S. Agricultural Commodities

In recent years, the prices of agricultural products have fluctuated widely. In part, these price movements have been the result of general inflationary pressures that have plagued the economy since the late sixties. A significant portion of these price movements, however, are the result of other structural shifts in the economy. Paramount among these other considerations is the increased exposure of American agricultural supplies to foreign demand. Owing to the imprecision surrounding expected foreign demand for American agricultural products, the domestic market has been caught off balance on numerous occasions. Notable among these occasions have been the Russian Wheat deals of the early sixties and seventies. Even when foreign net exports are not a large percentage of domestic harvests and/or stocks, the information about their likely future profile is markedly less available, accurate and timely than similar information about future domestic demands and supplies. For these reasons, it has been argued that net exports often have a large disturbing influence on domestic spot and futures price movements.

As a result of foreign demand pressures, and rising domestic channels, the U.S. markets for agricultural commodities have shown an increased sensitivity to domestic and foreign crop production projections. To the extent that the spot and futures markets have accurate information, the market process in a free economy will distribute resources efficiently across uses and over time. Obversely, unexpected surges in demand or unusually poor production forecasts will lead to inefficient resource allocations. Reporting delays, weather aberrations, etc. introduce imprecision and risk into both the spot and future markets. Insofar as more accurate crop projections improve efficiency and as each degree of coordination is reflected by an appropriately altered set of prices, improved information will be reflected in market prices and benefits to society. Reflection, however, is not synonymous with useful understanding.

Many examples of market responses to increased demand pressures and imprecise information can be found, yet each episode is sufficiently different to deny the formulation of a hard and fast bromide to combat any such future episodes.

The reason for this apparent intractability, when viewed in the large, lies in the structure of the commodities markets and the multi-channeled economic dialogue that takes place within them. When approached as a single message, the signal from the commodities markets may easily be misconstrued as just so much noise. In fact, the activity of the commodities markets is a logically structured process of rational economic behavior.

3.2.1 Objective of the Study

There are four general objectives of this case study:

- To specify the general structure of the agricultural commodities markets in order to better understand the market process with special emphasis on the influence of crop forecast information and foreign trade.

- To measure the influence of crop forecasts and net export demand on domestic agricultural commodity prices.

- To develop an empirically supported structure from which to assess the market impacts of government policy actions.

- To provide information needed to weigh the benefits of improved crop projections to society, and to identify linkages and guidelines for an analysis of the world markets.

3.2.2 Analytical Structure

The study, of course, does not attempt to tie together the myriad intricacies of the U.S. spot and futures markets in order to resolve the above issues in minute detail. Data considerations alone rule out such an ambitious task. Recognizing the empirical constraints on our mission, our research strategy is aimed at robust findings and conclusions about major issues, leaving more detailed analyses of secondary issues for some future study. With this operating thesis in mind, we integrate the three major analytical dimensions of the study without losing sight of our empirical imperative. The three analytical dimensions at the core of the study are:

- The basic market influences and their avenues of introduction. Here, the principal task is to identify the various factors acting through supply, demand, and general economic conditions on the spot and futures markets.

- The principal behavioral hypotheses and institutional characteristics. These relationships and analytical contructs tie together the various market influences into a formal portrait of the agricultural commodities markets.

- The distinction between long- and short-run decisions and patterns of market behavior. This distinction is crucial in order to weigh properly the impacts and incidence of exogenous influences on the commodities markets.

With respect to the first dimension, the market factors studied include domestic consumption, net exports, government stockpiling, domestic and foreign production, stock adjustments in the private sector, government parity price operations, commodity substitutes and complements, and general economic conditions such as the availability of credit and the rates of inflation on commodities and farm production items. Naturally, the factors influencing demand and supply are set forth separately for the spot and futures markets.

The behavioral hypotheses invoked to tie together the various market factors into a portrait of the commodities markets fall into two broad categories: general economic concepts that are not intrinsic to the commodities markets and constructs specific to these markets. The general assumptions include the following:

- Investment decisions are based on both return and risk considerations.

- Intertemporal decisions are based in part on expectations and these expectations may be influenced by known technical forecasts of physical outcome.

- The rate of change in prices is determined by imbalance between supply and demand.

- Future values are discounted back to the present.

The hypotheses intrinsic to the commodities markets include:

- Futures prices on the average tend to be reliable estimates of what should be expected on the basis of available information concerning present and future demand and supply. However, these prices may not reflect market expectations at each point in time owing to technical rigidities in the markets' response to changes in information on supply and demand prospects.

- Futures prices change in response to market imbalances between short hedging and long speculation.
- Intertemporal price spreads reflect, in part, the costs of storage and decay.

Finally, with regard to the third dimension:

- The causal structures of long-run patterns of behavior are distinct from their short-run counterparts.

3.2.3 Model Overview

Within the above framework, the number of possible analytical constellations or specific models that can be constructed is enormous. In keeping with our operating thesis, the myriad possible relationships have been combined into more general constructs that transmit the major analytical dialogue between the various market forces and factors. It is from these foundations that the empirical effort is launched.

The product of our blending of behavioral hypotheses and market influences is summarized in a sizeable set of equations, identities, and constraints. The full simultaneous interaction of this model is set forth in the main body of the study and a detailed redescription is beyond the scope of this summary. However, the dominant characteristics of the model are portrayed in the flow diagram presented in Figure 3.2. Hence, the principal structural linkages and directions of causality that define the architecture of the model are illustrated. The lines connecting the major variables of interest indicate the structural linkages, and the arrows denote the major directions of influence or causality. The simultaneity of the model can be verified by starting at any point (variable) in the mainstream of the model (any one of those variables determined within the model) and following the arrows full course through the model back to the starting point.

For the most part, the flow diagram does not illustrate the numerous exogenous influences that feed the various structures. The exceptions to this pedogogical stylistic are the major "policy" variables. These variables are government

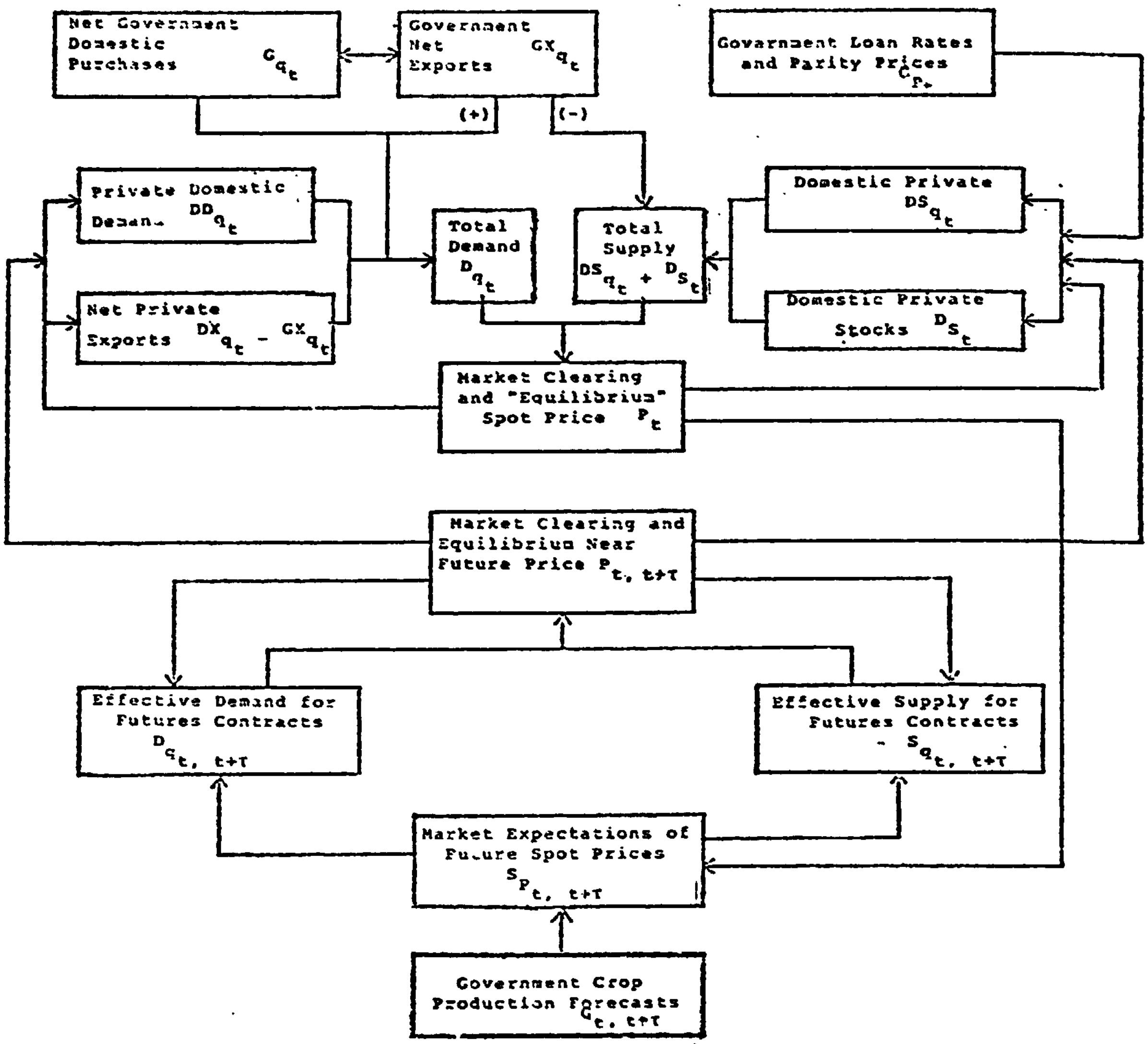

Figure 3.2 Flow Diagram of the Spot and Futures Markets Models for Agricultural Commodities

exports, GS_q, government domestic purchases $G^{(+)}$ for sales $G^{(-)}$, G_q, and United States Department of Agriculture crop production forecasts, G.

3.2.4 The Value of Improved Information: The ERS System

In the following paragraphs we present our estimates of the annual dishoarding benefits to consumers from potential ERS improvement over current crop forecast accuracy on soybeans and wheat. These estimates are based on likely ERS accuracy improvements (to be presented), the elasticities presented in Volume III, Part III and on 1973 prices and quantities. The actual calculation of these benefits is illustrated in the flow chart in Figure 3.3. Here, an assumed change of forecast error variation (a reduction) is traced through the system of elasticities to determine relative price and quantity impacts. These impacts then are combined with 1973 prices and quantities to provide the benefits estimates. It should be noted that conservative upper and lower bounds are given. The "upper bound" indicates the direct benefits to consumers using the estimated coefficients. The lower bound represents an estimate of the direct benefits to consumers where the "slope" portion of the elasticities have been lowered or raised two standard deviations in order to obtain an unlikely low benefits value.

The size of the benefits from improved information depend in part on the assumed improvements in forecast accuracy. Outrageous assumptions as to accuracy improvements, of course, would invalidate the benefit figures. The improvements assumed here are thought to be conservative and are discussed further below.

a. Likely Accuracy Improvements from an ERS System

An analysis of the accuracy of crop forecasts by Gunnelson et al* concludes that the USDA tends to (1) underestimate crop size, (2) underestimate the size of changes in production from year-earlier levels and (3) undercompensates for error in previous forecasts when developing revised crop forecasts. Absolute forecasting errors are a function of the length of the forecasting period. Examples of average forecasting errors by month of forecast for various commodities are presented in Table 3.2 below.

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* Gunnelson, G. et al, "Analysis of the Accuracy of USDA Crop Forecasts," American Journal of Agricultural Economics, Vol. 54, No. 4, Part 1, November 1972: pp. 693-645.

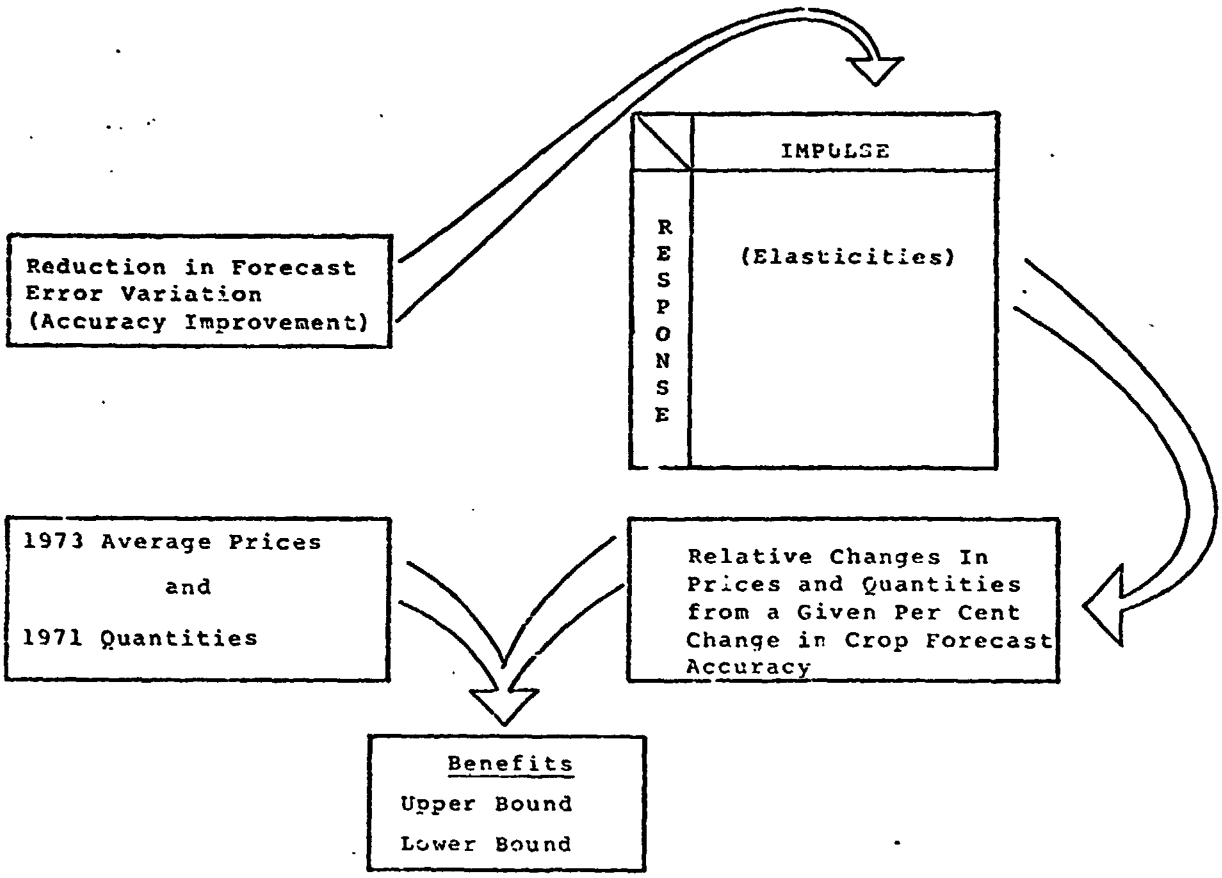

Figure 3.3 The Calculation of Benefits: Integrated Impact of Information on U.S. Agricultural Commodities.

Table 3.2 Size of Average Absolute Percentage Forecasting Error in USDA Crop Forecasts by Commodity and Forecast Month, 1929-1970[a]

	Absolute Error by Forecast Month (Percentages)								
Commodity	December	April	May	June	July	August	September	October	November
Barley					7.1	3.1	2.2		
Corn					9.2	5.9	4.0	2.8	2.0
Oats					4.9	2.9	2.4		
Potatoes						5.5	4.5	3.2	2.6
Soybeans						5.6[b]	5.1[c]	3.7[c]	2.9[c]
Spring Wheat					10.7	6.7	3.0	2.8	
Winter Wheat[d]	11.5	8.5	7.6	6.9	4.0	2.1			

[a]Forecasting error equals the absolute difference between the forecast and the December revised estimate expressed as a percentage of the December revised estimate.

[b]Percentages computed from data for 1944-1970.

[c]Percentages computed from data for 1940-1970.

[d]Error percentages for December winter wheat forecasts computed from data for 1942-1970. Error percentages for other winter wheat forecast months computed from 1929-1970 data.

Source: Gunnelson, G. et al, "Analysis of the Accuracy of USDA Crop Forecasts" American Journal of Agricultural Economics, Vol.54, No.4, Part 1. November 1972. pp. 639-645.

Crop production estimates are generally arrived at as the product of two components: acreage and yield per acre. Approximately one-half of the inaccuracy of U.S. wheat and soybean production forecasts is in the estimation of the acreage component. Thus, even if remote sensing could improve only the acreage portion of the reduction estimate, a significant improvement in the production forecast would result. Based on the Task Force on Agricultural Forecasting Report,* current data strongly suggest that ERS may improve acreage forecasts by at least 50 percent throughout the forecast period. That is, ERS-based acreage forecasts would have less than half the error variation of current USDA acreage projections. Thus, in the benefits estimates to be presented, the calculations assume only a 25% improvement in production forecast error variation. Since studies of ERTS-1 yield estimates suggest that similar improvements may be made here and since timing, completeness and dependability improvements have not been considered, the assumed ERS improvement in production forecasts are considered to be conservative.

The potential accuracy improvements in ERTS-1 over current USDA methods are shown in Figure 3.4. It is on the basis of these data that our ERS accuracy improvement assumptions were made.

b. Benefits Estimates

The estimated direct benefits to consumers from a 25% reduction in forecast error variation are summarized in Table 3.3. These values were calculated using the assumed ERS accuracy improvement together with the elasticities presented in Vol. III, Part III and 1973 prices and quantities.

The actual calculation of the benefits are set forth in Tables 3.4 and 3.5. The upper bound benefits value is based on the reported estimation coefficients. The lower bound benefits were calculated using impulse response coefficients two standard deviations below (or above) their estimated value. In a statistical sense it is highly unlikely that the consumer benefits from a 25% reduction in crop forecast error variation will fall below the lower bound benefits values. Moreover it is worth noting that these benefit estimates are especially conservative insofar as they only reflect the direct benefits to consumers and do not include the likely yield estimate improvements and secondary effects such as those brought about by the increased availability of loanable funds.

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* Wood, D.B., et al, "The Use of the Earth Resources Technology Satellite (ERTS) for Crop Production Forecasts," Task Force on Agriculture Forecasting, Goddard Space Flight Center, Draft Final Report, July 24, 1972.

Table 3.3 Estimates of Annual ERTS Benefits Based on a Reduction in Crop Production Forecast Error Variation as Determined by Agriculture Task Force Report		
Crop	Annual Benefits, $ million (1973)	
	Lower Bound	Upper Bound
Soybeans	71	337
Wheat	35	212
TOTAL	106	549

The data sources and assumptions used for estimating these effects and benefits are numerous and they are fully listed in Volume III, Part III of this report.

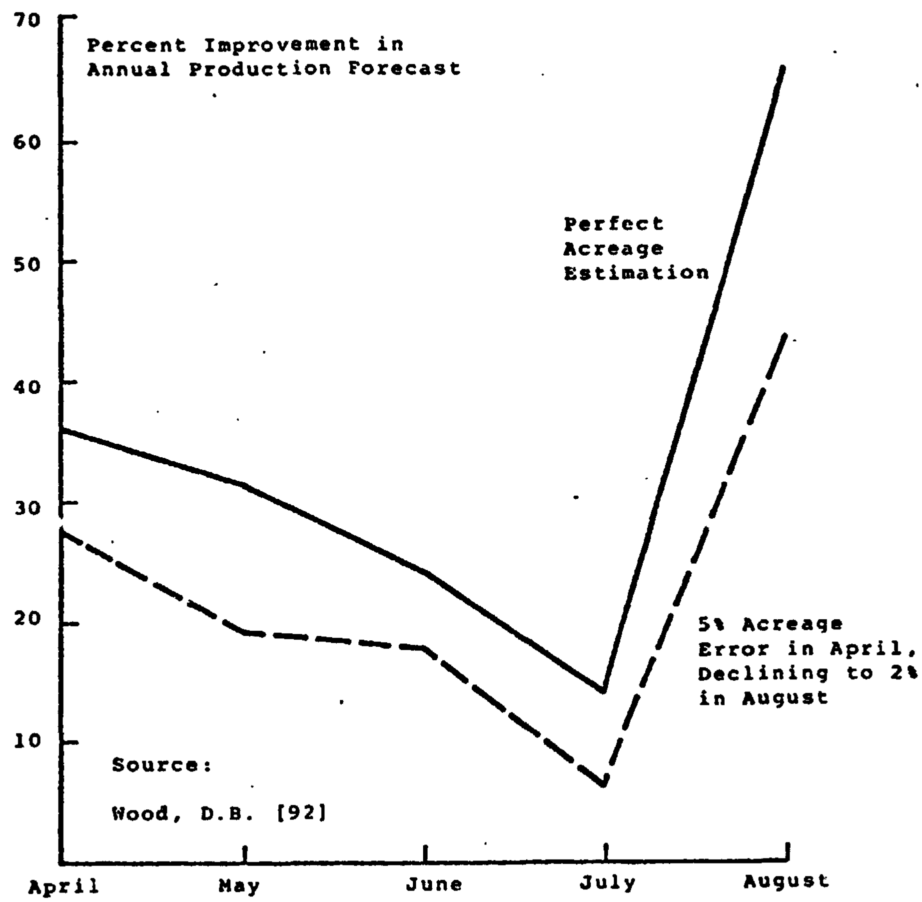

Figure 3.4 Illustrative ERTS-1 Accuracy Improvement In Crop Forecasts

Table 3.4 Direct Consumer Benefits Estimates for Soybeans

__Upper Bound__

$$U_s = \begin{pmatrix}\text{\% Change in Fore-}\\ \text{cast Error Variations}\\ .25\end{pmatrix} \begin{pmatrix}\text{Accuracy Elasticity}\\ \text{of Short Hedging}\\ .038\end{pmatrix} \begin{pmatrix}\text{Hedging Elasticity}\\ \text{of Private Stocks}\\ 1/.184\end{pmatrix} \begin{pmatrix}\text{\% Change in Spot Price}\\ \text{from a 1\% Change in}\\ \text{Quantity} \quad \frac{1}{1.280}\end{pmatrix} \begin{pmatrix}\text{1973}\\ \text{Price}\\ \$6.52\end{pmatrix} \begin{pmatrix}\text{1973}\\ \text{Quantity}\\ \text{1,283 mill.bu.}\end{pmatrix}$$

= \$337 million

__Lower Bound__

$$L_s = \begin{pmatrix}\text{\% Change in Fore-}\\ \text{cast Error Variations}\\ .25\end{pmatrix} \begin{pmatrix}\text{Accuracy Elasticity}\\ \text{of Short Hedging}\\ .026\end{pmatrix} \begin{pmatrix}\text{Hedging Elasticity}\\ \text{of Private Stocks}\\ 1/.338\end{pmatrix} \begin{pmatrix}\text{\% Change in Spot Price}\\ \text{from a 1\% Change in}\\ \text{Quantity} \quad \frac{1}{2.262}\end{pmatrix} \begin{pmatrix}\text{1973}\\ \text{Price}\\ \$6.52\end{pmatrix} \begin{pmatrix}\text{1973}\\ \text{Quantity}\\ \text{1,283 mill.bu.}\end{pmatrix}$$

= \$71 million

Table 3-5 Direct Consumer Benefits Estimates for Wheat

Upper Bound

$$U_w = \begin{pmatrix}\text{\% Change in Fore-}\\ \text{cast Error Variation}\\ .25\end{pmatrix} \begin{pmatrix}\text{Accuracy Elasticity}\\ \text{of Short Hedging}\\ .365\end{pmatrix} \begin{pmatrix}\text{Hedging Elasticity}\\ \text{of Private Stocks}\\ 1/1.982\end{pmatrix} \begin{pmatrix}\text{\% Change in Price}\\ \text{from a 1\% Change}\\ \text{in Quantity } 1/.394\end{pmatrix} \begin{pmatrix}\text{1973}\\ \text{Price}\\ \$2.31\end{pmatrix} \begin{pmatrix}\text{1973}\\ \text{Quantity}\\ \text{786.6 mil.bu.}\end{pmatrix}$$

$$= \$212 \text{ million}$$

Lower Bound

$$L_w = \begin{pmatrix}\text{\% Change in Fore-}\\ \text{cast Error Variation}\\ .25\end{pmatrix} \begin{pmatrix}\text{Accuracy Elasticity}\\ \text{of Short Hedging}\\ .145\end{pmatrix} \begin{pmatrix}\text{Hedging Elasticity}\\ \text{of Private Stocks}\\ 1/3.422\end{pmatrix} \begin{pmatrix}\text{\% Change in Price}\\ \text{from a 1\% Change}\\ \text{in Quantity } 1/.55\end{pmatrix} \begin{pmatrix}\text{1973}\\ \text{Price}\\ \$2.31\end{pmatrix} \begin{pmatrix}\text{1973}\\ \text{Quantity}\\ \text{786.6 mil.bu.}\end{pmatrix}$$

$$= \$35 \text{ million}$$

3.2.5 Estimation Strategy

Estimating the model presents a number of practical and methodological difficulties. The so-called practical problems centered around the data requirements. In order to distinguish between long-and short-term patterns of behavior, data with a monthly frequency are selected. However, many of the data series are inconsistent or non-existent. In the latter case, representative monthly series are constructed from quarterly data using accounting identities and/or linear pro-rating schemes. In the former case, the most important data construct is a futures price index. No attempt has been made to develop an optimal price index here. Instead, the generally accepted "near futures" price are employed as the representative price.

