PRELIMINARY BENEFIT/COST ANALYSIS OF CANADIAN SATELLITE/AIRCRAFT REMOTE SENSING APPLICATIONS

Donald J. Clough

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* This report was prepared for the Canada Centre for Remote Sensing (CCRS) as the first of a planned series of benefit/cost analyses. It represents views of the author, but not necessarily those of the CCRS Director or of any Agency of the Government of Canada.

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1. INTRODUCTION

1.1 Caveats

This paper is the first of a planned series of papers on the benefits and costs of remote sensing in Canada. At this pre-satellite stage a basis for measuring economic benefits and costs is not developed, but the paper is offered as a starting point for further discussion and analysis.

Undoubtedly some of the estimates of benefits and costs discussed in this paper will be received sceptically. It may seem that there is a lack of rigor and a weakness of supporting argument. At this stage, my main purpose is to provide some information, no matter how incomplete, in response to the Treasury Board's stated requirements for benefit/cost analysis of public expenditures. A secondary purpose is to focus attention on the problems of benefit/cost estimation and to solicit constructive criticism, discussion and ideas about classes of benefits.

1.2 Background

On July 19, 1969, the Cabinet Committee on Science Policy and Technology instructed the Department of Energy, Mines and Resources (EMR) to establish an Interdepartmental Committee on Resource Satellites and Remote Airborne Sensing, supported by a Program Planning Office (PPO). On November 28, 1969 Cabinet allocated initial funds to the PPO.

On May 7, 1970, the Cabinet instructed EMR to negotiate a memorandum of understanding between EMR and the U.S. National Aeronautics and Space Administration (NASA), for a cooperative experimental program of remote sensing of earth resources from aircraft and satellites. The Cabinet assigned this program a high priority.

On February 11, 1971, the Treasury Board approved the establishment of an organization within EMR to be known as the "Remote Sensing Centre", on the basis that it was to serve a number of federal and provincial agencies. It is now known as the Canada Centre for Remote Sensing (CCRS).

On May 18, 1971, an agreement was signed between EMR and NASA over the issue of control over the distribution of Earth Resources Technology Satellite (ERTS) observations of Canada. As a result of this agreement, Canada will receive data transmitted directly from ERTS satellites to a Canadian ground receiving station.

On July 29, 1971, the Cabinet directed that an integrated remote sensing program be undertaken in Canada beginning in fiscal year (FY) 1972/73. This program embraces a number of activities, including airborne remote sensing, satellite remote sensing, sensor development, and the diffusion of new technologies for data acquisition, data processing and data interpretation.

Dr. L. W. Morley, who was largely responsible for the development of the CCRS, has been appointed as its first Director.

1.3 Summary of Benefit/Cost Analysis

An evaluation of ten major remote sensing benefit/cost studies was completed for NASA by Interplan Corporation in March, 1971. This evaluation indicated that the costs of the U.S. Earth Resources Survey (ERS) Program would be about $20 million to $50 million per satellite year, while the estimated potential benefits that were judged to be "valid" would exceed $1.4 billion per year. These were considered by Interplan to be reasonable "order of magnitude" indicators of costs and benefits, and are summarized in this paper. The estimated potential benefits are net after accounting for changes in user agency costs.

Some of the categories of U.S. benefits cited in the Interplan Report are not applicable in Canada. However, many of the U.S. benefits of remote sensing would also occur in Canada to some extent. In this paper the potential Canadian benefits are estimated by extrapolating the results of the U.S. benefit/cost studies to Canada, on the main assumption that the U.S. figures which Interplan judged to be "valid" are generally acceptable. The basis for extrapolation to Canada is an assumption that aggregate potential Canadian benefits would be about one-tenth of aggregate potential U.S. benefits (roughly proportional to population and general economic activity). Thus the Canadian figure would be about $140 million per year. This basis is of course subject to debate, but at present there seems to be no other quick and economical way to get order-of-magnitude pro forma estimates.

Using this method of comparison with the U.S. studies, salted with some opinions about uncertainties, obtained from experts in fields of application in Canada, the potential benefits of remote sensing in Canada would most probably be between $25 million and $250 million per year. This range of uncertainty spans a factor of ten, which is not a wide margin for error in this kind of technological forecasting.

It will take time to reach the forecast level of potential annual benefits, depending on the research and development and promotional activities of the CCRS and the rate of adoption of remote sensing activities by user agencies. The bottleneck in adoption will be largely in data interpretation. Under the best R and D and promotional strategies, it seems likely that the forecast potential benefits could be fully realized in about 5 years. Under weak R and D and promotional strategies, the Canadian potential benefits might not be realized until at least 15 years.

Figure 1 shows a plot of hypothesized flows of future benefits, assuming "best" and "worst" time-frames for the realization of future benefits, and assuming a region of uncertainty for potential annual benefits between $25 million and $250 million per annum.

The discounted present values of the streams of estimated future benefits, discounting at 10 percent per annum over a 20-year planning period, would be approximately as follows:

		Present Values ($ Million)		
	Potential Annual Benefits	"Best" Time-Frame (5 years)	"Worst" Time-Frame (15 years)	"Best-Worst" Difference
Optimistic Uncertainty Limit	250	1,600	900	700
Middle Estimate	140	900	500	400
Pessimistic Uncertainty Limit	25	160	90	70

The 1972/73 budgeted activity level of the CCRS is about $6.2 million, and budget forecasts are based on an annual growth of about $0.25 million, chiefly to cover increases in manpower costs. The discounted present value of this stream of future budgeted costs, discounting at 10 percent per annum over 20 years, would be about $75 million.

Larger budget levels have been suggested, with the additional amounts to cover an accelerated development of data interpretation methods, regional and specialized interpretation centres across the country, and accelerated R and D related to remote sensing programs following the ERTS-A and -B satellites. One such larger budget forecast for example, is based on reaching a budget of $12 million in 1973/74, with an annual increase of about $0.5 million per annum thereafter. The present value of this stream of future budgeted costs, discounting at 10 percent per annum over the 20-year planning period, would be about $140 million.

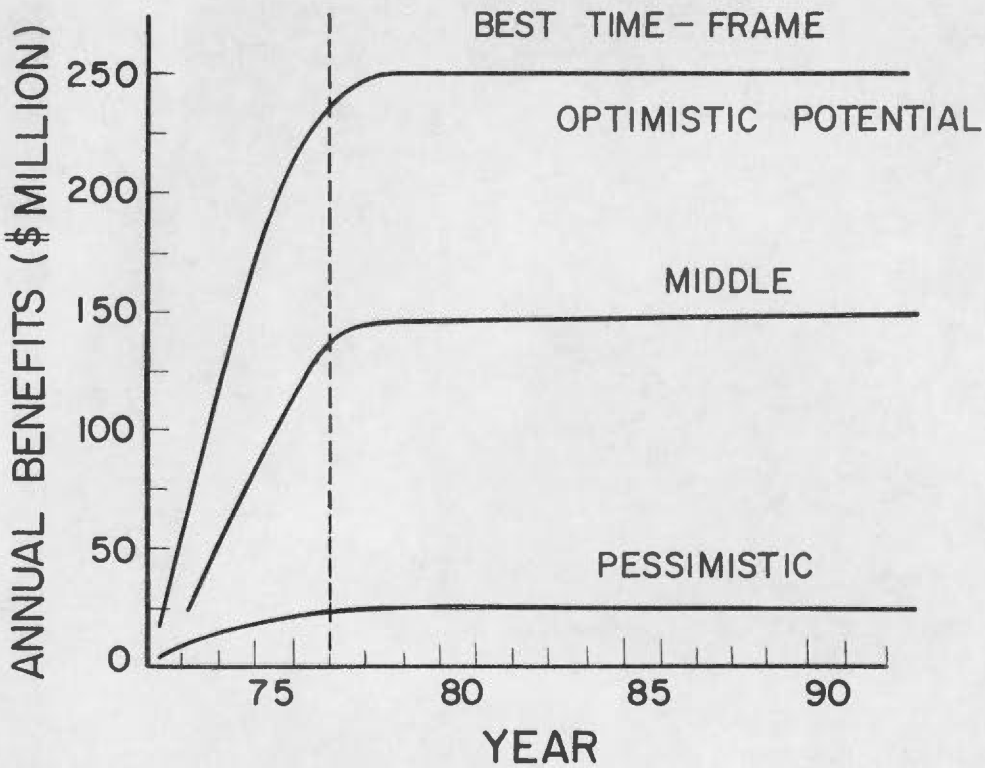
On the assumption that the potential benefits would be realized in the "worst" time-frame of 15 years in the case of the lower budget, and in the "best" time-frame of 5 years in the case of the higher budget, the present values of benefits and costs probably fall into the following ranges. ($ millions).