In addition to the problems of data construction, three methodological issues warrant some mention. First, the identification of, and distinction between, long-and short-run patterns of behavior. Secondly, the identification of the dynamic structures to be estimated. Finally, the interdependence of the structures and their simultaneous estimates.

1. Frequency Band Model Building:
   The Distinction Between the Long-and Short-Run

Any economic model must be specified with respect to the length of the decision interval (e.g., days, weeks, etc.). Decision rules conventionally are defined relative to a specific time horizon since the causal structure of the decision process may differ with these various time perspectives.

Following, at least in spirit, the approach taken by Labys and Granger, and suggested by Granger and Hatanaka, the variables in the model are separated into a long-run trend/cycle component and a short-run, seasonal, and irregular component. Long-run trend/cycle and short-run seasonal and irregular models then are estimated separately. The complete time series profile of the model is obtained by combining the two distinct "frequency-band" models after their estimation.

2. Dynamic Structures and Their Estimation

In economics, the relationship between an impulse and a response rarely is instantaneous. Instead, the response tends to build up over time. Typically, these "dynamic" relationships are explained by some combination of both lagged dependent variables and distributed lags on other explanatory variables. Often, either of these lag structures contain an infinite number of parameters. However, for practical purposes, these relationships must be replaced by "parsimonious" finite parameter approximations. In this regard, the approach of Box and Jenkins is followed to identify the trend/cycle and seasonal relationships.

3. An Approach to System Estimation

The model developed includes a number of jointly dependent variables in the structures. That is to say, many of the dependent variables are to be "explained" in part by other variables to be explained. These interdependencies can lead to serious estimation problems if single equation estimation methods are used. However, not all system estimation techniques are equally desirable.

3.2.6 Empirical Results and Policy Conclusion

Following the estimation strategy outlined above, models are estimated for soybean and wheat using monthly data. In general the statistical results are most encouraging. The squared correlation coefficients on the trend cycle equations all exceed 90 per cent and the series of estimation residuals do not exhibit statistically significant serial correlation. The estimating equations for the seasonal movements all have squared correlation coefficients in excess of fifty percent and with one technical exception have serially uncorrelated residuals. It must be noted that the seasonal and irregular series contain a majority of the "noise" in the original data series. From the estimation results obtained, the following general conclusion can be made:

- The general structure of the spot and futures markets for agricultural commodities are very similar. That is not to say that the impulse response relationships are identical but rather that the structural linkages are similar as hypothesized.

- The accuracy of crop forecasts, as measured by their error variation, exert a statistically significant influence on the futures market in both the long- and short-run.

- Hedging activity is closely related to physical stocks of agricultural commodities.

- Movements in cash or spot prices are closely related to movements in physical supplies.

- Net private exports are highly responsive to U.S. prices and per capita foreign food production.

- Domestic private demands for wheat and soybeans are responsive to the spot prices for those commodities.

- Production of soybeans and wheat is responsive to both cash and futures prices.

- Prices of commodities move directly with crop forecast accuracy. That is, increases in forecast inaccuracy lead to higher commodity prices, ceterus paribus and obversely, improvements in crop forecast accuracy lead to lower commodity prices.

- Domestic production is very responsive to prices and increases in foreign demand will create upward pressures on prices.

- Foreign demand for U.S. soybean and wheat closely reflects foreign per capita food production.

- Regular seasonal patterns exist in the futures markets for soybeans and wheat.

- Long-term credit availability is an important influence in the commodities markets and is influenced by inflation and the factors influencing the rate of inflation.

In addition to the general conclusions presented above there are at least three important conclusions that warrant special mention:

- Improvements in Crop Forecast Accuracies as analyzed by the Agriculture Task Force Report in the accuracy of wheat crop production forecasts promise tens of millions of dollars benefit to society when applied to wheat and soybean forecasts. The likely improvements promised by an ERS system are shown in Figure 3.4 and the benefit estimates for wheat and soybeans are shown in Table 3.3.

- Improved crop production forecasts will not impinge on U.S. government domestic agricultural policy objectives and operations. In fact, improved crop forecasts will enhance the soundness of those objectives and the precision of these operations.

- Improved estimates of foreign food production used wisely by all trading parties can lead to "pareto optimal" exchange where neither party is worse off and at least one part is better off.

3.2.7 Data Sources Used in this Case Study for Empirical Estimation of ERS Information Benefits

The following publications constitute the major sources of data used in this case study:

- Weekly Grain Market News. This source is one of the most complete data libraries for the grain markets in general. Included in its lists are weekly price changes, CCC sales, domestic stocks, exports, and crop forecasts.

- The Grain Market News. This source provides both weekly and monthly summaries of the weeks markets, exports of wheat and flour, Government activity, and U.S. prospective plantings.

- The Quarterly Stock of Grain in All Positions Report. This source provides a quarterly breakdown of the stocks of wheat by size, location, and ownership.

- Commitments of Traders in Commodity Futures. This source contains monthly figures for total futures trading volume, open interest and long and short hedging and speculative positions.

- The Statistical Annual of the Chicago Board of Trade. The source contains monthly U.S. stocks of wheat, corn and soybeans.

- Food Grain Statistics. The USDA publication reports monthly CCC exports and quaretерly U.S. supply and disappearance.

- Crop Production Reports, Prospective Plantings Report, and Annual Summary. These publications give monthly planting intentions, acreage, yield for all crops including soybeans.

- Fats and Oils Situation Reports. This data source includes soybean oil prices, the prices of other oils, exports, and Government buying and selling operations.

- The Feed Situation Report. This publication includes price, export and Government operations data for soybean meal and competing animal feeds.

- The Monthly Report of the Federal Reserve System. This publication contains weekly and monthly credit and interest rate statistics.

- The Survey of Current Business. This publication includes monthly GNP, and commodity price index numbers, among other statistics.

- Food and Agricultural Organization: Production Yearbook. This United Nations publication includes annual food production and population figures for all major regions of the world as well as index numbers of their per capita food production.

- Food and Agricultural Organization: Trade Yearbook. This United Nations Publication reports annual trade figures for all major regions of the world. Included here are annual prices.

3.3 The Distributional Benefits of Improved Grain Crop Forecasts in U.S. World Trade. (Rough Order of Magnitude Estimate)

Grain distribution benefits arise from the smoothing out of the flow of a commodity from grower to user resulting from improved forecasts. Figure 3.5 illustrates this phenomenon where Q^* is assumed to be the true availability of a commodity which is associated with the price P^*. If the forecast has an error of $+E$, then the forecasted quantity is Q_2, with an associated price P_2, and the benefit, defined as the consumer welfare is given by the area $E(P^*+P_2)/2$. However, since the actual quantity available is Q^* rather than Q_2, the erroneous market price P_2 results in a shortage in the next period, when the quantity available in the market becomes Q_1 instead of Q^*. The corresponding price becomes P_1 with a resulting disbenefit represented by the area $E(P^*+P_1)/2$. Hence, the resultant disbenefit is represented by the area of the shaded rectangle, $E\Delta P$ where $\Delta P = P_1 - P^* = P^* - P_2$. If, instead of a straight line, a hyperbolic demand curve is drawn which corresponds to a constant elasticity of demand, the result ceases to be exact in the sense that the areas of triangles cease to be equal. However, if the error E is small compared to Q*, the result remains within an acceptable bound of approximation. In any case, the benefit accruing from an improved forecast is the amount by which the area of the shaded rectangle decreases with the improvement of forecast.

This study is restricted to a particular agricultural commodity, viz. - wheat. The rationale for this selection is that the volume of production of wheat is the highest among all the staple crops of the world. In this study, the quantity of wheat available for U.S. domestic consumption is expressed in terms of the production and consumptions in different parts of the globe. Forecast errors, both under the conventional as well as under the improved forecast system, are imposed on the production figures of the different parts of the world and the compilation is made of the corresponding ranges of uncertainty over which the quantity available for local consumption varies as a result of forecast errors. Next, the disbenefits under the conventional as well as the improved systems are calculated as explained in Figure 3.5. The difference between the two is the net benefit of the improved system over the conventional system. It should be noted that with an earth resources observation system, the forecast all over the world improves significantly, especially for those countries for which the conventional forecast methods used at present are too simplistic to be accurate. However, in this analysis the benefit has been studied under the assumption that the improved forecast facilities are available to the United States alone, with the rest of the world maintaining the conventional forecast methods. Thus, the benefits calculated in this section are significantly smaller than what could be realized in the case of world-wide improvement of forecast accuracy.

3.3.1 Mathematical Model

Historical data on wheat flow for the last thirteen years show that the main producers of wheat are the United States, Canada, Argentina, and Australia. This is based on the fact that hardly ever do these countries import wheat.

Accordingly, the countries of the world are divided into the following classes:

Class 1: U.S.A.

Class 2: Canada, Australia, and Argentina

Class 3: The rest of the world

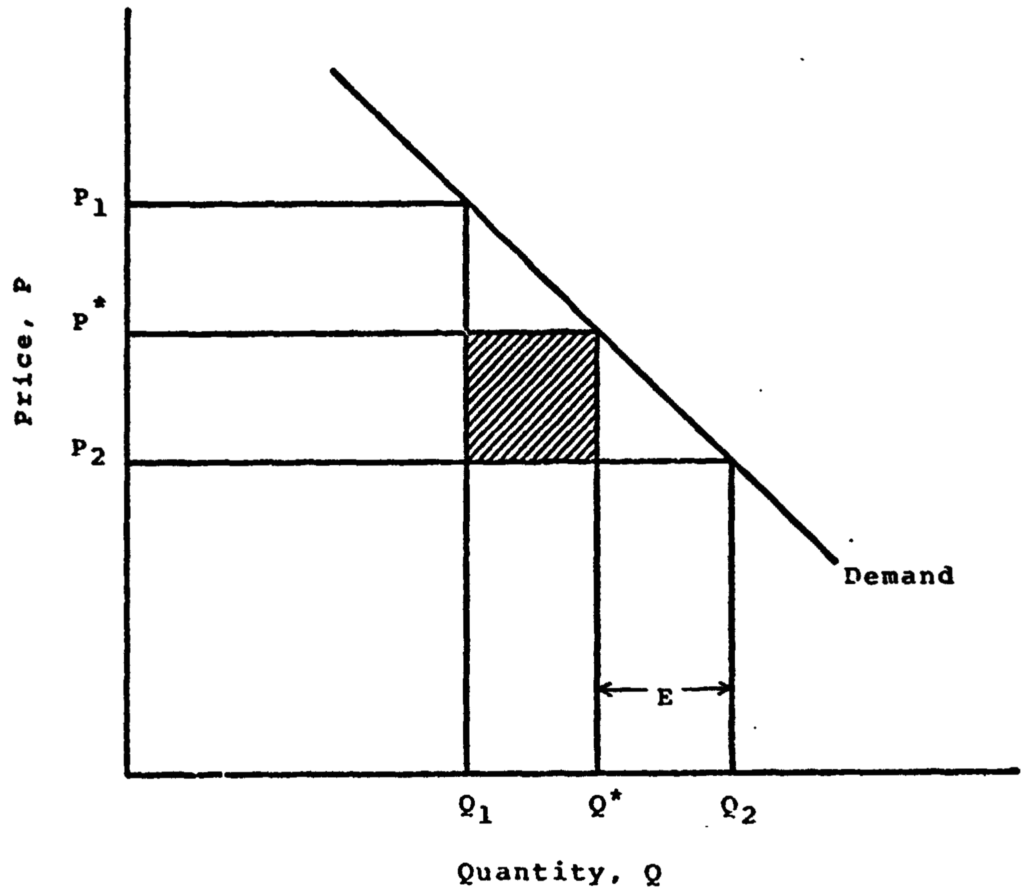

Figure 3.5 Effect of Crop Forecast Uncertainties

The flow of wheat among the various countries can be represented by the following variables and assumptions:

- Q_1: The wheat available in the domestic market for U.S. consumption
- Q_2: The export of U.S.
- Q_3: The inventory of U.S.
- Q_4: The wheat available in the domestic market of Class 2 countries for their consumption
- Q_5: The export of Class 2 countries
- Q_6: The inventory of Class 2 countries
- Q_7: The production of Class 3 countries

Assumptions:

1. There is no export from U.S. to Class 2 countries
2. There is no export from Class 2 countries to U.S.
3. There is no export from Class 3 countries to either U.S. or Class 2.
4. There is no carry-over inventory associated with Class 3 countries.

Thus:

T_1 = total U.S. production = $Q_1 + Q_2 + Q_3$

T_2 = total production of Class 2 = $Q_4 + Q_5 + Q_6$

T_3 = total production of Class 3 = Q_7

T_4 = wheat available in the domestic market of Class 2 = Q_4

T_5 = total consumption of Class 3 = $Q_2 + Q_5 + Q_7$

The variables T_1 through T_5 are treated as exogenous variables. The endogenous variables are Q_1 through Q_7, out of which Q_1 is of relevance in calculating the U.S. domestic benefit. In order to compute the exogenous variables, they are first expressed as linear combinations of all the prices in the form of demand equations. The coefficients of these demand equations are estimated in the least squares sense from historical data on various flow quantities and their corresponding prices. Out of the seven flow variables described above, the inventories (i.e., Q_3 and Q_6) are not tagged with any price, the remaining five quantities get associated with their corresponding price tags. These five prices are now solved from the five equations that describe the five exogenous variables. Next, these prices are inserted in the demand equation describing Q_1 to compute the value of Q_1.

It is clear that if forecast errors are superimposed on the exogenous variables T_1, T_2, and T_3 (i.e., the production figures of the various countries), the computed value of Q_1 will vary accordingly. Hence, an upper and a lower bound on Q_1 can be obtained for any given range of forecast errors on T_1, T_2, and T_3.

3.3.2 Results

It is assumed from Figure 3.1 that the forecast error for the United States, under the conventional forecast system, is typically $\pm$5% at the beginning of the growing season, and $\pm$2.5% at the end of the season. Assuming that 50% of these errors are due to sampling which can be significantly improved under an earth observation satellite system, it can be expected that the errors for the U.S. under improved forecast system will be $\pm$2.5% at the beginning of the season and $\pm$1.25% at the end of the season. The forecast errors for the Class 2 countries are comparable to those of the United States. For some of the Class 3 countries, the forecast errors can be as high as 24%. However, this high percentage does not apply to some of the countries of Western Europe. Further, due to the averaging effect, the cumulative error of all the countries in Class 3 will rarely hit such a high value.

A typical value of the error of Class 3 countries under the conventional system is assumed to be 12% at the beginning of the season, and 6% at the end of the season.

When these errors, as experienced under the conventional system at the end of the growing season are imposed on T_1, T_2, and T_3, the bounds on Q_1 as computed from the model become:

$$17.63 \leq Q_1 \leq 24.17$$

The disbenefit associated with this uncertainty on Q_1 is calculated as explained in connection with Figure 3.5 using a hyperbolic demand curve with constant price elasticity of 0.1, and is given by

$$C_{end} \text{ (conventional)} = \$365.68 \text{ million}$$

It is clear that in a hypothetical situation, where perfect information is available all over the world, C_{end} (perfect) becomes zero which implies an annual U.S. benefit of 365.68 million dollars.

However, under the assumption that only U.S. enjoys the benefit of improved forecast (i.e., the range of error gets reduced to half its present value), and the rest of the world carries on with the conventional forecasting procedure, the upper and lower bounds on Q_1 become:

$$17.86 \leq A_1 \leq 23.94$$

The corresponding disbenefit becomes:

$$C_{end} \text{ (improved)} = \$329.51 \text{ million}$$

Thus, the annual benefit to U.S. due to improvement on U.S. forecast alone at the end of the season is given by

365.68 - 329.51 = \$36.17 million

The same analysis is done for the improvement on U.S. forecast at the beginning of the season, and the corresponding benefit turns out to be \$70.16 million. Assuming that these two benefits are weighted equally, the average annual U.S. benefit due to improvement of U.S. forecast alone turns out to be \$53.16 million. It should be noted that the U.S. benefit due to world-wide improvement on wheat forecast is much higher, as indicated earlier.

3.4 An Ad Hoc Case Study in Water Management

The Feather River Project, primary components of which are the Oroville Dam and Oroville-Thermalito Power Facilities, represents a key segment of the California State Water Plan and has a major impact on flood control, irrigation, and hydro-electric power generation. In order to determine the potential benefits that could accrue with ERS satellites for this project, it is necessary to understand the manner in which the current system is operated. With this understanding, it is possible to calculate how ERS would impact on the system and the economic consequences of such an impact. The Feather River Project provides three major economic benefits, i.e., flood control, irrigation, and power generation.

3.4.1 Forecasting Water Runoff in the Absence of ERS

An accurate prediction of the monthly inflow rates for the Oroville Reservoir is necessary for better management of the Oroville Reservoir and the California Water Project. Currently, predictions are provided on February 1st for the entire water year (October 1 - September 30) and updated monthly through May 1st. Figure 3.6 shows the April to July forecast results for the October 1972 to September 1973 water year.

This figure points out several interesting phenomena which indicate the potential need for more and better information on which to base forecast runoff. From the diagram, it is apparent that forecast accuracy does not improve from month to month as might be expected. Also it is seen that the eighty percent confidence bound diverges from the actual runoff with each new forecast up to April and apparently does not begin to converge until actual runoff data are available.

Current pred'cting techniques provide accuracy to within approximately twenty-five percent for both short term and long term predictions. The uncertainty of the "correctness" of these predictions is an important factor in the supply of economic water and can in itself either provide significant quantities of economic water or, for every poor predictions, limit the supply drastically. Currently, the percentage uncertainty seems rela-

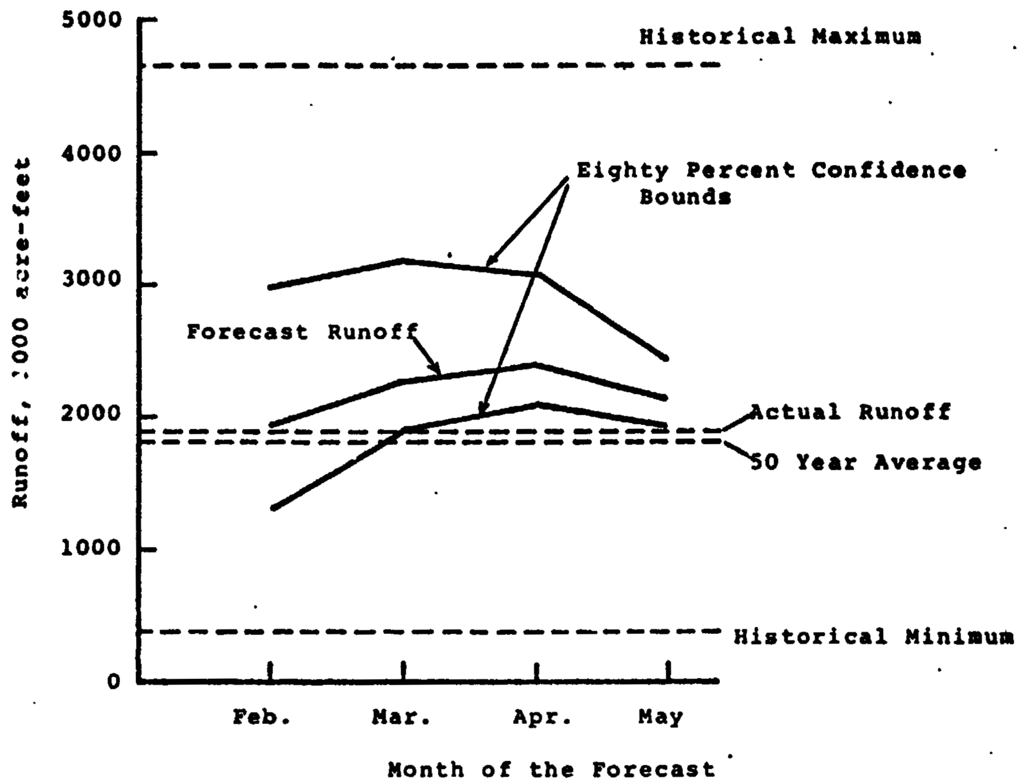

Figure 3. 6 Unimpaired Runoff into Oroville Reservoir for the Period 1 April 1973-31 July 1973: Predicted vs. Actual (Without ERTS)

tively large (note the eighty percent band on Figure 3.6) and it appears that much fruitful work could be done on obtaining improved data and methods of prediction. The investigation of remote sensing (ERS) applications to the management of the Feather River therefore, holds great promise.