	"Worst" Time-Frame		"Best" Time-Frame
Optimistic Limit of Potential Benefits, B_u	900		1,600
Pessimistic Limit of Potential Benefits, B_L	90		160
Costs of CCRS Operations, C	75		140
(B_u-C)	825		1,460
(B_L-C)	15		20
(B_u/C)	12:1		11:1
(B_L/C)	1:1		1:1
Difference, b_u		700	
Difference, b_L		70	
Difference, c		65	
(b_u-c)		635	
(b_L-c)		5	
(b_u/c)		11:1	
(b_L/c)		1:1	

If the assumptions are plausible, from these figures it appears that the larger budgets may be justified. At the lower limit, the estimated incremental benefits would be about the same as the incremental costs. But at the upper limit the estimated incremental benefits would be about 11 times the incremental costs.

These estimated limits of benefits are subject to doubt, even though they span a tenfold range of uncertainty. However, they may be considered to be reasonable indicators of the potential payoffs to be realized from the activities of the Canada Centre for Remote Sensing.

In addition to the estimated tangible economic benefits, there would be certain intangible benefits related in general to the pursuit of the National Policy, and in particular to the National Policy themes of (1) safeguarding sovereignty and independence, (2) enhancing the quality of life, and (3) ensuring a harmonious natural environment. The CCRS was evidently approved by Cabinet in the first instance on the basis of intangible benefits related to the National Policy.


BEST TIME - FRAME
OPTIMISTIC POTENTIAL
MIDDLE
PESSIMISTIC
ANNUAL BENEFITS ($ MILLION)
250
200
150
100
50
0
75
80
85
90
YEAR

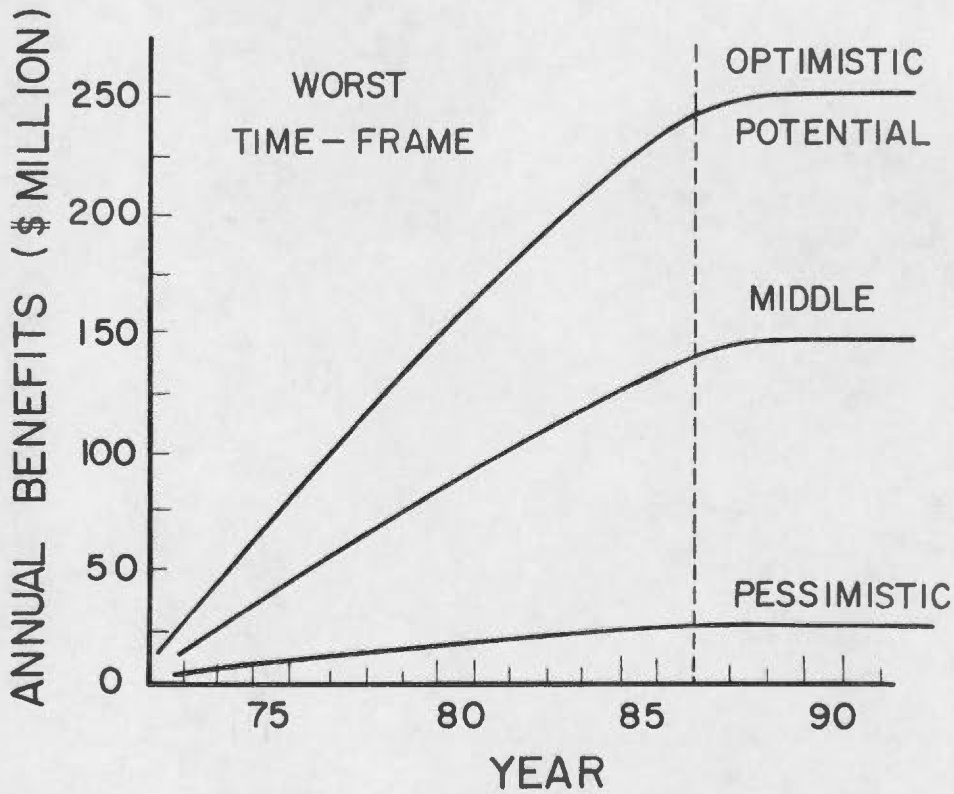

WORST
TIME - FRAME
OPTIMISTIC
POTENTIAL
MIDDLE
PESSIMISTIC
ANNUAL BENEFITS ($ MILLION)
250
200
150
100
50
0
75
80
85
90
YEAR

Figure 1

2. U.S. EARTH RESOURCES SURVEY PROGRAM

The U.S. Earth Resources Survey Program (ERS) is divided into three components - the Aircraft Program, the Spacecraft Program (unmanned and manned), and Supporting Research and Technology. The Canada Centre for Remote Sensing has programs which are complementary to these U.S. programs.

2.1 U.S. Aircraft Program

This component of the ERS Program is being used (a) to obtain multi-spectral data of earthly phenomena for analysis by users in various disciplines related to resource management, and (b) to evaluate new remote sensor systems provided by supporting research and development. The aircraft are used as platforms to carry combinations of sensors. Two types of remote sensors are employed: (1) those that "illuminate" targets and receive reflected radiation (e.g., radar), and (2) those that operate as passive monitors of natural and cultural emissions or reflections from the earth's surface and near-surface environment (e.g., infra-red scanning, photography). The aircraft program provides a necessary support for the satellite program, chiefly in the testing of new sensing instruments under simulated satellite operating conditions, and in checking the validity of satellite observations.

2.2. U.S. Spacecraft Program, Unmanned

The U.S. National Aeronautics and Space Administration (NASA) has a number of earth resources survey satellites in various stages of planning and development. Among these are the Earth Resources Technology Satellites (ERTS) and the Earth Observation Satellite (EOS). Funding for ERTS-A and -B satellites has been approved, and the following launch schedule is expected:

ERTS-A	May, 1972
ERTS-B	Late 1973
ERTS-C	Early 1975 (may be deleted)
EOS	Early 1976

It is expected that a series of satellites will follow these, and the analyses in this paper assume continuity over a 20-year period.

ERTS-A and -B are designed to determine the usefulness and operating efficiency of the system, to flight test the sensors, and to provide data to the user community. The principal performance and design characteristics of the ERTS-A and B have been specified as sun synchronous (for daylight sensing), circular, near-polar orbit (496 naut. mile), an orbit-adjust capability, an attitude control of less than 0.7°, an onboard data recording facility, 20-minute sensor operation per orbit, wideband data transmission (20 MH_z, S-band), a payload capacity of 350 pounds, and the ability to repeat coverage every 18 days during a lifetime of 1 year. The proposed sensors for ERTS-A include:

1. Three high-resolution return-beam vidicon TV cameras (resolution 300-600 feet per line-pair; a coverage of 100 by 100 naut. miles, green, red and near-infrared spectral bands).