The problem of current prediction accuracy and timing leads one to question the process by which information is gathered and related to the forecast runoff. Current predictions are based on historical data leading one to assume that flow rates from year to year are similar in nature. However, as shown by Figure 3.7 different years can produce substantially different flow patterns, thereby limiting the accuracy of using historical records to predict future runoffs. Also, in support of this assertion is Figure 3.8 which plots the historical runoff rates for another area of the California Water Project. From the "typical" example, it is apparent that any attempt to work with an average year would produce large prediction errors. It is necessary therefore to take a much closer look at the mechanics of runoff and its prediction.

From Figure 3.8, it is clear that there is a large variation in the April to July runoff, with the average runoff for the lowest of the trimodal peaks being less than a third of the value for the highest of the trimodal peaks. If ERS, early enough each year, can contribute to predicting which of these peaks is the relevant one for that year, a large economic benefit would result.

3.4.2 Economic Benefits from ERS Information

The direct activities that benefit from improved ERS information are shown by Figure 3.9. With or without ERS information, the Oroville Dam will be managed in such a way as to insure, with virtual certainty, the absence of flooding. Better water management will not show up directly in terms of flood control, but will be effected in the other economic activities shown in Figure 3.9. Therefore, the value of ERS information in flood control of the Feather River will be treated as zero.

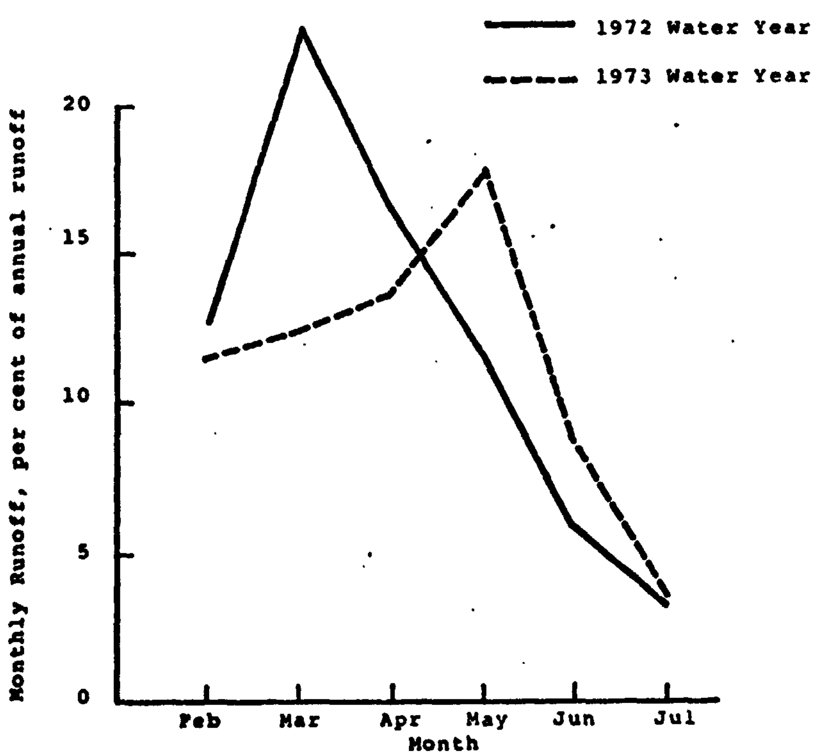

Figure 3.7 Comparison of Monthly Runoffs at Oroville Reservoir for 1972 and 1973 (Without ERS)

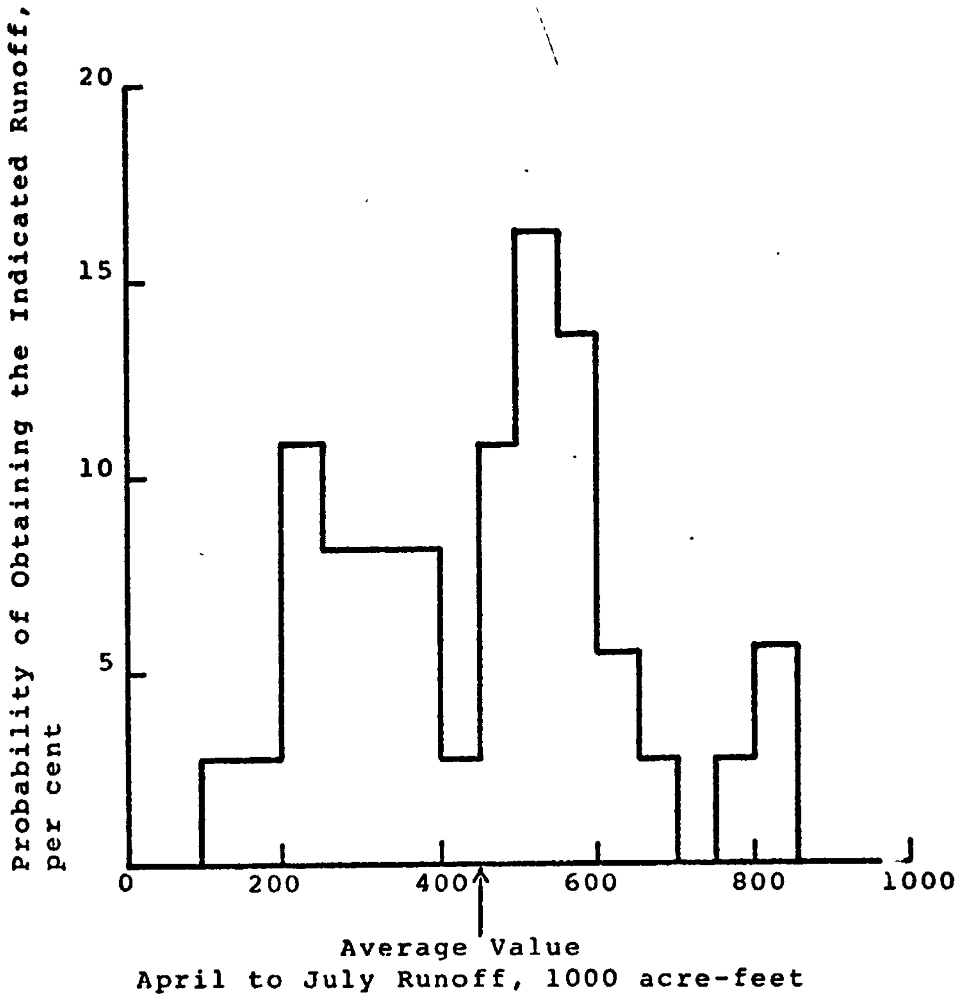

Figure 3.8 Historical Probability Distribution of Water Inflow of a Typical River of the California State Water Project

Water that is used for hydroelectric power generation, subsequently can be used for other activities such as recreation, navigation, residential, industrial, and agricultural programs. The bulk of this water, about 90%, is used for agricultural purposes, both in the Feather River System and for the U.S. in general.

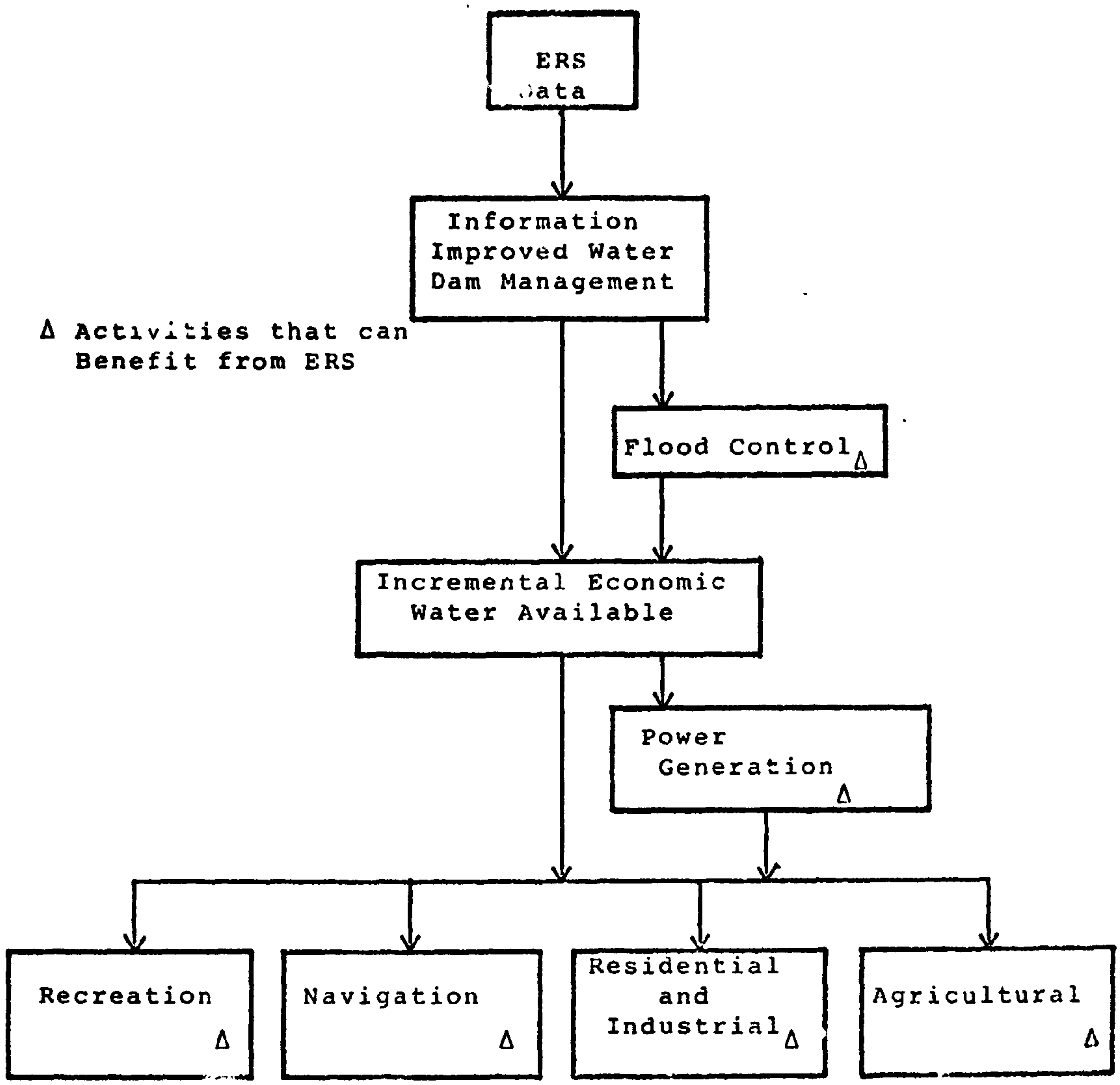

Figure 3.9 Activities That Benefit From Improved Water Management

Current and improved operations due to better information can be illustrated partly by Figure 3.10. Instead of managing the water level in the absence of ERS information such that the expected water level at the dam is at point C, with ERS information the water level is at point B. Both cases provide the same degree of safety, but with ERS information an additional amount of water (given by the distance BC) is available for economic use. The distance A minus C corresponds to some specified level of required unfilled flood control water

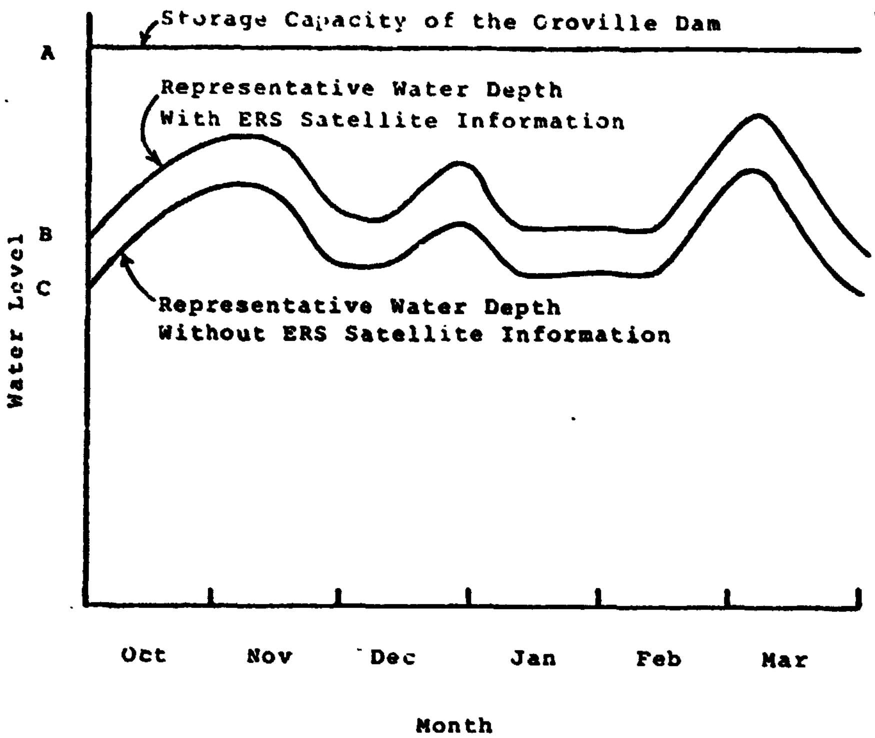

Figure 3.10 Effect of Improved Information on Steady State Water Levels

volumes given by Figure 3.11. For example, level C may represent a flood control reservation of 550 thousand acre-feet, which corresponds to a ground wetness level of 7.0. It is assumed in this study that a ground wetness of 7.0 is representative of average conditions during winter and spring months.

3.4.3 Estimated Improvement in Forecasting with ERS Information

If ERS data cuts the information and modeling error by 20% then an additional 110 thousand acre-feet of economic water are available, as represented by the distance BC on Figure 3.10.

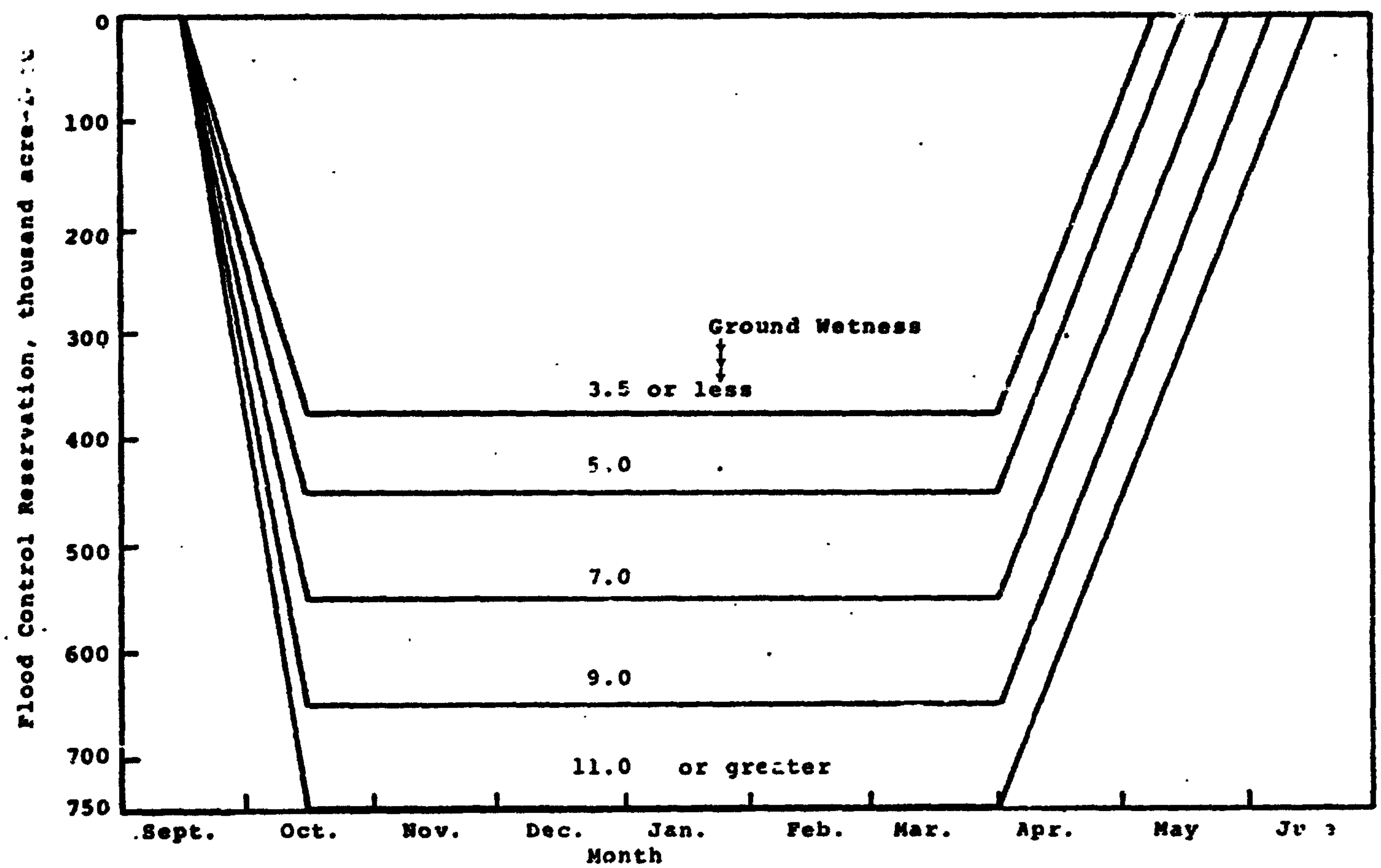

Figure 3.11 Schedule of Required Unfilled Floor Control Volume by Ground Wetness Index for Oroville Reservoir

That ERS can perform to this degree appears to be supported by the recent reports of a number of principal investigators. Some of these principal investigators are Alexander, Burgy, Cooper, Hoffer, Holgren, and Meier. A description of their reports is given in Volume V, Appendix G.

From another standpoint it can be stated that ERS will improve forecasting accuracy. The sampling error of area mensuration is inversely related to a power of area. In certain cases where the area in question is geometrically regular enough:

$$\text{Error, } e = \frac{b}{\sqrt{A}}$$

b = a function of resolution, technique used, etc.

A = geographical area of coverage

If, with the same b coefficient for ERS and aircraft, ERS provides an area of snow coverage and ground wetness coverage 16 times that currently monitored by aircraft, then, by using ERS, the percentage error in the snow cover and ground wetness information content is reduced by 75 percent. For more complicated cases the reduction of percentage error may be even greater since sampling error will then be inversely related to a large power of A (between 1/2 and 1).

Of course, snow cover and ground cover information is only a part (but a major part) of the information required to make accurate runoff forecasts. Accuracy of forecasts also will be degraded by inaccuracies in the runoff model. Therefore, a 20% increase in the accuracy of forecasts is a conservative estimate, given the proven capabilities of ERS, the likely extent of increase in area coverage by ERS and the numbers used in the EarthSat Report. In the EarthSat Report on Inland Water Management, estimate benefits presented in their tables are based on a 25%, 50%, and 75% increase in forecasting accuracy.

3.4.4 Benefits in Irrigation

Agricultural studies analyzing the value of water for irrigation were conducted by Brown and McGuire in 1967. From this analysis, they obtained estimates from two sets of data of approximately $15 and $19 per acre-foot of water. For the Feather River Area, the total equivalent unit charge per acre-foot is $13.46, which is low in comparison to the rest of the state.

The value of 110,000 additional acre-feet of water at $13.46 per acre-foot is $1,480,000 per annum. Since the price of crops has increased by at least 50% since 1967, when the value of $13.46 per acre-foot of water was calculated, an increase of 40% for the value of water is conservative. Multiplying the value per acre-foot by the number of acre-feet yields the annual benefit from increased water for irrigation and other non-hydroelectric power purposes in 1973 dollars of $2,070,000.

The other reservoirs in the California State Water Project have a combined capacity that is approximately two-thirds of Lake Oroville. Therefore, an additional $1,380,000 per annum can be assigned to irrigation benefits in California. From the EarthSat report on water management* (p.99), the potential net benefit for irrigation activities in California is approximately 40% of the total for ten Western states. Therefore, an estimate of the total benefit from additional irrigation is $8,580,000 per annum.

3.4.5 Benefits in Hydroelectric Power Generation

To calculate the value of 110,000 acre-feet of water for power generation, it is necessary to (a) determine the amount of kilowatt-hours (kwh) that can be generated by this amount of water and to (b) determine the incremental value per kilowatt-hour (kwh). Potential hydroelectric power is a function of the volume of water and the average height of that water. Given the gross static-head at Oroville of 615 feet, and a gross static-head of 103 feet at Thermalito, and using a power conversion efficiency of 90%, an acre-foot of water at Oroville-Thermalito is equivalent to 658 kilowatt hours of electricity. The total amount of additional hydroelectric power is therefore 72,400,000 kwh.

Because of the highly regulated nature of the utility industry, a serious problem arises in determining the true incremental economic value of a kilowatt-hour. According to the EarthSat Report, the additional power generated can be used for peak power generation, where the value of a kwh is much higher than for off-peak power generation. The value of this power is equal to the value of such power generated by the least expensive alternative means. This value, based on the latest available information, appears to be at least two cents per kwh. The annual value of this hydroelectric power is therefore equal to or greater than $1,450,000.

In order to calculate the potential increase in hydroelectric power for the U.S., based on the Feather River results, an examination was made of those major U.S. drainage basins where snowmelt would be an important determinant of water

*EarthSat, Corp., Report on Water-Resources Management, undated.

runoff. Within these drainage basins, only large hydroelectric power plants (i.e., those with a generating capacity over 100,000 kw) were included in the calculation.

The Oroville-Thermalito power plants generated an annual average of 2.45 billion kw of electricity in the years 1971 and 1972 (i.e., 3.264 billion in 1971 and 1.635 billion in 1972). This average represents 2.29% of the estimated total production of large hydroelectric plants in the six designated drainage basins in 1973. Results for the Feather River increased by a factor of 43.6 gives an annual nationwide benefit of $63,000,000. However, to be conservative, it is assumed that only two-thirds of these large plants in the six designated river basins benefit from ERS. This adjustment yields an annual benefit to the U.S. of $42,000,000.