2. A 4-channel multispectral point scanner (resolution 440 feet per line-pair; 100 naut. mile swath coverage; green, red, near-infrared and infrared spectral bands).

3. Data collection equipment.

The EOS satellite will continue terrain surveys and some meteorological research and it will also initiate measurement of oceanographic phenomena (sea state, ocean surface temperature, colour, current, sea ice, coastal processes) and environmental quality. It is expected to provide higher resolution than ERTS-A and -B.

A series of Small Applications Technology Satellites (SATS) is proposed to supplement the ERTS satellites in order to provide early, rapid space-flight testing of sensors and subsystems. These spacecraft will be small, single-purpose, simplified and optimized for particular experiments.

The U.S. Department of the Interior has a program called EROS - Earth Resources Observation System - for the utilization of spacecraft technology in resources surveying and management. There is no EROS satellite as such. The satellites referred to under EROS are NASA's ERTS satellites and their successors.

2.3 U.S. Spacecraft Program, Manned

The ERS Program also employs manned spacecraft for acquiring data via remote sensors. Early colour photographs taken on Mercury, Gemini and Apollo flights demonstrated the potential of remote sensing from space platforms and led to the first controlled multi-spectral experiment (S065). This experiment was performed from Apollo 9 using four Hasselblad cameras - one with colour infrared (IR) film and three with black and white film used with filters to match the near-IR, green and red bands proposed for the ERTS-A television camera.

NASA has plans to launch a series of satellites in its Manned Orbiting Research Laboratory Program (MORL), which is related to the ERS Program. The first satellites in the series are called SKYLAB satellites; their launch dates have not yet been announced, but the first is expected sometime in 1973. The first SKYLAB will carry as part of its equipment an Earth Resources Experiment Package (EREP) which will collect data on earth resources. This equipment will include six 70-mm multispectral cameras with six different filter-film combinations, four black and white and two colour (S-190); one infrared spectrometer with a 0.4 to 15.5 micron range (S-191); one 10-band microwave multispectral scanner (S-192); and one K-band radiometer-scatterometer-altimeter (S-193/194).

2.4 U.S. Supporting Research and Technology

Supporting research and technology chiefly involves (1) sensor and sensor-platform instrumentation research and development, (2) ground data handling hardware and software research and development, (3) sensor-signature data interpretation research and development (both human and machine interpretation).

3. CANADA CENTRE FOR REMOTE SENSING

The CCRS has programs which are complementary to the U.S. programs outlined in Section 2. (They are described in the document entitled "CCRS Remote Sensing Objectives and Programs Current Status November 1971", a CCRS working paper prepared by this author.)

3.1 Background

On May 14, 1971 an agreement was reached between NASA and the Canadian Department of Energy, Mines and Resources (EMR), for a joint experimental program of remote sensing of resources from aircraft and satellites*. Under this agreement, the Canadian Prince Albert Satellite Station (PASS), will receive data directly from the ERTS satellites. The data will be processed at the CCRS Ground Data Handling Facility in Ottawa, and a variety of hard (permanent) and soft (transient) outputs will be available for user agencies.

The general objectives of the CCRS involve five main elements: (1) central control of remote sensing data, (2) diffusion of a new remote sensing technology, (3) production and distribution of data and services to user agencies, (4) assurance of system reliability, and (3) program planning and evaluation. The main objectives and operational sub-objectives are spelled out in detail in the document cited above.

New technologies are being developed in the U.S.A. and in Russia relating to remote sensing. These new technologies include new sensors and instrumentation, new sensor platforms (satellites, aircraft, balloons), new ground readout facilities, new computer hardware and software capabilities for unprecedentedly high rates of data processing, new information retrieval, display, and image-producing facilities, new computer-assisted interpretation methods, and a spectrum of new services to support the users of remote sensing data and derived information. Rather than relying entirely on imported technologies, it is important that Canada participate actively in research and development related to these technologies.