3.5 Land Cover Case Study

3.5.1 The Purpose and Major Findings of the Study

The purpose of this study was to examine the economic potential, defined for this study as cost savings, of an ERTS type satellite in the development, updating and maintenance of a nationwide land cover information system in the post-1977 time frame. As envisioned in this study, the national information system must be capable of satisfying at least the land cover information requirements of all Federal civilian agencies under existing Federal statutes. The study examines several alternative acquisition systems for land cover data and the relevant information acquisition, data processing and interpretation costs associated with each alternative. The basic problem was to determine, on a total life cycle cost* basis, under which conditions of user demand (area of coverage, frequency of coverage, timeliness of information, and level of information detail) an ERTS type satellite would be cost effective and, if so, what would be the annual cost savings benefits.

Major conclusions of this study are:

1. An ERTS type satellite is a cost-effective system for satisfying the expected level of demand for land cover information in the post-1977 period. This is predicated upon an annual demand level of six times coverage of the continental United States plus Alaska, with each mapping mission to be completed within 60 days and the mapping information classified to Level II detail, (USGS - Circular 671 classification scheme) and more detailed coverage (Level III) of the

* Throughout this report we refer to life cycle costs which were computed over the period 1975-1993 in 1973 dollars discounted at 10% to 1974.

same area once every five years. To satisfy this demand level, the cost-effective system requires two satellites simultaneously in orbit. However, high and low altitude aircraft with ground survey teams are also necessary components of a cost-effective data acquisition and processing system for this level of demand.

2. A three-satellite system with high and low altitude aircraft and ground survey teams is cost-effective at an annual demand level of twelve times coverage of the U.S. at Level II, with each mapping mission to be completed within 30 days and Level III coverage of the U.S. once every five years.

3. In the post-1977 time frame, automatic (e.g., computer) interpretation and classification techniques will be technically and economically preferred over manual interpretation methods.

4. The expected annual cost savings that accrue from an operational ERTS as a component of a Nationwide Land Cover Information System is $23 million of undiscounted 1973 dollars (as compared to an aircraft only system).

5. The satellite configuration assumed for purposes of this analysis is not the optimum configuration to accomplish both the U.S. and the global coverage missions at minimum cost. Further cost savings can be realized by modifying the configuration of an operational ERTS system. A joint systems engineering and economic analysis of various satellite configurations for accomplishing both missions should be undertaken.

The following sections of this chapter will address several important questions relevant to the purpose and findings of this study. What is the basis or need for a nationwide land cover information system and how might such a system be organized and operated? What will be the likely demand for land cover information in the post-1977 time frame, and what are the technical alternatives for satisfying these demands? Finally, what are the major variables which impact the life cycle cost of the alternative data acquisition systems and which systems alternatives are economically preferred at various levels of demand for land cover information?

3.5.2 The Need for a Nationwide Land Cover Information System

In July of 1973, a Federal Mapping Task Force which had earlier been established by the Director of the Office of Management and Budget issued a report* on Federal agency surveying and mapping activities. This report summarized the work and results of a major inquiry concerning: (1) the existing data collection programs of various Federal civil agency and military domestic mapping programs, and (2) an investigation of systems and procedures to achieve both improved economies in these data collection programs and increased responsiveness to user needs. The Task Force report underscored three major problems which have long been associated with Federal civilian mapping programs:

- uncoordinated, single-purpose surveys and mapping which benefit only one user agency
- a growing mass of unmet national demand for mapping data and products
- the inability of the present structure of data collection programs to deal efficiently and responsively with growing and changing demand requirements.

Throughout our own study we have repeatedly confirmed these earlier observations. We have inquired into the present day data collection activities of various Federal agencies, we have studied reports on the utility of more extensive and more timely earth resources information, and we have interviewed responsible officials of civilian Federal agency mapping programs concerning their data needs and their present efforts. We find that the need for land cover information in the United States far exceeds the present day data collection activities.

We agree with the primary conclusion of the Federal Mapping Task Force, that in order to rectify this imbalance most efficiently, there is an urgent need to consolidate the fragmented data collection efforts of the many Federal agencies into a new centralized mapping organization. This need leads directly to a Nationwide Land Cover Information System.

3.5.3 Conceptual Description of a Future Nationwide Land Cover Information System

Figure 3.12 provides an overview of the organization and operation of a future Nationwide Land Cover Information System. At the outset, two points must be clearly understood.

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* Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying, July, 1973.

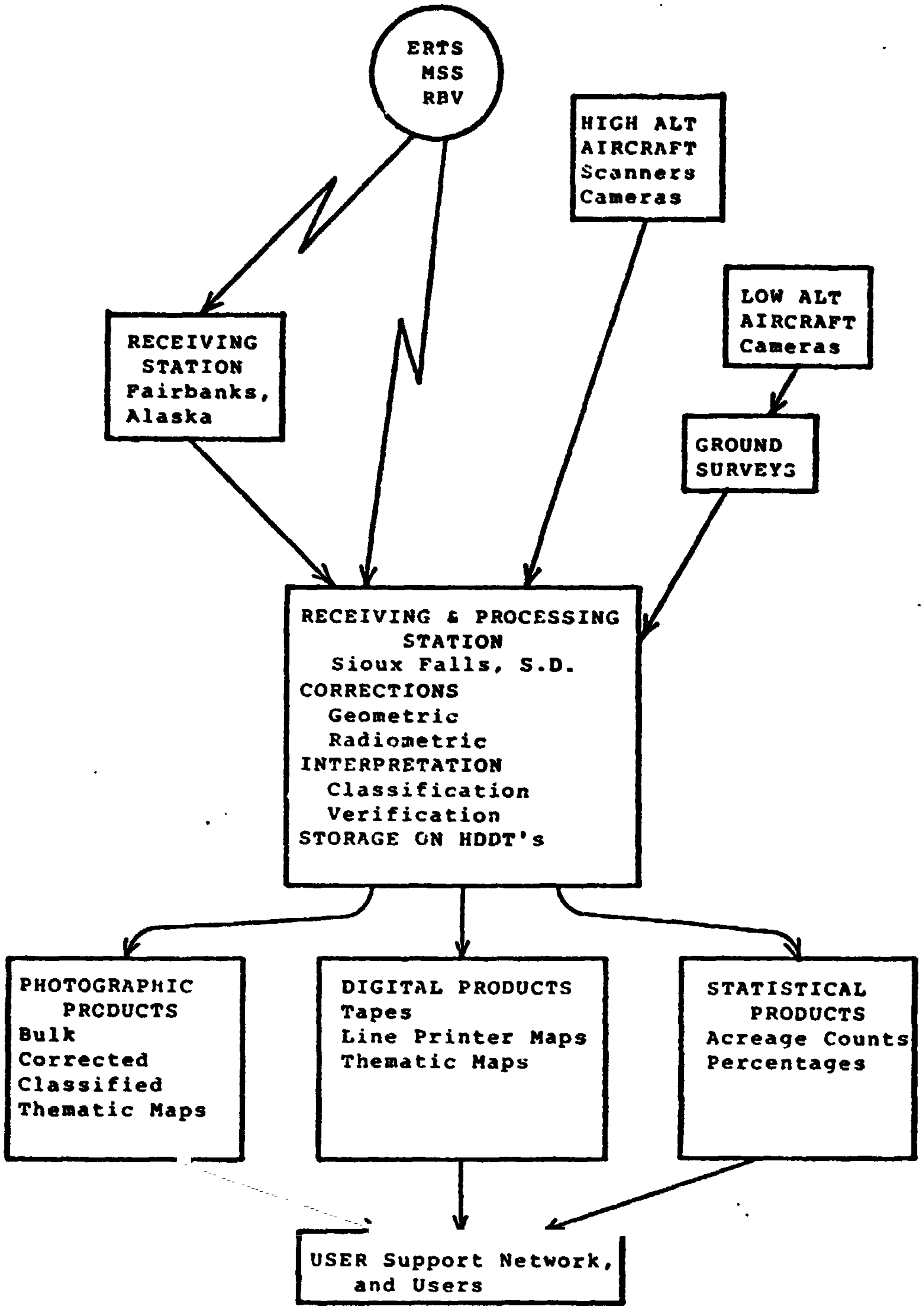

Figure 3.12 Conceptual Flow Through Land Cover Information System

We have not undertaken in this study a systems engineering analysis of a Nationwide Land Cover Information System. We have only sketched out our own rough concept of a national information system for the purpose of identifying the cost elements that are relevant to a cost effectiveness analysis of an ERTS type satellite as a major information acquisition component. A second, related point is that we considered in this analysis only the central core of a nationwide land cover information system. It is likely that there will be a network of user service facilities, organized perhaps on a regional basis, which will distribute resource management data products from the core facility to the various users. *The support network of user service centers has not been considered in this study since the investment and operations cost of any such network would be common to all the alternative data acquisition systems.* Table 3.6 lists the remote sensing platforms which acquire data for the national information system. The projected 1977 capabilities of the several sensors for acquiring information at various levels of detail are shown in Table 3.7. The method of processing and classification, manual or automatic (computer) techniques has a major influence in this regard. Using manual interpretation methods, ERTS images can provide Level I information, as has been demonstrated by several ERTS investigators (See References 1, 6, 8 and 9 on page III - 18 of Appendix III in Vol. VI, Part II). Many investigators reported manual mapping of some Level II categories from ERTS but they could not satisfy the 90% accuracy standard recommended in the USGS-Circular 671. Typical accuracies reported for Level II information obtained via manual techniques range from 50% to 70%. Computer processing and classification techniques are relatively new and the state of the art is in its infancy. Already, very promising results have been reported by ERTS principal investigators; the only type of information for which consistent difficulties have been encountered is the Urban subcategories of the USGS land use classification scheme, specifically, Urban-commercial, Urban-industrial and Urban services. With the exception of these Urban subcategories, computer processing of ERTS images will undoubtedly permit the mapping of Level II information* at 90% accuracy standard. Figure 3.13 is an example of a computer generated color coded land use map prepared by NASA/JSC Earth Resources Laboratory of the Mississippi Test Facility in Bay St. Louis, Mississippi.

3.5.4 Overview of the Study Approach

Figure 3.14 depicts the study approach in overview form. The analysis begins with projections of the demand for land cover information which each technology system must satisfy on an equal capability basis. For the purposes of this analysis

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* See References 10, 13, 14, 15 and 17 on page III-19 of Volume VI, Part II.

Table 3.6 Remote Sensing Data Acquisition Elements for A Nationwide Land Cover Information System

Platform	Sensor
Satellite - ERTS -type	Multispectral scanner Return Beam Vidicon
High Altitude Aircraft-U-2	Multispectral Scanner 6 inch metric camera
Low Altitude Aircraft - Commercially Available	9" x 9" 1:24,000 photographic images

Table 3.7 Projected Sensor Capabilities For Acquiring Information At Various Levels of Detail

Manual Processing				Automatic (Computer) Processing			
	ERTS	HA	GT		ERTS	HA	GT
Level I	✓	✓	✓	Level I	✓	✓	✓
Level II		✓	✓	Level II	✓	✓	✓
Level III			✓	Level III		✓	✓

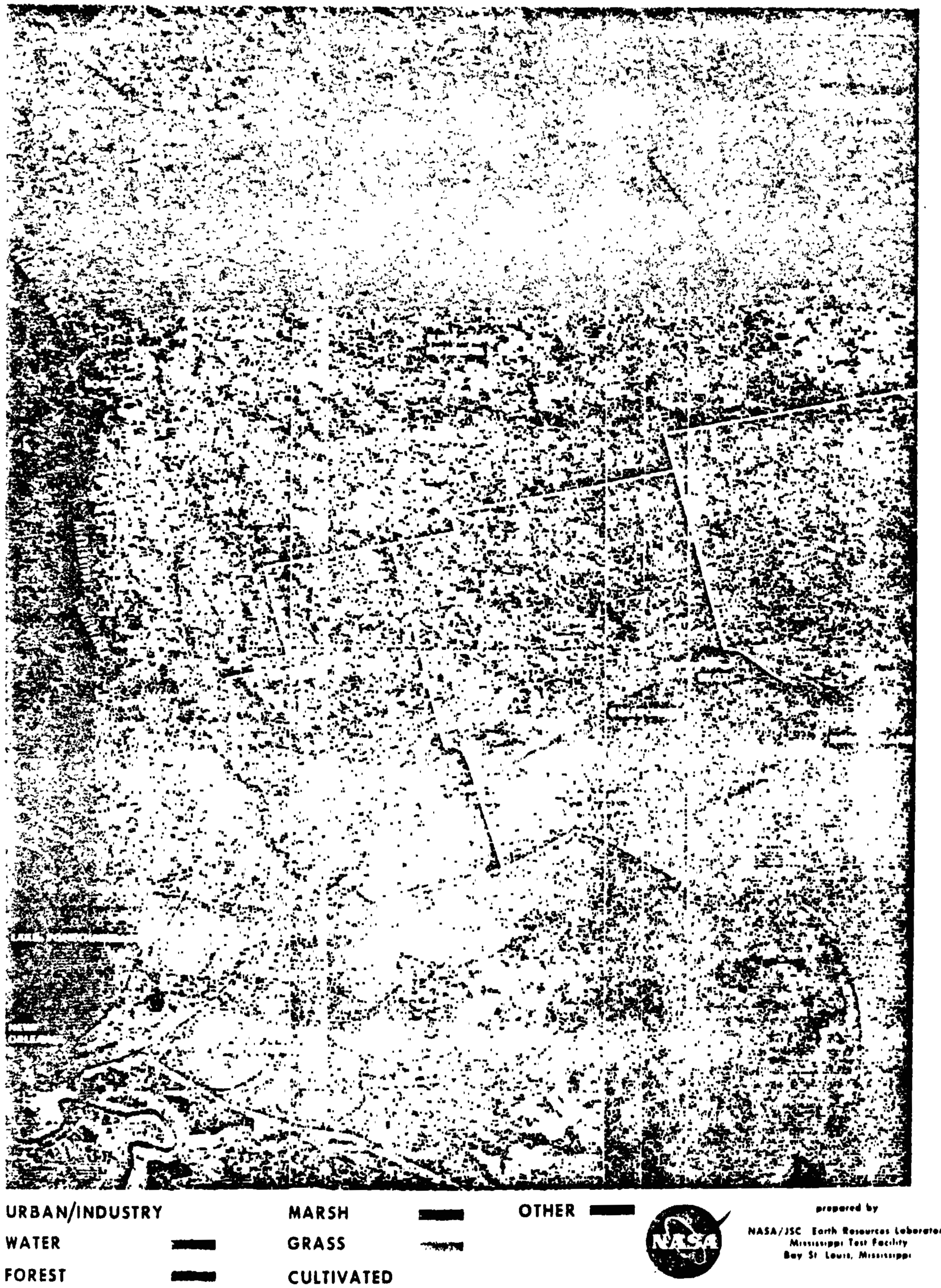

Figure 3.13 Computer Derived Land Use Classification of ERTS-1 Data Acquired August 7, 1972 - Mississippi Gulf Coast

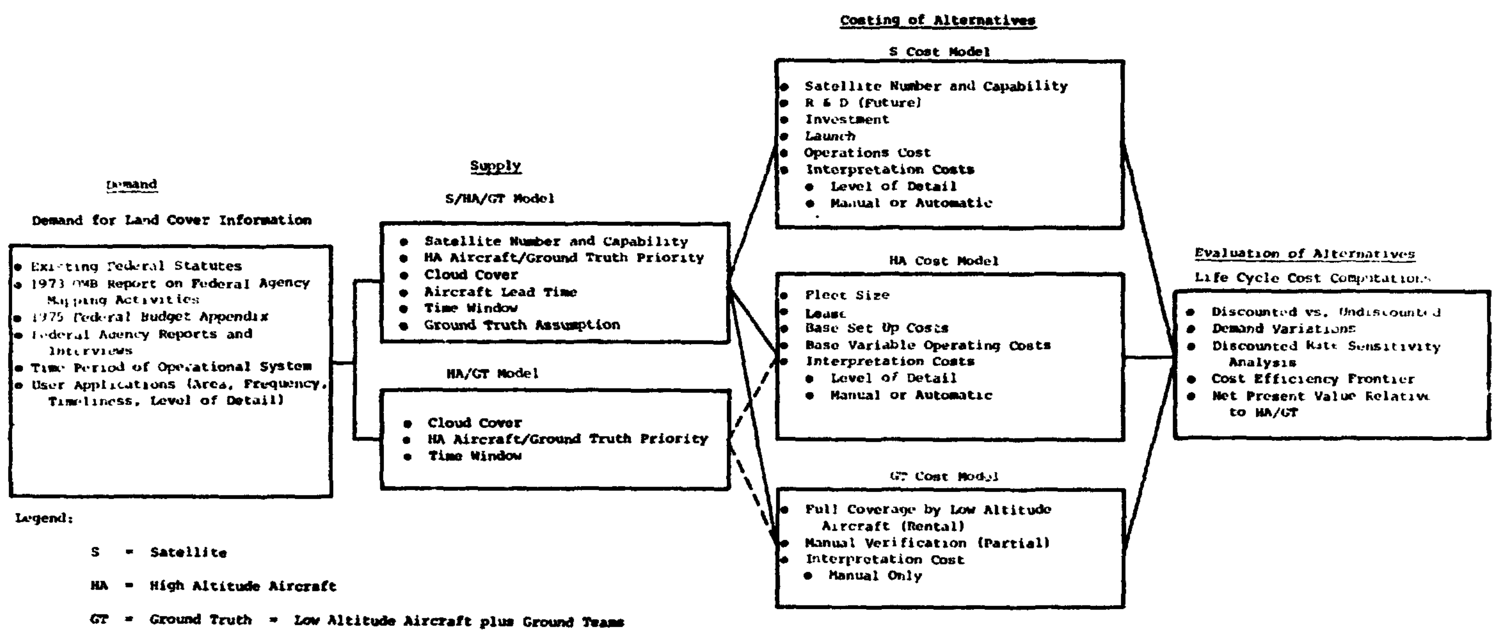

Figure 3.14 Overview of the Study Methodology

only demand which requires full target coverage is considered. Thus, demand requirements which can be satisfied by a probability sample of a given target area have been excluded from our analysis.

The analysis of demand for remotely sensed land cover information focuses on four major characteristics of user demand: area of target, timeliness of information, frequency of update, and level of information detail. *The target area* refers to the percentage of the United States that must be covered to satisfy a specific demand requirement. Though actual user-desired targets vary continuously from small regions of the United States to the full United States, this analysis classifies user demand into one of four area requirement categories: 100%, 10%, 1% or .1% of the United States. *Timeliness of information* (also called user time window) refers to the maximum allowable elapsed time (in days) during which the remote sensing of land cover information must be completed in order to satisfy the user. This important characteristic varies from once every five years to weekly. *The frequency of coverage* refers to the number of times that targets of a given size, timeliness and level of detail requirement are covered during one year. Note that the frequency of coverage is a composite of users who want repeated coverage of a given target area as well as users who want one-time coverage of targets of a given size which are geographically or temporally distinct. *The level of information detail* reflects the scale required which, in turn, is determined by the type of information needed to fulfill the user requirements. In our study, Level I information corresponds to a mapping scale of 1:500,000, Level II, 1:125,000 and Level III, 1:24,000.

Using the above four demand characteristics, a search was made of the existing Federal statutes that either mandate or enable Federal civil agency land cover mapping programs. An analysis of Federal Agency demand for remotely sensed land cover information in the 1977 time frame (under existing Federal statutes) was made for the "land use planning community" and separately, for "all land cover users." Detailed findings are documented in Chapter 3 and Appendix III of Volume VI, Part II of this report. After eliminating overlapping data gathering requirements of the various Federal agency users, we conclude that most of the Federal demand requirements for both user groups is for Level II information; the coverage requirement extending over the entire continental United States and Alaska land area at an annual mapping frequency of four times, seasonally, i.e. within 90 days. The vast majority of Federal agency demand for full target coverage (non-sampling applications) arises from the land use planning community. We did not identify any Federal requirements for Level I information for either the land use planning community or other Federal land cover users.

In any event, however, it should be noted that Level II mapping information can readily be aggregated to provide Level I information. We did find substantial Federal demand for Level III information, but full coverage of the United States is required only once every five years.

Demands upon a national land cover information system will be limited to Federal users only. A separate ECON study documents the need for earth resource management data from state, regional and local government units as well as the needs of the industrial and academic community. Quantitative estimates of the demand for land cover information in the post-1977 period from all sources are highly uncertain, at present. We have therefore explored the economics of ERTS over a range of future demand levels, from two times coverage of the U.S. at Level II within 180 days to twelve times coverage of the U.S. at Level II within 30 days.

On the supply side of the analysis, there are several alternative technical systems considered for the acquisition and processing of the land cover user-requested data. Each technical system is made up of two or more of three basic remote sensing components; namely an ERTS-1 type satellite, high altitude aircraft and a ground truth system which is defined to mean a low altitude aircraft with ground follow up teams. These remote sensing components (hereafter designated S, HA and GT), are combined to form the several data acquisition systems indicated in Table 3.8.

For purposes of this analysis, each of the two and three tier technology choices listed in Table 3.8 has an implied priority ranking associated with the use of its constituent data acquisition systems. The priority ranking is defined by the ordering of the components of a given technology choice. For example, the S/HA/GT technology implies that in our analytical models the satellite component will satisfy as much of the user demand as is possible, consistent with its capability to satisfy the level of information detail requirement of the user, and the user timeliness requirement and to overcome cloud cover problems. Whatever portion of user demand that cannot be satisfied by the satellite is assigned to high altitude aircraft and whatever demand is left unsatisfied by that component is assigned to the ground truth system. To illustrate, if the user demand were to obtain Level II information over one tenth the area of the U.S. within a specific 30-day period then, given an 18 day satellite revisit time, the satellite would acquire only a fraction, say p, of its assigned target, where p depends on the amount of cloud interference that it encountered over the target during 1-2/3 passes. In this case, the high altitude aircraft

Table 3.8 Alternative Data Collection Systems For Nationwide Land Cover Information System	
Three Tier Systems	Two Tier Systems
1. S/HA/GT	1. HA/GT
2. 2S/HA/GT	2. S/GT
3. 3S/HA/GT	3. 2S/GT
	4. 3S/GT

Legend: S refers to an ERTS type satellite
HA refers to high altitude aircraft (U2)
GT refers to low altitude aircraft and ground survey follow up teams

component (HA) of the S/HA/GT technology would be assigned to provide remote sensing coverage over that portion of the user target area left unsatisfied by the satellite. Moreover, the HA component may also fail to complete the mission due to cloud cover problems and tight time requirements; in which case, the ground truth component (GT) consisting of low altitude aircraft and supporting ground teams are assigned to complete the task. The specific assumptions and methodolgy that are used for analysis of the three tier and two tier systems are described in Chapter 4 of Volume VI, Part II of this report.

The analytical models depicted in Figure 3.14 allocate the projected user demand to the S, HA and GT components in accordance with the characteristics of user demand, cloud cover problems, capabilities of the component sensors and operational constraints imposed on the analytical models. Once the demand has been allocated to the three basic remote sensing components, the costs of satisfying these demands are calculated in the costing models, taking into account the many investment and operating cost elements of each system. The basic annual cost information for each of the technology choices are then reassembled and compared in the evaluation model.

3.5.5 Results

Life cycle costs were computed for each of the two and three tier data acquisition systems previously described. Total program cost comparisons were made for the alternative systems (1) over a range of land cover demand levels, (2) using automatic and manual data processing and intrepretation techniques and (3) under two different user cloud cover requirements. The basic problem underlying and guiding these life cycle cost comparisons was to determine under which conditions of user demand (area of coverage, frequency of coverage, timeliness of information and level of information detail) an ERTS-type satellite would be cost effective and, if so, what would be the annual cost savings benefits.

Our analysis begins by considering only Federal user agency demand for land cover information under existing Federal statutes. Next, we address the national resource management information needs of all user groups, Federal and otherwise. For this case, demand projections in the post-1977 time frame are highly uncertain; thus a parametric demand-cost analysis is made. Finally, in order to estimate the likely cost savings benefits of ERTS, we evaluate the system alternatives for three particular demand scenarios which we believe will bracket the actual national demand for land cover information in the post-1977 time period. A description of the results of these analyses follow.

A comparison was made of the life cycle costs required to satisfy 1977 Federal agency demand using either manual or automated data processing and classification techniques. Life cycle summary costs are shown separately in Table 3.9 for the "land use planning community" and, separately, for "all land cover users." The projected 1977 Federal agency-Land Use Planning demand* principally involves four times annual coverage of the U.S. at Level II, Level III coverage of the U.S. once every five years and fractional coverage of the U.S. at Level II and Level III at more frequent time intervals. The projected 1977 Federal agency-All Land Cover Users demand* encompasses the Land Use Planning demand and additional fractional coverage of the U.S. at Level II and Level III at more frequent intervals. Two different user cloud cover requirements, 0-30% and 0-10% allowable cloud coverage, were also considered. The cost-effectiveness analysis of the technical alternatives for satisfying Federal agency information demands revealed two important results:

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* Precise descriptions of demand are provided in Tables 3.4 and 3.5 of Chapter 3, Vol. VI, Part II of this report.

Table 3.9 Discounted Total Program Cost to Satisfy 1977 Federal Demand For Land Cover Information Under Existing Federal Statutes

User Group	Program Cost, $ millions (1973)*			
	User Cloud Cover Requirement Allowable (Needs 0-30%)		User Cloud Cover Requirement Allowable (Needs 0-10%)	
	Manual Interpretation	Automatic Interpretation	Manual Interpretation	Automatic Interpretation
Land Use Planning Community Only	518.9 HA/GT 688.9 S/HA/GT	316.5 HA/GT 337.1 S/HA/GT	616.7 HA/GT 786.7 S/HA/GT	428.0 HA/GT 454.2 S/HA/GT
All Land Cover Users	937.2 HA/GT 1107.2 S.HA/GT	613.3 HA/GT 701.8 S/HA/GT	1120.1 HA/GT 1290.1 S/HA/GT	835.7 HA/GT 881.6 2S/HA/GT

S refers to an ERTS type satellite
HA refers to high altitude aircraft (U2)
GT refers to low altitude aircraft and ground survey follow up teams
*Discounted at 10% to 1974

1. An all aircraft system is cost-effective when considering only Federal agency demands for U.S. coverage and a mixture of satellite, high and low altitude aircraft provide the next best alternative.

2. Automatic data processing techniques are economically preferred over manual methods.

The fact that a satellite component does not emerge as an essential component of a cost-effective system for satisfying Federal agency demand can be attributed to the Level III information requirements of Federal users. While these requirements cannot be satisfied by ERTS, they can be satisfied by high altitude aircraft and at less cost than would be required by low altitude aircraft and ground survey teams. Subsequent analysis shows that the satellite component becomes economically attractive with increasing Level II information demands and that when the projected demands arising from all earth resource management needs are considered, a "with" satellite system is cost-effective.

As regards automatic versus manual data processing, Table 3.9 indicates that in every instance of comparison, there are significant cost savings advantages that accrue to the automatic techniques over manual techniques. This result was to be expected given the differences in the projected capability of these techniques in the 1977 time frame for acquiring increasingly detailed land cover information. Using ERTS, manual techniques can provide only Level I information with the necessary accuracy while automated techniques can provide both Level I and Level II type information. Similarly, using high altitude aircraft, manual techniques can provide Level I and Level II while all levels of classification detail can be obtained from automatic techniques.

Table 3.9 also provides some interesting insights into the effects of users' cloud free coverage requirements. As one would expect, the more stringent cloud free coverage requirement of 0 to 10% causes a major increase in total program costs. This is due to the fact that in order to satisfy a fixed user timeliness requirement, the satellite and high altitude aircraft systems must yield a greater portion of the user target to the low altitude aircraft and ground survey teams. Thus, in addition to incurring expensive investment cost of the satellite and high altitude aircraft systems, one is forced to increase the activity level of the most expensive (incremental cost) data acquisition component. The impact of more stringent user cloud free coverage requirement will, of course, grow increasingly severe as the user timeliness requirement is tightened. Subsequent results quantify this effect.

Federal statutory demand for land cover information constitutes only a segment of the national demand. State governments, regional and local governmental units, industrial and academic users will also contribute to the total demand. It is difficult to project, quantitively, the scope and nature of the total national demand. Consequently, a parametric set of demand requirements were considered which focused on increasing Level II information requirements for continental U.S. and Alaska. The annual Level II coverage requirement was varied from two times coverage within 180 days each to twelve times coverage within 30 days for each coverage. In addition to varying the full U.S. Level II requirement, the parametric demand analysis includes the other information requirements* that were projected for the 1977 Federal agency demands (All Land Cover Users) under existing Federal statutes.

The results of the parametric demand -- cost analysis is shown in Table 3.10. For each demand level, total program costs are compared for the all aircraft system and the lowest cost two or three tier "with" satellite system. This analysis is based upon automatic data processing methods which previously were shown to be economically preferred over manual methods. It is clear from this table that ERTS is cost-effective at an annual demand level of six times coverage of the U.S. with a user timeliness requirement of 60 days for each such coverage. Note however that a two satellite system is required in order to overcome cloud cover problems. Another interesting effect concerning the impact of cloud cover is evident from Table 3.10. The more stringent cloud cover requirement (0-10%) reduces the multiple satellite system breakdown demand level. Table 3.10. shows that a two-satellite system is cost effective at six times coverage of the U.S. given a (0-30%) cloud cover requirement, while for the same demand level a three-satellite system is cost effective given a (0-10%) cloud cover requirement. As expected, the cost savings of the "with" satellite system over the aircraft only system increase substantially as the demand for Level II information increases beyond six times coverage of the U.S.

Figure 3.15 displays the cost-capability frontier for the two user cloud-free coverage requirements explored in this study. The cost-capability frontier is defined by the locus of the lowest program cost alternatives for varying capability levels. The full cost ERTS curve represents the cost-capability frontier under the asumption that the total program cost are borne entirely by a U.S. coverage mission. The incremental cost ERTS line represents the cost capability frontier under the assumption that the investment costs for a

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* See Table 3.5 of Chapter 3, Volume VI, Part II of this report.

Table 3.10 Summary of Total Program Cost (1977-1993) to Provide Level II Mapping Information of Continental U.S. and Alaska Using Automatic Data Processing (Millions of 1973 Dollars Discounted at 10% to 1974)

Annual Level II Coverage Frequency and Timeliness	Allowable Cloud Cover 0-30%	Allowable Cloud Cover 0-10%
Twice at 180 days each	488.5 HA/GT 646.9 S/HA/GT	616.3 HA/GT 779.2 S/HA/GT
Four times at 90 days each	613.3 HA/GT 701.7 2S/HA/GT	835.6 HA/GT 881.6 2S/HA/GT
Six times at 60 days each	815.6 HA/GT 758.4 2S/HA/GT	1137.3 HA/GT 984.4 3S/HA/GT
Eight times at 45 days each	1044.3 HA/GT 798.2 3S/HA/GT	1476.5 HA/GT 1129.5 3S/HA/GT
Twelve times at 30 days each	1548.3 HA/GT 997.9 3S/HA/GT	2168.3 HA/GT 1603.4 3S/HA/GT

Legend: S refers to an ERTS-type satellite
HA refers to high altitude aircraft (U2)
GT refers to low altitude aircraft and ground survey follow up teams

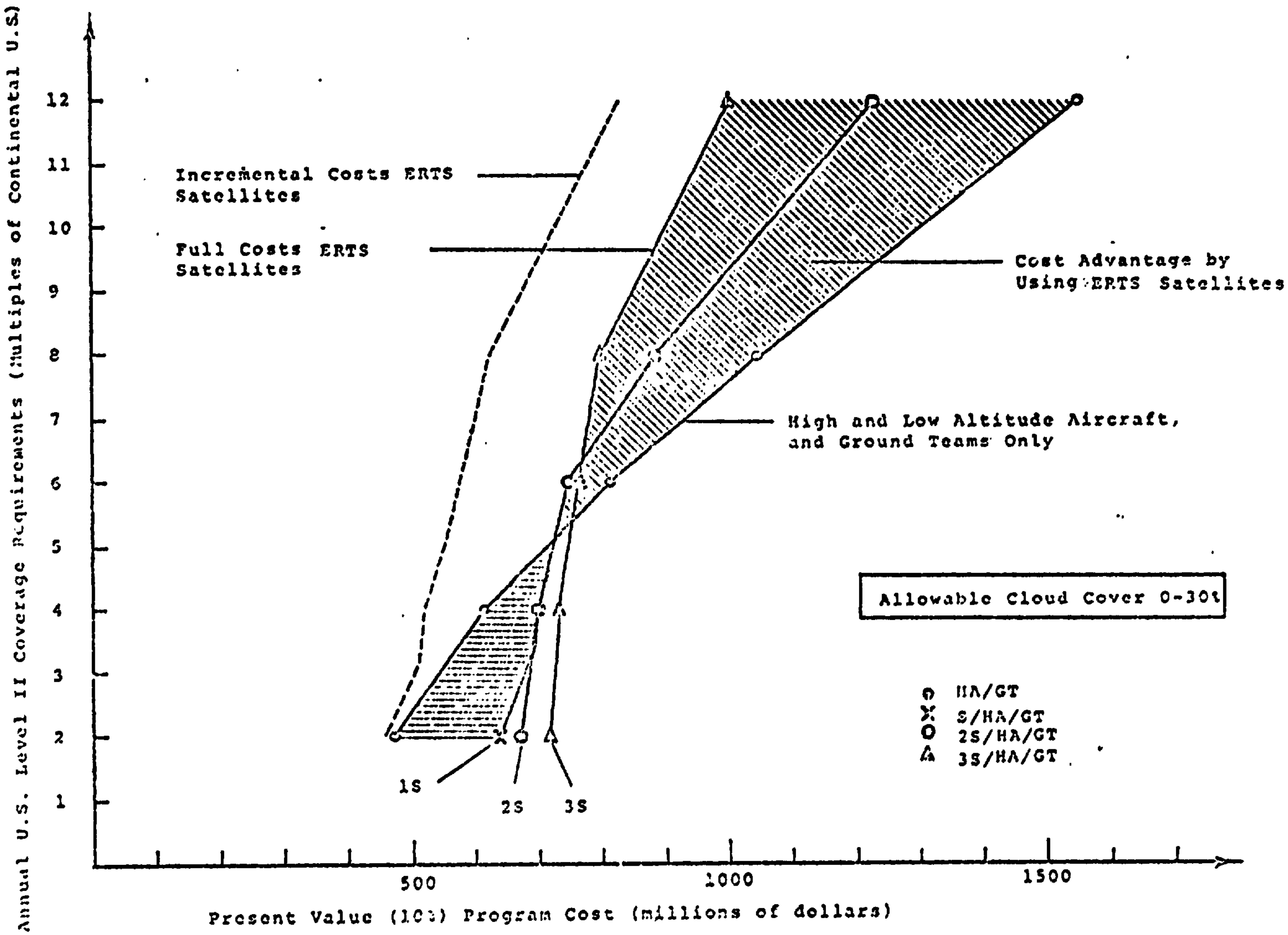

Figure 3.15 The ERS Cost Efficiency Frontier

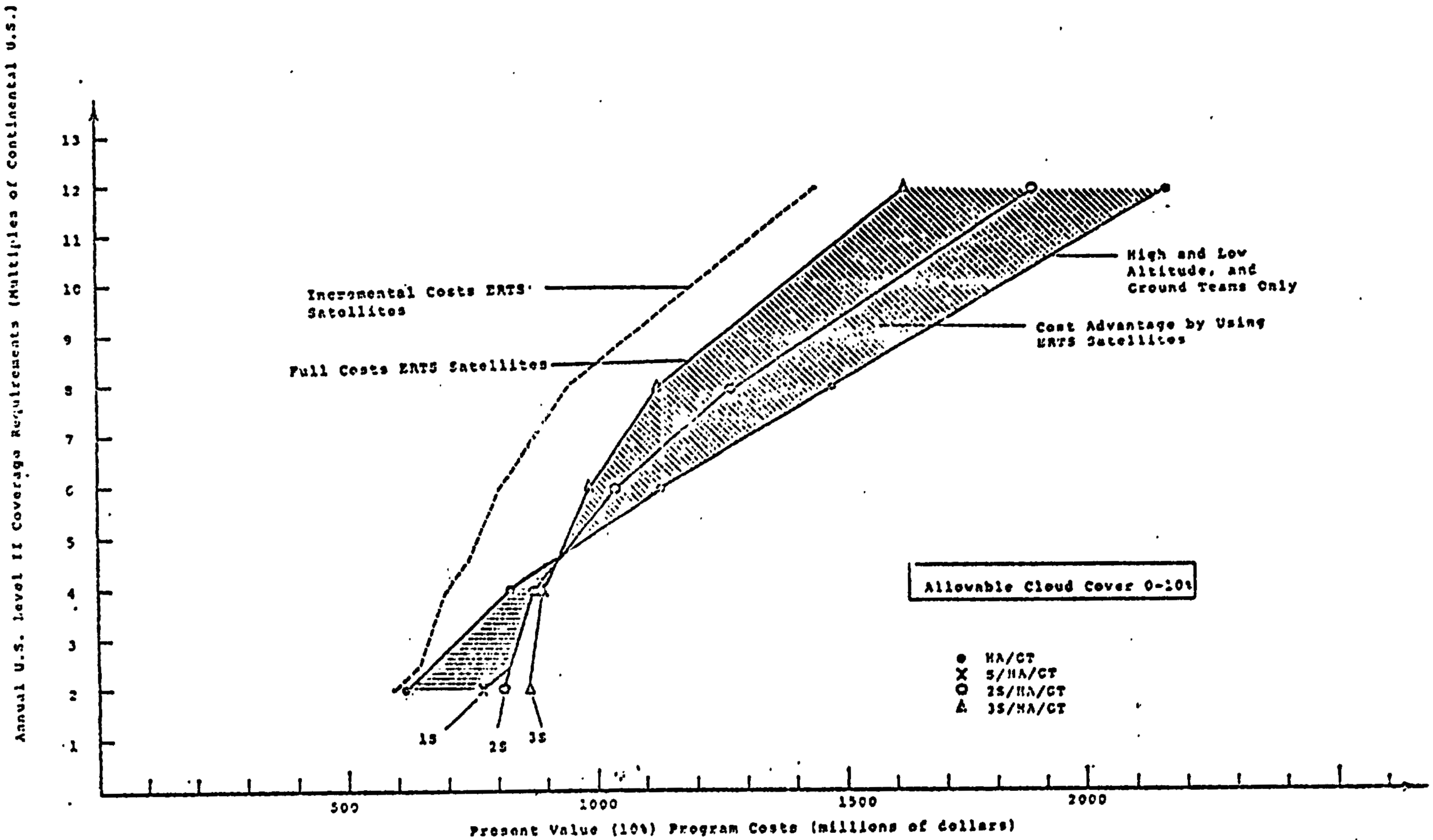

Figure 3.15 The ERS Cost Efficiency Frontier (Continued)

one satellite system would be incurred in any event for a global coverage mission.

Thus far, the analysis has identified the cost-effective mixture of satellites, high and low altitude aircraft and ground truth for satisfying various demand requirements that may arise during the period of an operational Nationwide Land Cover Information System. The final phase of the analysis estimates the *likely* future demands for land cover information considering all potential users and the economic benefits that are likely to accrue to ERTS. Despite the uncertainties inherent in estimates of future nationwide demand, we have defined three demand scenarios that we believe will bracket the actual future nationwide demand for land cover information. Each demand projection includes all the projected information requirements of Federal agency users in 1977 except the full U.S., Level II coverage. In addition, we have included Level II information requirements for the U.S. plus Alaska at annual frequencies varying from six times coverage within 60 days each during the period 1977-1993 to six times coverage within 60 days over the period 1977-1980 and eight times coverage within 45 days each over the period 1981-1993.

The cost-effectiveness analysis for these projected demand levels is based upon automatic data processing methods which previously were shown to be economically preferred over manual methods. Table 3.11displays the total program costs for the lowest cost "with" and "without" satellite systems to satisfy these future demand levels given a user allowable cloud cover requirements of 0-30%. Also shown are the net present values (discounted cost savings) of the lowest cost "with" satellite system relative to the lowest cost "without" satellite system and the equivalent undiscounted annual cost savings of the "with" satellite system over the period 1977-1993. Table 3.12provides corresponding results for an allowable cloud cover requirement of 0-10%. As indicated in these tables, the annual economic benefits (cost savings) of ERTS as a component of a Nationwide Land Cover Information System are projected to range from $7.9 to $17.0 million or from $21.0 to $37.1 million depending upon the user cloud cover requirement. The best point estimate of the annual cost savings that accrue to ERTS is probably defined by the middle of the projected range of cost savings, this being $23 million.

3.5.6 Recommended Future Study Efforts

This study has not attempted to answer all major questions that arise with respect to a nationwide land cover information system and/or the role of ERTS in such a system. Indeed, there are several important limitations of this study which should be highlighted:

Table 3.11 Discounted Total Program Cost (1977-1993) to Satisfy the Projected Future Nationwide Demand for Land Cover Information -- Level II Information -- Automatic Data Processing -- Allowable Cloud Cover (0-30%) (Millions of 1973 Dollars Discounted at 10% to 1974)

Projected Level II Demand	All Aircraft System	Lowest Cost With Satellite System	Net Present Value	Equivalent Undiscounted Annual Cost Savings 1977-1993
1977-1993 Six times at 60 days	815.9 HA/GT	758.4 2S/HA/GT	57.5	7.9
1977-1984 Six times at 60 days 1985-1993 Eight times at 45 days	892.3 HA/GT	797.4 2S/HA/GT	94.9	13.0
1977-1980 Six times at 60 days 1981-1993 Eight times at 45 days	954.2 HA/GT	829.9 2S/HA/GT	124.30	17.0

Legend: S refers to an ERTS type satellite
HA refers to high altitude aircraft (U2)
GT refers to low altitude aircraft and ground survey follow-up teams

Table 3.12 Discounted Total Program Cost (1977-1993) to Satisfy the Projected Future Nationwide Demand for Land Cover Information -- Level II Information -- Automatic Data Processing -- Allowable Cloud Cover (0-10%) (Millions of 1973 Dollars Discounted at 10% to 1974)

Projected Level II Demand	All Aircraft System	Lowest Cost With Satellite System	Net Present Value	Equivalent Undiscounted Annual Cost Savings 1977-1993
1977-1993 Six times at 60 days	1137.6 HA/GT	984.5 3S/HA/GT	153.1	21.0
1977-1984 Six times at 60 days 1985-1993 Eight times at 45 days	1251.0 HA/GT	1032.5 3S/HA/GT	218.5	30.0
1977-1980 Six times at 60 days 1981-1993 Eight times at 45 days	1342.7 HA/GT	1072.0 3S/HA/GT	270.7	37.1

Legend:
S refers to an ERTS type satellite
HA refers to high altitude aircraft (U2)
GT refers to low altitude aircraft and ground survey follow-up teams

- The treatment of the cloud-cover-data acquisition problem represents only a first cut analysis. A more in-depth study of the impact of cloud cover is warranted.

- Within the context of an ERTS type satellite, the satellite system configuration analyzed in this report is *not* an economically optimum one for satisfying both the U.S. and global coverage mission. A joint systems engineering and economic analysis of various satellite configurations for accomplishing both missions should be undertaken. Parameters of the ERTS systems can be improved, at little added RDT & E cost, and with substantial reduction in total space system life cycle costs. These include the life time of spacecraft and instrumentation, reliability of space system and subsystems, on-board data processing - data relay systems - ground processing (real time), and space shuttle system impact on reducing launch cost (joint missions to polar orbits), subsystems costs and minor repair and refurbishment capabilities. All of these potentially important (and cost saving) aspects have not been considered here.

- Satellites with greater technical capability than ERTS (higher spatial and spectral resolution) have not been considered in our analysis. Though we have postulated the use of an ERTS type satellite over the 1977-1993 time frame, we do not rule out the possiblity of realizing further cost reduction by the introduction of more sophisticated satellite system such as EOS in the 1980's. The economically preferred IOC date of an advanced satellite system should be investigated.

4. OVERVIEW OF ERS APPLICATION AREAS

The survey presented here of potential ERS benefits differs from previous studies in using a three-level classification structure oriented to economic benefits. Through the first two levels, the structure is all-inclusive. On the first level, management functions are divided into eight classes called Resource Management Areas, selected to encompass all economic earth resources. On the second level, each Resource Management Area is divided into nine Resource Management Activities. The Resource Management Activities are defined to be an all-inclusive list of activities that are undertaken in the management of resources and are ordered sequentially in the natural progression by which they generally occur. The Resource Management Areas and Activities are listed in Table 4.1. Notice that the activity names are the same for the various areas. Differences occur only on the third level.

Table 4.1 List of Resource Management Areas and Resource Management Activities

Resource Management Areas

1. Intensive Use of Living Resources: Agriculture
2. Extensive Use of Living Resources: Forestry, Wildlife and Rangeland
3. Inland Water Resources
4. Land Use
5. Nonreplenishable Natural Resources: Minerals, Fossil Fuels and Geothermal Energy Sources
6. Atmosphere
7. Oceans
8. Industry

Resource Management Activity

1. Cartography, Thematic Maps and Visual Displays
2. Statistical Services
3. Calendars
4. Allocation
5. Conservation
6. Damage Prevention and Assessment
7. Unique Event Recognition and Early Warning
8. Research
9. Administrative, Judicial & Legislative

The set of Resource Management Areas and Resource Management Activities forms a matrix (area-activity). Within each element of this matrix, specific Resource Management Functions (RMFs) are performed. The economic benefits attributable to remote sensing are achieved through these functions. Clearly, the list of RMFs in each element of the matrix cannot be exhaustive. Nonetheless, an attempt is made to include all such functions considered in previous reports and on which remote sensing makes a measurable impact. Table 4.2 lists the set of RMFs considered in this study. It should be obvious that some of these RMFs result in rather small benefits attributable to remote sensing whereas others have a very large potential benefit. Needless to say, it is not possible to claim either finality or complete objectivity for the scheme, but perusal of the following complete list of RMFs studied by ECON, Table 4.2 will give some feeling for its merits. The RMFs are classified uniquely; any related RMF in another area must differ significantly to be included.