Rather than relying on the haphazard and piecemeal adoption of innovations imported at a late date from other countries, it is important that the Canada Centre for Remote Sensing provide guidance for the adoption of both Canadian and foreign innovations at an early date.

Resource management and environmental control agencies have needs for a broad spectrum of remotely sensed data, varying from simple black-and-white and colour aerial photography through infra-red

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* The CCRS is a division of EMR, established to provide services to users in other Canadian government agencies as well as to non-governmental agencies, under the guidance of an Inter-Agency Committee on Remote Sensing (IACRS).

photography, microwave, radar and laser beam imagery, and multi-spectral scanning from low altitude and high altitude aircraft and satellites. It turns out that airborne remote sensing is essential for the verification of satellite remote sensing. It also turns out that airborne and satellite sensing are complementary, each providing different kinds of data and derived information. The CCRS presently produces and distributes airborne remote sensing data and related services to user agencies, and will begin producing and distributing satellite data soon after the launch of ERTS-A (May, 1972).

There are risks involved in both satellite and airborne remote sensing programs. For example, an ERTS satellite launching could fail. Or the chance failure of aircraft equipment could ground available aircraft, creating an intolerable backlog of uncompleted priority projects. For these and other reasons, a certain degree of operational redundancy is necessary to assure reliability in the flow of data and derived information to user agencies.

Substantial costs are involved in all of the programs of the CCRS. Substantial benefits are also expected, but they are difficult to measure at the present time. Both costs and benefits are subject to the usual uncertainties of new programs which involve new technologies and the development of new uses and a new market. This is the context for program planning and evaluation, which will be carried out by the CCRS on a continuing basis. The evaluations presented in this paper are part of an ongoing series of evaluations.

3.2 CCRS Aircraft Program

The CCRS aircraft program uses a fleet of four aircraft: one Dassault Falcon, one CF-100 and two C47 (DC3) aircraft. These aircraft have the following specifications:

Dassault Falcon - Manufactured by Dassault (France), the Falcon is a pressurized high-altitude jet (40,000 feet plus) powered by two G.E. turbofan engines and extensively equipped with advanced navigation and other avionics equipment. It serves as a stable platform for an array of very sophisticated sensing equipment which are protected from the environment and accessible from inside the aircraft. The sensors include:

1. Texas Instrument Type RS14 Infrared (I.R.) Scanner (with short and long I.R. wavelength channels).
2. Ryan 703 Microwave Radiometer.
3. Ryan 720 Microwave Scatterometer.
4. Astrodata 7100 Time Code Generator.
5. Flight Parameter System (feeding into recorder).
6. Instrumentation Tape Recorder (14 track, digital).
7. Digital Tape Recorder.
8. Chart Recorder (6 channel).
9. RC8 Camera.
10. Hasselblad Camera Pack (four units).

CF-100 - Operated by the Department of National Defence, the CF-100 is a rather old single-engined military jet aircraft with an operational ceiling near 40,000 feet. It has limited navigational and other avionics equipment. It serves as a platform for an array of sensing equipment which are not fully protected from the environment and not accessible from inside the aircraft. A typical array of sensors includes:

1. Vinten F95 Camera Pack (seven units, 70 mm).
2. Wild Heerbrugg RC10 Camera.
3. HRB Singer Reconofax Infrared Line Scanner.
4. Hulcher 109 Camera.

C-47 - Operated by the Department of National Defence, the C-47 is a military version of the DC3. It is a twin piston-engine transport-type aircraft which operates between 1,000 and 10,000 feet. A typical array of sensors includes:

1. Four 70 mm cameras.
2. Daedalus Infrared Line Scanner.
3. Zeiss Camera (85 mm, super-wide angle).
4. RC10 Camera.
5. Various Radiometers.
6. Special Radar Altimeter (Forest Management Institute).
7. Closed Circuit TV (for Track Recovery).

3.3 CCRS Satellite Program

Under the agreement with NASA, the CCRS will receive data directly from ERTS satellites "on-line". Canada is the only country that has entered into such an agreement with the U.S.