Within each Resource Management Area, benefit estimates are made. These estimates of equal capability, increased capability, and new capability benefits are given in Tables 4.3 and 4.4. The remainder of this chapter summarizes the benefit evaluation process under each Resource Management Area.

4.1 Intensive Use of Living Resources: Agriculture

Present annual farm value of living resources in terms of domestic agricultural crops and livestock represent over 6.0% of our gross national product (over $60 billions). The present worldwide shortage of food resources and the great fluctuation in the prices of agricultural and livestock commodities make it imperative that these resources be managed better than they are at present. Currently economic losses to the general public resulting from poor management of these resources can be attributed directly to incomplete, insufficient and erroneous knowledge of the state (e.g., expected production, both domestic and worldwide, pest and disease infestation) of these resources.

Major public benefits can result from data available from a state-of-the-art ERS system.* Benefits of ERS data

* See Volume 3, Appendix A, RMF 1.2.1

Table 4.2 Resource Management Functions

1. Intensive Use of Living Resources: Agriculture

    1.1 Cartography, Thematic Maps and Visual Displays

        1.1.1 Worldwide survey of agricultural land
        1.1.2 Thematic mapping by crop type and soil type
        1.1.3 Soil surveys
        1.1.4 Monitor agricultural land use change
        1.1.5 Pest and weed surveys

    1.2 Statistical Services

        1.2.1 Domestic crop acreage and yield measurements:
            (a) distribution effects
            (b) minus distribution
        1.2.2 Worldwide crop acreage and yield measurements: distribution effects
        1.2.3 Livestock inventories

    1.3 Calendars

        1.3.1 Optimize planting schedules
        1.3.2 Optimize harvesting schedules
        1.3.3 Determine regional cyclical pest and insect infestations

    1.4 Allocation

        1.4.1 Allocation of agricultural land to specific crops
        1.4.2 Allocation of stock breeding areas

    1.5 Conservation

        1.5.1 Soil conservation

    1.6 Damage Prevention and Assessment

        1.6.1 Agricultural crop disease prevention
        1.6.2 Agricultural crop insect infestation prevention
        1.6.3 Agricultural crop weed infestation prevention
        1.6.4 Agricultural crop stress reduction
        1.6.5 Assessment of damage to agricultural crops due to disease, insect and weed infestation, stress, frost and other weather phenomena

Table 4.2 (continued)

1.7 Unique Event Recognition and Early Warning

- 1.7.1 Reduction of damage to agricultural crops due to massive unexpected insect or disease infestation
- 1.7.2 Climate changes affecting agricultural crop production
- 1.7.3 Unique internation trade events

1.8 Research

- 1.8.1 Monitor new agricultural practices
- 1.8.2 Monitor remedial actions taken in areas subject to climatological and soil changes

1.9 Administrative, Judicial and Legislative

- 1.9.1 Monitor compliance with federal and local agricultural regulations
- 1.9.2 Monitor compliance with federal farm income stabilization programs

2. Extensive Use of Living Resources: Forestry, Wildlife and Rangeland

2.1 Cartography, Thematic Maps and Visual Displays

- 2.1.1 Thematic mapping of forests and rangeland by vegetation type and characteristics
- 2.1.2 Rangeland mapping
- 2.1.3 Wildlife habitat mapping
- 2.1.4 Soil mapping of forests and rangelands

2.2 Statistical Services

- 2.2.1 Determine forest timber volume by type, location, and ownership
- 2.2.2 Determine forest land areas
- 2.2.3 Measure forest timber growth and removals by type and location
- 2.2.4 Forecast forest timber supplies by type and location
- 2.2.5 Determine commercial characteristics of standing timber
- 2.2.6 Determine proportions of timber destruction due to various natural agents
- 2.2.7 Prepare rangeland inventories

Table 4.2 (continued)

- 2.2.8 Measure rangeland yield
- 2.2.9 Forecast rangeland yield
- 2.2.10 Assess range forage conditions
- 2.2.11 Forecast range forage conditions
- 2.2.12 Assess wildlife habitats

2.3 Calendars

- 2.3.1 Establish green wave and brown wave calendars by forest or rangeland vegetation type
- 2.3.2 Establish calendar for cyclical patterns of insect infestation in forests
- 2.3.3 Determine schedule of grazing opportunities on rangelands
- 2.3.4 Establish calendar of wildlife habitat changes

2.4 Allocation

- 2.4.1 Manage timber harvest
- 2.4.2 Manage livestock grazing
- 2.4.3 Manage timber production investments
- 2.4.4 Manage forage production investments
- 2.4.5 Make multiple-use allocation decisions

2.5 Conservation

- 2.5.1 Design and monitor forest rehabilitation
- 2.5.2 Design and monitor rangeland rehabilitation
- 2.5.3 Monitor and limit damage to wetlands
- 2.5.4 Monitor and limit damage in the Giant Redwood and Sequoia forests

2.6 Damage Prevention and Assessment

- 2.6.1 Assess and reduce disease, weed, insect, and animal damage to forests
- 2.6.2 Assess and reduce disease, weed, insect, and animal damage to rangelands
- 2.6.3 Assess and reduce erosion damage to forests and rangelands
- 2.6.4 Assess and reduce fire damage to forests and rangelands
- 2.6.5 Assess and reduce pollution damage to wildlife areas

Table 4.2 (continued)

2.7 Unique Event Recognition and Early Warning

- 2.7.1 Monitor impact of the Alaskan Pipeline on wildlife

2.8 Research

- 2.8.1 Research forest management practices
- 2.8.2 Research forest and range fire-control techniques
- 2.8.3 Research rangeland management practices
- 2.8.4 Research methods of disease control and animal damage reduction in forest and rangelands
- 2.8.5 Research ecological relationships relating to wildlife

2.9 Administrative, Judicial and Legislative

- 2.9.1 Design forestry legislation and monitor compliance
- 2.9.2 Design rangeland legislation and monitor compliance
- 2.9.3 Design legislation related to wildlife and monitor compliance

3. Inland Water Resources

3.1 Cartography, Thematic Maps and Visual Displays

- 3.1.1 Map and survey free water areas
- 3.1.2 Map and survey snow, ice and glaciers
- 3.1.3 Map and survey ground water and aquifers
- 3.1.4 Map watershed areas
- 3.1.5 Map water pollution
- 3.1.6 Map potential water impoundment areas

3.2 Statistical Services

- 3.2.1 Predict fresh water supplies and floods
- 3.2.2 Inventory fresh water supplies and snow cover
- 3.2.3 Gather information for hydrological models
- 3.2.4 Inspect water impoundment areas
- 3.2.5 Monitor water salinity and pollution
- 3.2.6 Monitor thermal pollution of free water

Table 4.2 (continued)

3.3 Calendars

- 3.3.1 Monitor changes in free water areas
- 3.3.2 Monitor changes in snow, ice and glaciers
- 3.3.3 Monitor changes in ground water and aquifers
- 3.3.4 Monitor evapo-transpiration, soil moisture and drainage patterns
- 3.3.5 Monitor cyclical pollution patterns

3.4 Allocation

- 3.4.1 Manage water impoundment systems - for power generation
- 3.4.2 Manage water impoundment systems - for flood control
- 3.4.3 Manage water impoundment systems - for urban water supply
- 3.4.4 Manage water impoundment systems - for agricultural water supply
- 3.4.5 Manage water impoundment systems - for recreational purposes
- 3.4.6 Manage water impoundment systems - for navigation
- 3.4.7 Plan changes in drainage and water impoundment systems

3.5 Conservation

- 3.5.1 Conserve fresh water resources

3.6 Damage Prevention and Assessment

- 3.6.1 Assess and reduce flood damage
- 3.6.2 Reduce damage to water impoundment systems from silting and sedimentation
- 3.6.3 Reduce pollution of free water

3.7 Unique Event Recognition and Early Warning

- 3.7.1 Provide early warning of disastrous floods
- 3.7.2 Provide early warning of lake eutrophication
- 3.7.3 Monitor changes in surface water supply due to geological changes

Table 4.2 (continued)
3.8 Research
3.8.1 Conduct hydrological research
3.8.2 Conduct flood control research
3.8.3 Conduct water pollution research
3.9 Administrative, Judicial and Legislative
3.9.1 Design government programs to reduce flood damage
3.9.2 Increase compliance with water pollution regulations
3.9.3 Aid in designing legislative controls for policy implementation
3.9.4 Aid in planning government projects for future water supply
4. Land Use
4.1 Cartography, Thematic Maps and Visual Displays
4.1.1 Worldwide cartography and thematic map making
4.1.2 Land use maps of the United States - Federal and State levels
4.1.3 Cadastral surveys
4.1.4 Federal and State thematic and topographic map making
4.1.5 Fault zone and lineament mapping
4.1.6 Improve and update existing Federal and State maps - U.S. Coast and Geodetic Survey
4.2 Statistical Services
4.2.1 Provide census estimates - demographical services
4.2.2 Regional and local land use inventories
4.2.3 Land use change statistics
4.2.4 Monitor changes in land use - Federal and State
4.2.5 Monitor land movements - sand dunes, wetlands, etc.
4.4 Allocation
4.4.1 Selection of Federal and State parks and recreational areas
4.4.2 Location of new towns or other developments
4.4.3 Local and regional zoning

Table 4.2 (continued)

4.4.4 Allocation of land for highways and other public construction programs
4.4.5 Selection of areas for land reclamation
4.4.6 Site location of airports and other major transportation modes

4.5 Conservation

4.5.1 Protection of agricultural and forest lands
4.5.2 Protection of wilderness areas

4.6 Damage Prevention and Assessment

4.6.1 Map sink, landslide and other hazardous areas
4.6.2 Assess impact of earthquakes and volcanic eruptions
4.6.3 Assess landslide damages

4.7 Unique Event Recognition and Early Warning

4.7.1 Monitor polar ice formations

4.8 Research

4.8.1 Determine efficient patterns of land use

4.9 Administrative, Judicial and Legislative

4.9.1 Manage Federal, State and Local Aid programs
4.9.2 Regulate land use in areas of critical environmental concern
4.9.3 Regulate land sales and land development projects
4.9.4 Manage Federal and State parks and recreational areas
4.9.5 Manage and plan Federal, State and local taxation

5. Nonreplenishable Natural Resources: Minerals, Fossil Fuels and Geothermal Energy Sources

5.1 Cartography, Thematic Maps and Visual Displays

5.1.1 Geological mapping
5.1.2 Map areas of potential geothermal energy sources

Table 4.2 (continued)

5.2 Statistical Services

- 5.2.1 Detect and inventory geographic areas of potential mineral deposits
- 5.2.2 Detect and inventory geographic areas of potential fossil fuel deposits

5.4 Allocation

- 5.4.1 Manage mineral exploration and extraction
- 5.4.2 Manage fossil fuel exploration and extraction

5.5 Conservation

- 5.5.1 Monitor strip and auger mining land reclamation

5.6 Damage Prevention and Assessment

- 5.6.1 Mine fire damage assessment
- 5.6.2 Prevent mine tailing slides
- 5.6.3 Detect fractures in mining areas

5.8 Research

- 5.8.1 Develop new methods of locating minerals
- 5.8.2 Develop new methods of locating hydrocarbon fuels

5.9 Administrative, Judicial and Legislative

- 5.9.1 Establish and enforce mine safety regulations
- 5.9.2 Establish policies for and administer offshore oil and gas lease sales

6. Atmosphere

6.1 Cartography, Thematic Maps and Visual Displays

- 6.1.1 Cloud location
- 6.1.2 Smoke and haze distribution
- 6.1.3 Sand and dust storm location
- 6.1.4 Thermal map of atmosphere
- 6.1.5 Noxious gas air pollution monitoring

Table 4.2 (continued)

6.2 Statistical Services

- 6.2.1 Cloud cover and cloud shadow statistics
- 6.2.2 Air quality monitoring
- 6.2.3 Weather forecasting
- 6.2.4 Wind mapping

6.5 Conservation

- 6.5.1 CO_2 concentration and greenhouse effect monitoring
- 6.5.2 Monitor jet contrail water vapor condensation and carbon dioxide effects on weather and air

6.6 Damage Prevention and Assessment

- 6.6.1 Monitor effects of thermal and other pollution sources on weather
- 6.6.2 Monitor airborn pollution effects on the environment
- 6.6.3 Monitor effects of volcanic eruptions on air quality

6.7 Unique Event Recognition and Early Warning

- 6.7.1 Determine clear air turbulence location
- 6.7.2 Provide severe storm warnings
- 6.7.3 Monitor climatological changes

6.8 Research

- 6.8.1 Research on effects of thermal sources on weather
- 6.8.2 Research on air - sea interactions
- 6.8.3 Research on dispersion of pollution in the atmosphere
- 6.8.4 Research on weather phenomena

6.9 Administrative, Judicial and Legislative

- 6.9.1 Control of particulate pollution
- 6.9.2 Control of noxious gas sources
- 6.9.3 Provide a data base for establishing appropriate air quality regulations

Table 4.2 (continued)

7. Oceans

7.1 Cartography, Thematic Maps and Visual Displays

7.1.1 Oceanographic mapping
7.1.2 Thermal mapping of the oceans
7.1.3 Mapping ocean ice and polar caps

7.2 Statistical Services

7.2.1 Monitor ocean food supply

7.3 Calendars

7.3.1 Monitor tides and currents in coastal waters
7.3.2 Monitor the movement of the major oceanic currents

7.4 Allocation

7.4.1 Optimize ocean fisheries management
7.4.2 Optimize ocean plant food harvesting
7.4.3 Improve coastal zone management
7.4.4 Optimize ocean shipping routes

7.5 Conservation

7.5.1 Improve shoreline protection programs
7.5.2 Control ocean pollution
7.5.3 Monitor oil slicks

7.6 Damage Prevention and Assessment

7.6.1 Reduce ocean resource losses due to man-made coastal engineering changes

7.7 Unique Event Recognition and Early Warning

7.7.1 Early warning of oceanic and coastal area disasters

7.8 Research

7.8.1 Research on ocean parameters
7.8.2 Research on estuarine ecology

Table 4.2 (continued)

7.9 Administrative, Judicial and Legislative

7.9.1 Aid in enforcing national and international regulations and agreements
7.9.2 Aid in designing legislative controls and administrative procedures

8. Industry

8.1 Cartography, Thematic Maps and Visual Displays

8.1.1 Mapping ice build-up and break-up in shipping lanes.

8.2 Statistical Services

8.2.1 Aids to the survey of industrial growth and decline

8.3 Calendars

8.3.1 Long range temperature cycles

8.4 Allocation

8.4.1 Site selection for industry, residential and institutional construction
8.4.2 Transportation of commodities

8.7 Unique Event Recognition and Early Warning

8.7.1 Monitoring the environmental impact of construction and operation of the Alaskan pipeline

8.9 Administrative, Judicial, and Legislative

8.9.1 Monitor compliance with zoning and construction permits

Table 4.3 Measured Annual Potential U.S. ERS Benefits, by, Say, 1985*
(Firm Benefit Estimates Derived from In-Depth Case Studies Only)

Resource Management Areas	Benefits by Type. $ millions (1973)			
	Equal Capability	Increased Capability	New Capability	TOTAL
1. Intensive use of Living Resources: Agriculture	5.5	106-247	141-302	252.5-554.5
2. Extensive Use of Living Resources: Forestry, Wildlife, & Rangeland	4.0	3.7	54.5	62.2
3. Inland Water Resources	3.3	3.3	50.6	57.2
4. Land Use		53.5**		53.5**
5. Nonreplenishable Natural Resources: Minerals, Fossil Fuels, and Geothermal Energy Sources	1.6-3.9			1.6-3.9
6. Atmosphere	1.5-10.5			1.5-10.5
7. Oceans	.55	1.2-3.7		1.75-4.25
8. Industry	+	+	+	+
TOTAL	16.3-27.7	167.6-311.1	246.1-407.1	430-746

*All numbers in this table are substantiated in detail by case studies documented in Volumes III through X. Assumes assured continuity of service.

**This number derives from legal and statutory requirements outlined in Volume VI.

+Substantial benefits may be possible due to remote sensing from space but have not been quantified nor, specifically, were they attributed to ERS. See Volume X for discussion.

Table 4.4 Total Projected Annual Potential U.S. ERS Benefits by, Say, 1985* (Benefit Estimates from Table 4.3 Plus Expected Benefits Not Verified by In-Depth Case Studies)

Resource Management Area	Benefits by Type, $ millions (1973)			
	Equal Capability	Increased Capability	New Capability	Total
1. Intensive Use of Living Resources: Agriculture	58.3	164.4-479.4	503.6-974	726.3-1511.7
2. Extensive Use of Living Resources: Forestry, Wildlife, & Rangeland	4.0	3.7	84.5	92.2
3. Inland Water Resources	29.1-65.2	27.6-62.5	50.6	107.3-178.3
4. Land Use		53.5**		53.5**
5. Nonreplenishable Natural Resources: Minerals, Fossil Fuels, and Geothermal Energy Sources	34.6-80.9			34.6-80.9
6. Atmosphere	1.5-10.6	.5-1.2	5.1-27.3	7.1-39.1
7. Oceans	5.6-13.3	1.2-3.7	††	6.8-17.0 ††
8. Industry	†	†	†	†
TOTAL	133.1-232.3	250.9-604.0	643.8-1136.4	1027.8-1972.7

*All numbers in this table are substantiated in detail in Volumes III through X. This table includes all benefits reported in Table 4.3 plus additional benefits which are generally valid order of magnitude numbers but which are not backed up by in-depth case studies. Assumes assured continuity of service.

**This number derives from legal and statutory requirements outlined in Volume VI.

†Substantial benefits may be possible due to remote sensing from space but have not been quantified nor, specifically, were they attributed to ERS. See Volume X for discussion.

††Benefits result from high resolution thermal monitoring of the North Pacific to the United States. They will not be captured by an ERTS-like ERS system if other satellites with greater capability are in use in this area. Therefore these benefits are not included here.

applications in the management of living resources will result in two main areas.

(1) Cost savings by the Federal government in obtaining the same quality data on the state of living resources. These amount to 5.5 million.
(2) Public benefits derived from better management decisions as a result of improved and/or previously unavailable data on the state of our living resources. These *increased* and *new* capability benefits are estimated to be between $106 and 247 million annually for increased and, additionally, between $141 and 302 million annually for new capability benefits.

In general, U.S. cost saving benefits have been estimated at the Federal level only and accrue mainly to the Department of Agriculture (USDA). Hard benefits result only from cost savings requiring no staff reductions in USDA. These include 4.2 million in savings to State Departments of Agriculture in crop forecasting and $1.3 million in the assessment of crop damage.

Additional potential benefits of $52.8 million are possible. These include up to $37 million per year in domestic soil survey activities presently subcontracted by the Soil Conversation Service of USDA that could be accomplished by an ERS system, and an additional transfer of activities to an ERS system which could save the Agricultural Stabilization and Conservation Service $15.8 million per year in costs in the enforcement of provisions of the Agricultural Adjustment Act of 1938.

The substantial benefits of improved management decisions accrue from sources of improved agricultural crop statistics (increased capability benefits) and previously unavailable agricultural crop data (new capability benefits). Increased capability benefits result primarily from improvements to USDA's domestic crop production forecasts through a demonstrated ERS capability of improving acreage and yield estimates. Better decisions by inventory holders of major U.S. crops result in at least $106 million dollars annual benefits. The U.S. benefits of reliable worldwide crop production forecasts are estimated at between $265 and $471 million per year. These benefits are based on two models for estimating the public benefit of improved information in the agricultural sector developed by ECON.* The ability of ERS to identify crop vigor would lead to a substantial benefit in reducing crop losses.

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* See Chapter 3 of this volume and Volume III, Appendix A, RMF 1.2.1.

Benefits derived from improved management decisions, based on a capability to provide previously unavailable data, are also substantial. Data provided by ERS satellites will enable farmers to make better location of agricultural lands. An economic model developed by ECON* estimates the public benefits due to improved allocation of agricultural lands to be $15.4 - 118.8 million per year.

For the interested reader we include as a footnote a recent exchange between members of the U.S. Congress and appropriate government officials.** The above estimates are summarized in Table 4.5

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* See Volume III, Appendix A, RMF 1.4.1

** House Appropriations Com. Hearings (FY'74 DOA Pt.1, Page 354):
"MR. SCHERLE. I have always been vitally concerned about the statistics and methods of reporting. As you admit, they have not been too accurate, sometimes you appear to throw a dart at a board and see what you come up with, even though we give additional money each year for betterment of the system.
"You say that you have sample methods. Why don't you take one State, Iowa, or Illinois--it doesn't make any difference--where your agriculture production is heavy and why don't you let the land-grant college in that particular State run the statistical reporting service for you for a quarter of 6 months or even a year? Why don't you use the county agents in every single county that travel that whole county day after day?
"I have farmed for 25 years and even to this date I don't know how you get your samples. When I get them in the mail I file them in a bucket and pay no attention to them. I am sure there are thousands that do that so there is no way you could get an accurate picture. If I keep more cows or heifers I am going to lie to you, so-and-so, as did my neighbor. We are not going to tell you the truth, and you know that, Doctor.
"MR. PAARLBERG. No, I don't know that.
"MR. SCHERLE. We want to throw you off base as far as you possibly can so you are coming up with figures which are rather long than short.
"MR. WHITTEN. What you are saying Dr. Paarlberg is that you know these factors, and how to allow for them?
"MR. PAARLBERG. That is precisely the point.
"MR. WHITTEN. That is the art of it? How big a tale they are going to tell you?
"MR. PAARLBERG. We have a correction factor we apply to gentlemen like Congressman Scherle."

Table 4.5 Magnitudes and Types of Net Annual Benefits by Resource Management Activities-Intensive Use of Living Resources: Agriculture

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
1.1 Cartography, Thematic Maps and Visual Displays			
1.1.2 Thematic Mapping by Crop Type & Soil Type	(3.5)[a]		
1.1.3 Domestic Soil Surveys	(33.5)		
1.2 Statistical Services			
1.2.1 Domestic Crop Acreage and Yield Measurements:	4.2[b]		
(a) Distribution Effects		106-247 (0-174)	
(b) Minus Distribution Effects			141-302[c]
1.2.2 Worldwide Acreage and Yield Measurements: Distribution Effects			(265-471)+ additional Non U.S.

a. Parentheses imply soft benefit estimates.
b. Hard benefits from cost savings to state departments of agriculture.
c. Total hard benefits lower limit of about $251 million derivable from a variety of effects. See RMF 1.2.1 for explanation.

Table 4.5 Magnitudes and Types of Net Annual Benefits by Resource Management Activities–Intensive Use of Living Resources: Agriculture (cont'd.)

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
1.4 Allocation			
1.4.1 Allocation of Agricultural Land to Specific Crops			(15.4-118.8)
1.5 Conservation			
1.5.1 Soil Conservation			(82.2)
1.6 Damage Preservation and Assessment			
1.6.1 Agricultural Crop Disease Prevention		(38)d/	
1.6.2 Agricultural Crop Insect Infestation Prevention		(18)d/	
1.6.3 Agricultural Crop Weed Infestation Prevention		(2.4)d/	
1.5.4 Agricultural Crop Stress Prevention		See RMF 3.4.4	
1.6.5 Assessment of Damage to Agricultural Crops due to Disease, Insects & Weed Infestation, Stress, Frost & Other Weather Phenomena	1.31	Unquantified	

d. For conservatism, only lower limit is included here.

Tabel 4.5 Magnitude and Types of Net Annual Benefits by Resource Management Activities-Intensive Use of Living Resources: Agriculture (cont'd)

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
1.7 Unique Event Recognition and Early Warning			
1.7.1 Reduction in Crop Damage Due to Massive Insect Infestation			e
1.7.2 Unique International Trade Events			f
1.8 Research			
1.8.2 Monitor Remedial Actions Taken in Areas Subject to Climatological & Soil Changes			See RMP 1.5.1
1.9 Administrative, Judicial, and Legislative			
1.9.1 Monitor Compliance with Federal & Local Agricultural Regulations		Small	
1.9.2 Monitor Compliance with Federal Farm Income Stabilization Programs	(15.8)		
Total:			
Hard benefits documented in ECON Case Studies	5.5	106-247	141-302
Soft Benefits	(52.8)	(58.4-232.4)	(363-672)

e Potential benefits of up to $200-500 million every 2-4 years as periods of controllable stress might occur, but not counted in totals shown here.

f Potential benefits of up to $200-500 million every 2-4 years as unique events occur, but not counted in totals shown here.

In addition to the benefits reported above, additional benefits are likely if the ERS system can differentiate between different levels of crop vigor. Reduced production losses due to insect disease and weed infestation result in an additional $58 million in public benefits per year, as estimated by rough order of magnitude models in Volume III.

Other less detailed analyses reported in Volume III imply the existence of other larger benefits to the United States and potential colossal benefits to the world community if the ERS data are made available to all.

4.2 Extensive Use of Living Resources: Forestry, Wildlife, and Rangeland

In preparing benefit estimates for the resource management functions of this resource area, a review of all available previous studies was made. These included the EarthSat case studies in forestry and in rangeland management (in draft form) being prepared for the U.S. Geological Survey and the Frank and Heiss* study prepared for RCA in 1968. Relevant conclusions of these studies supported some of our estimates.

The original work of the present study is concentrated in the areas where previous work appears inconclusive but substantial benefits seem likely. This is the situation with regard to forestry applications, for which significant ERTS-1 capabilities have been demonstrated, but benefit calculations have not been published except for small cost savings in inventory applications for federal agencies.

EarthSat** compares the costs of forest inventory work as currently performed by the U.S. Forest Service and the Bureau of Land Management with expected costs of an inventory procedure suggested by ERTS-1 investigator Jim Nichols at the University of California. The resulting cost savings estimates are significant compared with the total inventory budgets, but small on an absolute basis. The total annual budget of the Forest Survey (the data collection and statistical analysis arm of the Forest Service) is less than $4 million. For the national inventory work of the Forest Survey, EarthSat calculated an annual benefit of between $400,000 and $1,300,000. Similar small benefits are calculated for forest inventories of the Bureau of Land Management and the Timber Management and Planning Division of the Forest Service (the last is for timber management in the National Forest System).

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* Heiss, K. P., Frank, F., *Cost-Benefit Study of the Earth Resources Satellite Program: Grazing Land Applications*, under contract to RCA-Astro Electronics Div., Princeton, N.J., 1968.

** The EarthSat estimates are based on existing draft reports. No final estimates were available to ECON as of the time of this review.

The EarthSat Rangeland Case Study calculates cost savings benefits for rangeland inventories on an equal capability basis in the range of $2.7 million to $3.4 million. These figures represent present value of constant annual benefits of $435,000 to $548,000, assumed to continue from 1977 through 1986, and discounted to 1976.

The annual figures are calculated as a difference between conventional rangeland inventory costs (including aerial photography costs) and estimates of costs using ERS system information.

These cost savings benefits are very small compared to possible benefits achieved through the use of improved rangeland inventories in other statistical activities and in management activities such as scheduling of livestock grazing and purchases, management of forage production, conservation, research, and the legislative process. The EarthSat study presents estimates of some of these new capability benefits, classifying them as: (1) range resource reallocation; (2) range productivity improvement; and (3) livestock inventory adjustments. In the case of class (1) and class (2) the assumptions on the contributions of ERS information to the potential benefits under discussion are entirely arbitrary. Further, these potential benefits are themselves limited to those predicted by the Forest Service's FRES* report as resulting from implementation of management strategies developed on the basis of already existing information. Because of these limitations, we find the benefit estimates for these first two classes of no help in determining the potential value of an ERS system. In the case of the third class, however, livestock inventory adjustments, the results may be more helpful. The benefit estimate is $17 million to $28 million, representing the present value of additional earnings in the cattle industry from 1977 to 1986, discounted at 10% to 1976.

These figures are derived by extrapolation to the national level of results of a modification of the Halter-Dean model. The modification is a rough model of the rancher's use of ERS system information on range conditions in decision making, with the assumption that the delay in receiving this information is cut from 25 to five days on the average.

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* Forest Service, "The Nation's Range Resources", Forest Resource Report No. 19, Washington, D.C.: U.S. Government Printing Office, 1972. FRES is an acronym for Forest-Range Environmental Study.

Unfortunately, the critical price data used in this calculation refer to the years 1954 to 1963. The *output* of the model is adjusted by use of the wholesale price index, but this gives no clue to the impact of current or projected beef or feed prices on the earnings increment that constitutes the benefit.

EarthSat concludes that a cattle rancher could expect to improve his earnings per AUM* by $.437 by fully exploiting ERS range forage condition data, and extrapolates conservatively to the national level, resulting in a total annual benefit of $14.6 million. Though the procedures used to derive this annual benefit, particularly the use of prices from more than ten years ago, leave considerable doubt as to the reliability of the figure, it may be on the right order of magnitude. Accordingly, the present study quotes it as a "soft" benefit.

Another "soft" benefit is derived from the Frank and Heiss report, in which the authors conclude that a benefit of 0.5 percent of the value of the forage resource could be achieved through the proper use of ERS data in monitoring range conditions. The present study includes an estimate of the value of the national forage resource -- $3.0 billion. Thus, the "soft" benefit becomes $150 million in present value or $15 million annually.

In addition to our adaptation of previous work as outlined above, we estimated new capability benefits in forestry applications. These benefits are all associated with the capabilities of an ERTS-like system to make very significant improvements in forest inventory statistics.

One improvement is in timeliness. The inventory cycle for the National Forest Survey is currently between eight and 15 years depending on region but these goals are rarely met. The Forest Service would like to be able to reduce the cycle time further, to five years or less in the high timber producing areas. It appears that this goal can be met or surpassed with the aid of an ERS system. In itself, this is economically very valuable, since it has the same impact on management decision making as improved accuracy. The extent of uncertainty in net growth or volume of timber increases with the length of the inventory cycle, particularly on account of the highly variable effects of fire, insect, and disease damage.

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* Animal Unit Month - Roughly: the amount of forage consumed by one animal in one month, standardized for types and weights of foragers.

The precision of the measurements themselves is significantly improvable through the use of properly designed multistage sampling procedures. This also results in more accurate management information.

The fact that ERS data are specific to location implies that inventory variables can be reported on a location-specific basis. This also translates into improved accuracy of management information.

Finally, ERS-aided inventories can be much more comprehensive than conventional ones, and approximate inventory data can be collected for forest and range resources throughout the world.

Our benefit estimation procedure consists of quantifying the relationship between accuracy of management information and the properties of the inventory data mentioned above and then modeling the value of improved decisions based on the more accurate management information. This method is applied to timber harvesting decisions, and several kinds of forestry investment decisions.

In treating the value of improved timber harvesting decisions, it is important to realize that non-timber values such as watershed protection, forage, wildlife, and recreational use must be considered in the economic evaluation. If timber values alone are considered, the indicated harvest policy is to liquidate the asset and invest the proceeds in a more profitable activity than growing trees. To derive the correct benefits for this application, we use a value model of the forest resource which includes the non-timber components.

Our results are shown in Table 4.6. Total annual benefits calculated are $92.2 million, of which $62.2 million is "hard".

4.3 Inland Water Resources

Inland water is one of our most important resources. In the U.S., it has traditionally been treated as if it had no cost and as if there were no limits to its availability. In recent years, there has been greater recognition of the adverse effects of urban and industrial growth on water quality as well as the possibility of inadequate water supplies in densely populated areas. In addition to these new concerns, traditional water management problems such as flooding take on increased

Table 4.6 Magnitudes and Types of Net Annual Benefits by Resource Management Activity - Extensive Use of Living Resources: Forestry, Wildlife, Rangeland

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
2.2 Statistical Services			
2.2.1 Determine forest timber volume by type, location and ownership	0.8	0.4	**
2.2.7 Prepare rangeland inventories	1.9	1.8	***
2.4 Allocation			
2.4.1 Manage timber harvest	1.3	1.5	19.0
2.4.2 Manage livestock grazing			(15.0) *
2.4.3 Manage timber production investments			5.5
2.4.4 Manage forage production investments			(15.0)
2.4.5 Make Multiple-use allocation decisions			30.0
Total:			
Hard benefits documented in ECON Case Studies	4.0	3.7	54.5
Soft Benefits			(30)

* Figures in parentheses are order-of-magnitude estimates which are not supported by in-depth case studies

** This benefit realized through RMF's 2.4.1, 2.4.3, 2.4.5

*** This benefit realized through RMF's 2.4.2, 2.4.4, 2.4.5

Source: ECON, Inc.

importance as the pressures mount to develop flood plains and other marginal areas. Proper management of this valuable and potentially scarce resource has thus taken on greater importance.

The inland water resources of the study include inland surface and ground water, snow, ice and glaciers, and water impoundment systems and watersheds. Coastal wetlands and estuaries are included under other headings.

Benefits to Federal and intergovernmental agencies are estimated by the following procedure:

1. Equal-capability benefits

   a. Programs which mandate ERS-relevant activities are located by examination of Federal budget and congressional hearings.

   b. The proportion of the appropriate program budget which is devoted to data collection activities which fall within demonstrated ERTS capabilities is conservatively estimated by inference to agency budget justifications, congressional hearings, and the results of research by ERTS principal investigators. The results are then divided among those ERS activities which employ ERS photographic, multispectral scanner (MSS) capabilities, including thermal infrared, and those which make use of the ERS remote data-collection system (DCS).

   c. The cost savings for ERS photographic and MSS capabilities over aircraft has been conservatively estimated at 80%. (In the case of DCS-applicable activities, the incremental cost of data-collection platforms partly offsets savings due to increased efficiency of data transmission and collection.) Savings due to DCS are therefore assumed to be somewhat less than one-third as great as savings due to ERS photographic and MSS capabilities. The equal capability benefits for a given data-collection activity are therefore

$$ECB = .25AD + .8A(1-D)$$

where

ECB = equal capability benefit

A = budget allocation to ERTS-applicable data collection activities

D = fraction of program to be implemented by DCS.

(d) The results of (c) are allocated among the relevant RMFs.

2. Increased-capability benefits

As explained in Chapter 2, benefits due to increased capability are calculated on the assumption that the budget appropriation for ERS-relevant activities remain unchanged after the introduction of ERTS. Under free-market assumptions this corresponds to a situation in which demand for a good (in this case, information) is unitary-elastic. The increased-capability benefit is equal to the value to the user of the additional quantity of information minus its cost. This corresponds to the dotted area in Figure 4.1. Since the demand curve is of unitary elasticity, p = 1/q. Hence, in the case of ERS photographic and MSS capabilities;

$$ICB_P = \int_{.2q}^{q} \frac{1}{q}\, dq \;-\; .8 = .81$$

The increased-capability benefits in this case are thus approximately equal in magnitude to the equal-capability benefits. For DCS-applicable activities, the corresponding result is

$$ICB_D = \int_{.75q}^{q} \frac{1}{q}\, dq \;-\; .25 = .037$$

For these activities the increased-capability benefit is equal to approximately 15% of the equal-capability benefit.

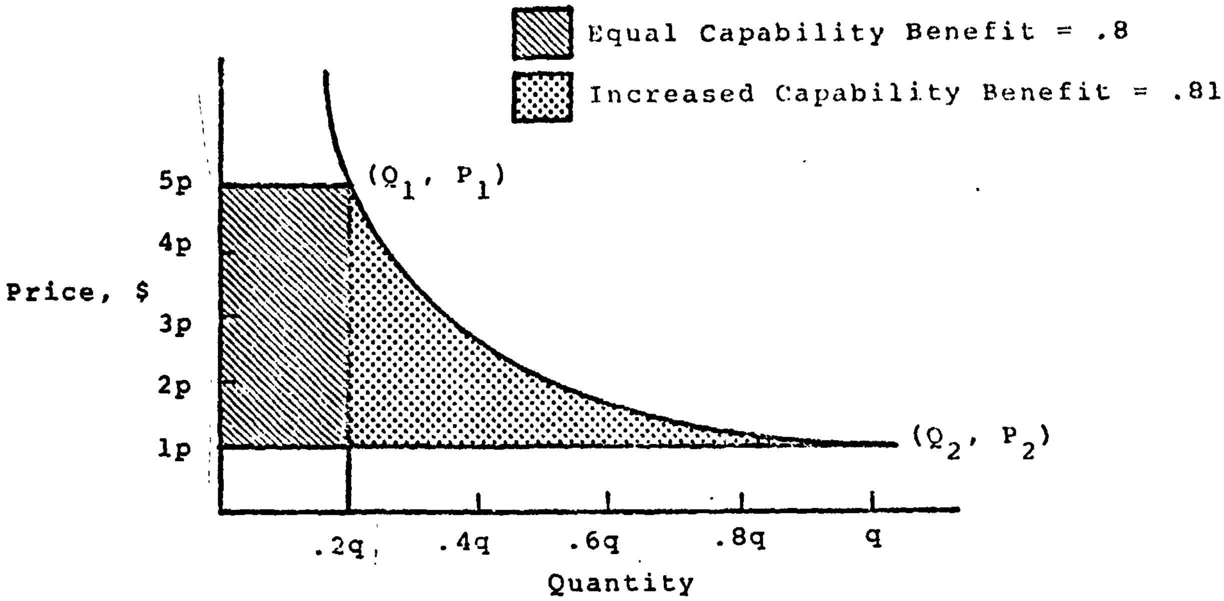

Figure 4.1 Equal Capability and Increased-Capability Benefits from ERTS Photograph and MSS Functions

In some cases the increased-capability benefit may be smaller than that given by the formulae presented above due to dependence of demand for ERS data-collection activities on other programs within the same budget category. An attempt is made to compensate for possible biases from this and other sources by conservative estimates of the proportion of each budget for which ERS is likely to be relevant.

In addition to the models just described, a case study in the management of inland water has been performed by ECON for the Feather River and the associated Oroville-Thermalito facilities. This case study is summarized in Chapter 3 of this volume and is presented in full in Volume V, Appendix F. The benefit estimates are summarized in Table 4.7.

4.4 Land Use

The growing Federal statutory demand for land use information is thoroughly documented in the Land Cover Case Study* which is appended as Volume VI, Part II of the present report.

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* "The Role of ERTS in the Establishment and Updating of a Nationwide Land Cover Information System", prepared for NASA under contract NASW-2558 by ECON, Inc., October 31, 1974.

Table 4.7 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Inland Water Resources

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
3.1 Cartography, Thematic Maps and Visual Displays			
3.1.1 Map and survey free water areas	(1.5-3.0)	(1.5-3.0)	
3.1.2 Map and survey snow, ice and glaciers	.2 (.4-.9)	.2 (.4-.9)	
3.1.4 Map water shed areas	.04 (2.0-3.9)	.04 (2.0-3.9)	
3.1.5 Map water pollution	(.2-.5)	(.1-.4)	
3.1.6 Map potential water impoundment areas	(1.5-3.4)	(1.5-3.4)	
3.2 Statistical Services			
3.2.1 Predict fresh water supplies & floods	.3 (2.0-4.4)	.3 (2.0-4.4)	
3.2.2 Inventory fresh water supplies & snow cover	.2 (2.1-4.2)	.2 (2.1-4.2)	
3.2.3 Gather information for hydrological models	.2 (2.7-4.9)	.2 (2.3-4.4)	
3.2.4 Inspect water impoundment areas	(1.5-3.0)	(1.5-3.0)	

Note: Figures in parentheses are order-of-magnitude estimates which are not supported by in-depth case studies.

Source: ECON, Inc.

Table 4.7 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Inland Water Resources (continued)

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
3.2.5 Monitor stream salinity & pollution	(.5-1.2)	(.4-1.0)	
3.2.6 Monitor thermal pollution of free water	(.3-.8)	(.3-.6)	
3.3 Calendars			
3.3.1 Monitor changes in free water areas	.2 (.6-1.2)	.2 (.6-1.2)	
3.3.2 Monitor changes in snow, ice and glaciers	.2 (.4-.9)	.2 (.4-.9)	
3.3.4 Monitor evapo-transpiration, soil moisture & drainage patterns	(.2)	(.2)	
3.3.5 Monitor cyclical pollution patterns	(.2-.6)	(.2-.5)	
3.4 Allocation			
3.4.1 Manage water impoundment systems-for power generation	.3 (.6-1.4)	.3 (.5-1.4)	42.0
3.4.2 Manage water impoundment systems-for flood control	.3 (.6-1.4)	.3 (.5-1.4)	
3.4.3 Manage water impoundment systems-for urban water supply	.3 (.6-1.4)	[illegible] (.5-1.4)	.9 1.9

Table 4.7 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Inland Water Resources (continued)

Resource Management Function	Benefits, & millions (1973)		
	Equal Capability	Increased Capability	New Capability
3.4.4 Manage water impoundment systems-for agricultural water supply	.3 (.6-1.4)	.3 (.5-1.4)	7.7
3.4.7 Plan changes in drainage & water impoundment system	(1.4-8.8)	(1.4-8.8)	
3.5 Conservation			
3.6 Damage Prevention and Assessment			
3.6.1 Assess & reduce flood damage	.3 (.5-1.5)	.3 (.5-1.5)	
3.6.3 Reduce pollution of free water	(.5-1.1)	(.4-.9)	
3.7 Unique Event Recognition and Early Warning			
3.7.1 Provide early warning of disastrous floods	.3 (1.0-2.1)	.3 (.6-1.6)	
3.7.2 Provide early warning of lake eutrophication	(.1-.4)	(.1-.3)	
.8 Research			
3.8.1 Conduct hydrological research	(1.5-3.0)	(1.5-3.0)	

Table 4.7 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Inland Water Resources (continued)

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
3.8.2 Conduct flood control research	(1.5-3.0)	(1.5-3.0)	
3.8.3 Conduct water pollution research	(.1-.4)	(.1-.3)	
3.9 Administrative, Judicial and Legislative			
3.9.1 Design government programs to reduce flood damage	.04 (b) (.1-.6)	.04 (b) (.1-.6)	
3.9.2 Increase compliance with water pollution regulations	(.5-1.1)	(.4-.9)	
3.9.3 Aid in designing legislative controls for policy implementation	(.1-.4) (c)	(.1-.3) (c)	
3.9.4 Aid in planning government projects for future water supply	(.1-.2) (b)	(.1-.2) (b)	
(d) Total:			
Hard benefits documented in ECON Case Studies..........................	3.3	3.3	50.6
Soft benefits......................	(25.8-61.9)	(24.3-59.2)	

(b) For benefits to this RMF see also RMF 3.4.7
(c) For benefits to this RMF see also RMF's 3.2.5, 3.3.5, 3.4.7, 3.6.3, 3.9.2, 3.9.4
(d) Totals may not correspond exactly with the sum of the values given in table because of rounding of individual entries.

This study is the basis for most of the benefits discussed here, which are cost savings and increased capability in the acquisition of data needed in land use mapping. There is also a growing demand generated by state land use planning. In assessing the potential ERS benefits associated with meeting this demand, the EarthSat interim report is used as a source. Also the results of various other applications of remotely sensed data to land use planning are reviewed.

In this resource area, new capability benefits are not estimated. Although there certainly are ways in which the unique features of satellite coverage will produce economic benefits in better land use planning, the specific estimates are most conveniently made in the context of the economic resources being managed, and thus are treated under other resource areas such as Industry, Agriculture, or Forestry.

Benefits are calculated based on the savings in mapping costs when performed by ERS relative to the cost of performing the same mapping by the next best alternative, namely high-altitude aircraft.

The cost of mapping with ERS per square km is obtained from the ECON Land Cover Case Study. It does not include the initial acquisition cost or annual operating cost of ERS, but only the incremental costs of the products themselves. Similarly, the cost of mapping with high-altitude aircraft does not include the cost of acquiring and maintaining the necessary aircraft and their bases. The total dollar benefits from replacing current mapping activities related to land use at the Federal and State levels are indicated at the end of Table 4.8.

4.5 Nonreplenishable Natural Resources: Minerals, Fossil Fuels and Geothermal Energy Sources

This resource area is concerned with the application of remote sensing techniques to the mineral and fossil fuel extraction and extraction-related industries. Use of remote sensors for locating and implementing geothermal sources of energy is also considered. The ERTS-1 satellite is the prototype sensor and its capabilities and their relation to economic benefits are discussed.

In these times of energy and raw materials shortages, techniques which may impact supplies or, at least, provide superior information for management of existing supplies will be considered very valuable.

Table 4.8 Federal Statutes in Support of Resource Management Function: Land Use

Resource Management Function	Applicable Federal Statutes
4.1 Cartography, Thematic Map and Visual Displays	
4.1.1 Cartography and Thematic Map Making	43 USC 31
4.1.2 Land Use Maps of the United States - Federal and State Levels	P.L.92-419, 7 USC 1010, 7 USC 427-427i, 43 USC 31, 43 USC 2, 42 USC 410L-2, P.L.90-448-Title XIII, 42 USC 4102, P.L. 90-448-Title VI, 40 USC 461
4.1.3 Fault Zone and Lineament Mapping	
4.2 Statistical Services	
4.2.1 Provide Census Estimates - Demographical Services	7 USC 427-427i, 16 USC 742
4.2.2 Regional and Local Land Use Inventories	40 USC 204, 16 USC 567A, 42 USC 410L-2, P.L.90-448 Title XIII, 42 USC 4102, P.L.90-448 Title VI, 40 USC 461, 16 USC 1001-1009, 33 USC 883E
4.2.3 Land Use Change Statistics	7 USC 427-427i, 43 USC 31
4.2.4 Monitor Land Movements - Sand dunes, Wetlands, etc.	16 USC 1301
4.4 Allocation	
4.4.1 Selection of Federal and State Parks and Recreation Areas	P.L.90-448 Title VI, 4[illegible]C 461, 16 USC 1001-1009, P.C. - 645 Title VII, 33 USC 709a
4.4.2 Location of New Towns and Other Development	42 USC 1962 A-1, P.C. 89-80
4.4.3 Allocation of Land for Highways and Other Rights-of-Way	
4.4.4 Selection of Areas for Land Reclamation	
4.4.5 Site Location of Airports and Other Major Transportation Modes	

Table 4.8 Federal Statutes in Support of Resource Management Function: Land Use (Continued)

Resource Management Function	Applicable Federal Statutes
4.5 Conservation	
4.5.1 Protection of Agricultural and Forest Lands	P.L.92-419, 7 USC 1010, 43 USL 315a-315f, 43 USC 1181
4.5.2 Protection of Wilderness Areas	16 USC 1301. 16 USC 742
4.6 Damage Prevention and Assessment	
4.6.1 Map Sink, Landslide and Other Hazardous Areas and Assess Damages	P.L.90-448 Title VI, 40 USC 461, P.L.92-367, 16 USC 1001-1009, P.L.66-645 Title II, 33 USC 709a
4.6.2 Assess Impact of Earthquakes and Volcanic Eruptions	
4.9 Administrative, Judical, and Legislative	
4.9.1 Manage Federal Revenue Sharing Programs	
4.9.2 Regulate Land Use in Areas of Critical Environmental Concern	P.L.88-577, 42 USC 410L-2, P.C.90-448 Title XIII, 42 USC 4102
4.9.3 Regulate Land Development Projects	
4.9.4 Management and Plan Federal, State and Local Taxation	
Undiscounted Annual Cost Savings Benefits 1977-1993, from ERTS-like ERS in meeting Federal Statutory Demand, $ millions (1973)	7.9-37.1

In an industry where approximately 8 billion dollars is annually poured into exploration, any technique which can improve upon either the quality or the quantity of that information, at a very low cost, has a great potential for reducing costs and expanding output.

The results from studies by the principal investigators have been encouraging, although direct sensing of minerals or fuels does not have much promise. However, geology has long been concerned with inferring sub-surface content from surface structure and earth resources satellites can, in some cases, provide data on surface structure. ERTS-1 data have been immediately useful for improving geologic maps, the basic tool from which all exploration proceeds. In particular, the synoptic view has proven invaluable at detecting subtle linears, whose correlation with mineral and fossil fuel areas is being demonstrated. ERTS-1 imagery has even uncovered some interesting structures called "hazy" anomalies which have not been detected on images from aircraft nor Skylab and whose nature are not yet known. These anomalies have shown very high correlation with known oil-bearing areas.

The repetitive nature of ERTS is also useful in this area. Seasonal variations provide increased information from geobotanical indicators of mineralization. The presence or absence of vegetation affects the ability to detect geologic boundaries.

Of primary value in repetitive coverage will be use of an ERTS-like system for monitoring disturbed land and reclamation for legal, environmental and safety purposes. Much stricter laws are being passed at the State and Federal levels which will require all stripped land to be adequately reclaimed. Enforcement of these statutes will be strategically and economically aided by the broad overview which an ERTS-like system can provide.

Among the studies reviewed for this report are the EarthSat report and Useful Applications of Earth-Oriented Satellites - Geology by The National Academy of Sciences. Of great value was the investigation by Eason Oil, "An Evaluation of ERTS Data for the Purpose of Petroleum Exploration."*

Benefits are found to be mostly in cost savings to existing geologic and geophysical operations. These benefits total 1.6 to 3.9 million dollars annually in the "hard" definition, but another 33 to 77 million dollars of "soft" benefits are indicated by the Eason Oil Report. These are summarized in Table 4.9.

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* McCown, Stonis, Petzel, Everet, "An Evaluation of ERTS Data for Purpose of Petroleum Exploration," Oklahama City; Eason Oil Company, 1974, NAS 5-21735.

Table 4.9 Magnitudes and Types of Net Annual Benefits by Resource Management Activity - Nonreplenishable Natural Resources: Minerals, Fossil Fuels, and Geothermal Energy Sources

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
5.1 Cartography, Thematic Maps and Visual Displays			
5.1.1 Geological Mapping	.6-2.9		
5.1.2 Map Areas of Potential Geoghermal Energy Sources	*		
5.4 Allocation			
5.4.1 Manage Mineral Exploration and Extraction	1.0		
5.4.2 Manage Fossil Fuel Exploration and Extraction	(33-77)		
Total:			
Hard Benefits documented in ECON Case Studies	1.6-3.9		
Soft Benefits......	(33-77)		

* A one-time benefit of $1 Million would be possible from an ERTS-like Satellite with a thermal infrared sensor.

4.6 Atmosphere

The work performed in this area is an effort to identify the possible activities in which an earth resources satellite might impact understanding and control of atmospheric phenomena, to establish how such a satellite might be used, and to estimate possible economic benefits from an ideal satellite and the more limited ERTS satellite. Most of the resource management functions described have either little benefit or unquantifiable benefits. That is not to imply that they are unimportant: every one represents an area of current concern which may be impacted by satellite. Small or unquantifiable benefits only mean that in the current economic market, the value of such a function is small, irrelevant, or unappreciated. As satellite information becomes more dependable and more thoroughly interpreted, these benefits may expand.

The major quantifiable benefits fall into the category of air pollution largely because there is a substantial amount of activity in this area. Ten years ago, these benefits would also have had to be listed as unquantifiable since no substantial economic foundations had been laid. The hard numbers arise from the demonstrated capability of the ERTS satellite to measure aerosol particulates. Such a capability means that already planned and existing aerosol and particulate monitoring stations may be unnecessary. Thus the estimate of between $1.5 million and $10.5 million is from the replacement of a large number of machines and personnel by a smaller more specialized group of data interpreters (RMF 6.1.2).

Soft benefits are attributed to anticipated results of demonstrated capabilities or anticipated but undeveloped capabilities which have a probable economic impact. Better interpretation of particulate pollution data and environmental damage lead to the large 5 to 27 million dollar figure (RMF 6.2.2). This comes from the increased ability of the society to adjust to more certain information. Similarly the approximately 1 million dollars from monitoring direct environmental effects and research reflect an estimate of other benefits of better data.

Simple economic models are contained in RMF's 6.1.2 and 6.2.2. The first merely discusses the cost of maintaining pollution monitoring stations and how the satellite might affect them. The second is more general and develops the notion of the very real cost associated with the uncertainty being felt as pressure mounts from automobile manufacturers and the energy crisis to relax clean air standards. The assumption in this model is that the satellite will, in some way, better enable us to estimate air pollution costs. Various satellite images of pollution-caused weather modifications and air turbidity indicate that this assumption is reasonable.

The Interplan, Dynatrend, and EarthSat studies* do not attack the air pollution problem with any depth. The first merely assumes a 50% reduction in pollution monitoring stations, apparently a randomly chosen number yielding a .35 million dollar benefit. Dynatrend argues that satellite sensors in conjunction with ground truth will be able to monitor regional air pollution, however they rather arbitrarily arrive at 5.5 million dollars as a benefit. The EarthSat-Booz Allen report concludes that no benefits are possible because of the low coverage frequency and low resolution.

The other resource management functions discussed in this section pertain mostly to weather related phenomena. The ERTS satellites are not specifically designed to observe weather or other atmospheric phenomena, however some of their capabilities will complement and extend those of other satellite systems. Weather prediction from a resources satellite is difficult because coverage is only once every 18 days and the field of view is limited. Cloud statistics taken repeatedly at the same time of day, however, may aid with our understanding of long term weather cycles and regional weather phenomena. Such information, combined with observations of ground conditions, may help with our understanding of the climatic changes that we already know are underway. Quantitative benefits for these functions cannot be derived since our ability to determine such information from space has not been demonstrated and earth-based programs are just commencing. Table 4.10 shows the benefit estimates in this area.

4.7 Oceans

Remote sensing has never had wide applications in oceanographic studies. The vast area involved and the great distances from home base have made aircraft sensing logistically unsound. The oceanographer's historic bias toward the vertical hampers the use of satellite data. And even if these difficulties were overcome, less than 10 percent of the ocean's mass would be probed from the air by passing sensors because light only penetrates a few hundred meters under ideal conditions.

In spite of these obvious obstacles, the possibilities from satellite overview are tremendous. Although not all the ocean's mass is detectable, that part which is sensable is by far the most significant. Satellite sensors can only detect that mass where light penetrates. But light is the primary

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* Dynatrend, "Final Report Evaluation of Benefits and Systems Features of Earth Resources Satellite Operational System (ERSOS)", Burlington, Mass., 1974.
EarthSat, "Case Study in Atmosphere", Beverly, Calif., 1974.
Review and Appraisal: Cost Benefit Analyses of Earth Resources Survey Satellite Systems, Document No. 7016R, March, 1971, Interplan Corporation, Santa Barbara, Calif.

Table 4.10 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Atmosphere

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
6.1 Cartography, Thematic Maps and Visual Displays			
6.1.2 Smoke and haze distribution	1.5-10.5		*
6.2 Statistica' Services			
6.2.2 Air quality monitoring			(5-27)+
6.5 Conservation			
6.5.2 Monitor jet contrail water vapor condensation & carbon dioxide effects on weather & air			(.1-.3)
6.6 Damage Prevention and Assessment			
6.6.1 Monitor effects of thermal & other pollution sources on weather			*
6.6.2 Monitor airborn pollution effects on the environment		(.25-.9)	*
6.7 Unique Event Recognition and Early Warning			
6.7.3 Monitor climatological changes			*
6.8 Research			
6.8.1 Research on effects of thermal so rces on weather		*	
6.8.3 Research on dispersion of pollution in the atmosphere		(0.1)	

* Asterisks indicate possibly significant, yet presently unquantifiable benefits

+Parentheses indicate soft numbers

Table 4.10 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Atmosphere

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
6.9 Administrative, Judicial and Legislative			
6.9.1 Control of particulate pollution	(.01-.05)		
6.9.3 Provide a data base for establishing appropriate air quality regulations		(1-2)	
Total:			
Hard Benefits documented in ECON Case Studies..............................	1.5-10.5		
Soft Benefits........................	(.01-.05)	(1.35-3.00)	(5.1-27.3)

source of the ocean's energy budget. The other sources are winds and the gravitational pull of the moon which are reflected in the detectable surface phenomena of waves and tides.

Detectable from satellite are the ocean surface and the upper ocean layers which contain or reflect: the motive forces that affect all ocean transportation and the safety of lives and structures in coastal areas; the photosynthetic activities upon which all marine life depends; the site of tremendous heat/energy exchange between water and air which significantly affects all weather; the continental shelves which contain valuable fuels and minerals; dangerous hazards to navigation in the form of reefs, shoals, sand bars, and islands; and coastal waters of great recreational and economic value, waters which are highly susceptible to contamination.

Most of the benefits accrue in the area of research. This is largely due to the dynamic nature of oceans. Because of their quickly changing conditions, usable information is not in the form of what the sea state is at present, but instead, what it will be tomorrow. These predictions necessitate involved forecasting models which are not yet in existence. The need for this future-oriented type of information holds for almost all ocean-related activities: weather prediction, fishery management and harvesting, marine construction, and ocean shipping. As a result, immediately quantifiable benefits are few while potential future benefits are great. In the interim, mathematical forecasting models must be developed and tested.

A further benefit which is possibly the greatest of all is information on the ocean food supply. The ocean contains tremendous quantities of edible, usable vegetation, which has been proven to be self-producing and quickly regenerative. Yet this benefit, too, is difficult to ascertain because present food demand levels are not sufficient to bring large quantities of this vegetation into the market. When this food will show significant or necessary importance depends upon how quickly mankind outgrows the land's ability to supply all his food. Remote sensing will designate areas for harvesting and, possibly. for planting too.

Due to the infancy of this remote sensing application, there have been few studies in this rea and very few which try to find quantifiable benefits. Studies cited in this report include:

- Greenblat, E.J. and Heiss, K.P., Cost Benefit Study of the Earth Resources Observation Satellite System-Estuarine and Coastal Management, a study report prepared for RCA Astro Electronics Division, Princeton, New Jersey, 1968.

- Useful Applications of Earth-Oriented, Satellites--Oceanography, National Academy of Sciences-National Research Council for NASA, 1969

- Cost Benefits for a National Data Buoy System, an essay, Travellers Research Center, October 1997, prepared under Coast Guard contract TCG-16790-A.

- Economic Benefits from Oceanographic Research, National Academy of Sciences--National Research Council, Publication 1228, 1964.

- Comittee on Polar Research, 1970: Polar Research, A Survey, National Academy of Sciences--National Research Council.

- Final Report on the Space/Oceanographic Study, General Electric Co., Missile and Space Division, Philadelphia, 1967.

- Applications of ERTS Data to the Regulation, Protection and Management of New Jersey's Coastal Environment---An Extension of SR-304 ERTS-1 Investigation,: New Jersey Department of Environmental Protection and Earth Satellite Corporation, June 1974.

In spite of the infancy of this application, great benefits are acknowledged in the area. The National Oceanic and Atmospheric Administration has several weather satellites up and many more planned. These satellites monitor the atmosphere and also the ocean surface--the source of much of our weather. A comprehensive ocean satellite system, SEASAT, has been proposed. This system will provide sensors necessary for ocean application including infrared and active microwave.

Although ERTS is not an operational satellite, and definitely not designed for Ocean applications, several benefits are quantified in this report. These benefits are of two general types, cost-savings to Federal and State budget activities, and benefits to coastal management authorities from improved information. Significant benefits from improved weather prediction, improved fisheries management, and identification of future ocean food supplies also exist, but are unquantified.

Nautical charting can be accomplished more comprehensively and much more cheaply than with presently available methods. Cost-savings benefits alone range from \$3.3M to \$6.7M.

Much of the ocean's waters permit light penetration sufficient to detect barriers to navigation; ocean bottom depths as deep as 60 meters have been seen by Skylab. Cost-saving in hydrographic mapping range from $1.7M to $6.0M. This does not even include unquantified benefits from avoidance of ship damage and more efficient ship routing. Benefits in pollution-detection will also be significant. A few of these benefits have been quantified. $.19 - .78 million, $.07 - .15 million and $.1 million (one time) have been documented for coastal zone management, shore-line protection, and new legislation respectively. See Table 4.11.

4.8 Industry

Industry is a Resource Management Area which covers all man-made resources of the nation including the industrial plant, residential and institutional buildings (and the institutions themselves), and the labor force. Since this study is the first to recognize industry as an independent Resource Management Area, the effort under this section is only exploratory and the results inconclusive.

Preliminary survey of the economic activities falling under "industry" suggests that major benefits could be expected from an improvement in entrepreneurial decision-making in the selection of site, design and time of construction of "industrial" facilities. The potential use of resource satellite images in the context of such allocational decisions has been demonstrated recently by two studies.

Gedney and VanWormer of the University of Alaska have used ERTS data to investigate geologic structures and fault zones in Central Alaska. A mosaic made up of 6 ERTS images led to the discovery of several previously undetected faults. A conjugate fracture system (scene of a 1968 earthquake) was found to run very close to a proposed bridge site and the proposed route of the Alaska pipeline over the Yukon River. Data derived from this mosiac points to the need for change in design and siting of these facilities, and is used by local planners.*

Adbel-Gwad and Silverstein of Rockwell International have constructed seismic-risk maps from ERTS images of Southern California, discovering unmapped faults (proved to be active by seismic date) and evidence of recent movement along other

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* Ralph N. Baker, "ERTS Updated Geology", Geotimes, August 1974, p.21.

Table 4.11 Magnitude and Types of Net Annual Benefits by Resource Management Activity - Oceans

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
7.1 Cartography, Thematic Maps and Visual Displays			
7.1.1 Oceanographic mapping	(5.0-12.7)**	*	
7.1.2 Thermal mapping of the oceans	*	*	
7.1.3 Mapping ocean ice an polar caps		*	
7.2 Statistical Services			
7.2.1 Monitor ocean food supply	*	*	
7.3 Calendars			
7.3.1 Monitor tides and currents in coastal waters	*	*	
7.3.2 Monitor the movement of the major oceanic currents	*	*	
7.4 Allocation			
7.4.1 Optimize ocean fisheries management		**	
7.4.3 Improve coastal zone management		.19-.78	
7.4.4 Optimize ocean shipping		*	
7.5 Conservation			
7.5.1 Improve shoreline protection programs		.07-.15	
7.5.2 Control ocean pollution		.62-2.5	
7.5.3 Monitor oil slicks	.55	.28	
7.6 Damage Prevention and Assessment			
7.6.1 Reduce ocean resources losses due to man-made changes		*	
7.8 Research			
7.8.1 Research on ocean parameters		**	*
7.8.2 Research on estuarine ecology		**	*
7.9 Administrative, Judicial and Legislative			
7.9.1 Aid in enforcing national and international regulations and agreements		*	
7.9.2 Aid in designing legislative controls and administrative procedures		.01	
Total:			
Hard benefits documented in ECON Case Studies.....	.55	1.2-3.7	
Soft Benefits...................	(5.0-12.7)		

Source: ECON

* Approximately $73.4 - 220.8M total benefits are possible via a satellite with a thermal infrared band for mapping of the North Pacific. However, it is likely that satellites other than ERTS e.g., SEASAT and NIMBUS G, will obtain this benefit.

** Parentheses indicate "soft" benefits

faults previously thought to be inactive. The new-found faults were undetected from previous ground surveys and conventional aerial photography. Several engineering firms studying potential sites for nuclear power plants in California have requested ERTS information on fault extensions and lineaments to be used in the analysis of seismic risks.*

We were unable to find any current use of ERTS data for decision-making in construction at the present time; the potential use, however, is clearly there.

Table 4.12 summarizes the areas of potential benefits to "industry" from an ERS systems investigated in this study classified according to Resource Management Activity.

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* Ibid., p. 22.

Table 4.12 Magnitude and Types of Net Annual Benefits by Resource Management Activity - Industry

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability	Increased Capability	New Capability
8.1 Cartography, Thematic Maps and Visual Displays			
8.1.1 Mapping ice build-up & break-up	small	moderate	moderate
8.4 Allocation			
8.4.1 Site selection for industrial, residential and institutional construction	*	*	*

* Benefits are potentially significant, but not exclusively due to ERS; see discussion in the RMP writeup.

5. A NEED FOR FURTHER USER INVESTIGATIONS

The purpose of this study is to provide an overview of the ERTS program from an economic viewpoint and to determine (1) the magnitude of "real" or measurable benefits that can reasonably be expected to flow from an ERS system by say 1985, given continuity of service, (2) the distribution of these benefits, and (3) the value of benefits foregone in the event of a one-year and a two-year gap in ERS service occurring after the useful lifetime of ERTS-B (1977-1978). The study has been conducted using a two-sided approach.

On the overview side, a substantial literature search was conducted to define the demand for ERS services through laws and statutes demanding land cover information and through budgetary allocations for ERS-type activities. The demand for ERS services was further established by investigating many potential applications of ERS information. The overview study also included a review of the activities and accomplishments of the ERTS-1 principal investigators, especially as they substantiate technically the capability of an ERTS-like ERS system for performing functions required to obtain the estimated benefits.

On the other side, specific applications of ERS information were selected for in-deph case studies. Two in-depth studies in agriculture, a land cover cost-effectiveness study, and an ad hoc case study in water management were completed. In some cases, significant contributions to the state-of-the-art of econometric modeling were made.

These studies confirm, through established economic principles and through principal investigator demonstrations of the operational use of ERTS-1 data, a lower bound of annual benefits of $430 to $746 million (1973) once ERS data are in use operationally. Moreover, the benefits will, by-in-large, accrue to society on the whole. Since these *minimum* benefits substantially exceed any reasonable estimate of ERS system and data processing costs, the *ultimate desirability* of an ERS system is now established.

In another part of the study, the present value of benefits foregone in the event of a one-year and a two-year gap in ERS service after the useful lifetime of ERTS-B was assessed. The benefits foregone in 1973 dollars are estimated to lie in the range of $147 million (assuming a one-year gap and discounting at 15% to 1974) to $420 million (assuming a two-year gap and discounting at 10% to 1974). These estimates are based only upon the minimum benefit estimates cited above and are thus also a lower bound. These results establish the desirability of maintaining continuity of service.

We believe that the above results reaffirm the need for further *user investigations* in the areas of agricultural crop forecasts and water management, in particular, the Large Area Crop Inventory Experiment currently in progress at the NASA Johnson Space Center and a water resources management demonstration designed by ECON.* These studies can further substantiate and refine the results obtained above and develop ERS user technology.

The major ERS issues yet to be faced deal now with the ultimate characteristics and structure that an on-going ERS system should have and the path by which one gets from ERTS to an operational system. Several observations, based upon the *economic* findings of this study, can be made:

1. A commitment to continuity of ERS service is essential if the economic potential of ERS benefits is to be achieved.

2. Development of an ERS system should be an evolutionary process that combines a hardware technology program and a user technology program to provide for both improving ERS technical services and improving use of ERS services.

3. ERS system services should be long term commitments so as to guarantee that services once begun will have assured continuity. This encourages user investment in ERS data processing and information processing equipment necessary to obtain economic benefits.

Any ultimate ERS system should be thought of as a multitier system, not merely as one, two or three satellites. This can include ground observers, low, medium and high altitude aircraft, low altitude satellites (such as EOS, NIMBUS G, and SEASAT), high altitude satellites (SEOS, SMS) and communications relay satellites (for example, TDRS). While the results of this study are obtained by addressing only the contributions of an

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* Design of a Water Resources Management Demonstration for the Use and Value of ERTS Information," Report No 74-2002-5, ECON, Inc. Princeton, New Jersey, April 15, 1974

ERTS-type satellite system, the direct benefits of an ERS system are substantially greater than the sum of the benefits attributable to each of its components taken separately. Thus, future studies, especially those related to ERS systems definition, should address the economic aspects of ERS in this *systems* context.