If, for one reason or another, the successors to ERTS-A and B are not suited to Canadian needs, it is recommended that the government seek cooperation from a number of other countries in the financing, design, manufacture and launching of a resource satellite to meet her own needs. If the design of such a satellite were to start in 1972, it would not be ready for launching until 1978.

The CCRS has budgeted for conceptual and preliminary design of a satellite (1972/73, "B" Budget). Concepts and applications will probably come largely from the Canada Advisory Committee on Remote Sensing (CACRS), and hard engineering design willhave to come from the Communications Research Centre (CRC) of the Department of Communications (DOC).

The CCRS proposes to explore the possibility of joint agreements with Japan for the development of a Canada-Japan satellite remote sensing program, as part of its Program of International Cooperation in Remote Sensing.

3.4 CCRS Station-Keeping Stratospheric Balloon Program

Many of the targets needed to be observed by remote sensing methods require almost constant surveillance (sea-ice reconnaissance, forest fires, disaster areas, urban activities, local air pollution of crops, etc.). For these purposes, satellites are inadequate because the frequency of coverage is not sufficiently great. Aircraft are too expensive to operate continuously. The concept of the station-keeping stratospheric balloon, which is not yet fully developed, may offer an exceedingly attractive benefit/cost ratio.

In 1971 a study contract was let to a private consultant to undertake an investigation of the feasibility of a vertically mobile lighter-than-air sensor platform. Funds are budgeted for further development work in FY 1972/73, and CCRS may enter into major design contracts in FY 1973/74 if funds are available.

3.5 CCRS Supporting Research and Technology

The CCRS operates what amounts to a production-distribution system for remotely sensed data and derived information. The system consists of a series of operations which are classified as data acquisition (aircraft, satellite, balloon), data processing (PASS receiver station, ground data handling centre), and data interpretation (by CCRS in-house and by user agencies in-house).

The most unusual feature of this production-distribution system is that it is never static. The equipment and facilities of the production system are being changed dynamically on a month-to-month basis. The rate of obsolescence is very high, and continuous development work is required simply to keep the production system operating at a level of efficiency consistent with the overall objectives of the U.S. and Canadian remote sensing programs. For example, the following major items occur:

(1) Sensor Development Program - continual design and modification of sensors, month-to-month.

(2) Ground Readout Station - redesign of antenna and related equipment to accommodate post-ERTS transmission frequency (8 GH_z rather than 2.2 GH_z), and relocation from Prince Albert to Churchill to obtain broader earth coverage.

(3) Ground Data Handling Centre - the central processor of the computer facility has an economic life of about 3 years, new peripheral output devices are appearing month-to-month, and special-purpose modifications are frequently required.

(4) National Air Photo Library - the efficient production and distribution of output imagery necessitates the development of new equipment and methods.

In addition to the constant development work that is required to keep the production-distribution system updated and working efficiently and economically, longer-range research and development work is required to realize the full potential benefits of remote sensing (see Section 5.1). Both in-house and contract R & D projects are necessary (with a 20% : 80% split between in-house and contract research budgets). This research is carried out chiefly under the following CCRS programs:

(1) Sensor Development Program.
(2) Research on Automated Methods of Interpretation and Handling.
(3) Canadian Resource Satellite Development.
(4) Station-Keeping Stratospheric Balloon.

This longer-range research is necessary for the continuing vitality of CCRS.

4. BENEFIT-COST ANALYSIS FOR THE U.S. EARTH RESOURCES SURVEY PROGRAM

4.1 Analysis Sources, U.S.A.

Pre-program estimates of costs and benefits for the ERS Program are described in a report entitled "Review and Appraisal: Cost-Benefit Analyses of Earth Resources Survey Satellite Systems" by Interplan Corporation, Santa Barbara, commissioned by NASA (7016R). That report, dated March, 1971, provides a document-by-document review and evaluation of the validity of the following ten major documents concerned with cost-benefit analysis of parts of the ERS Program:

	Document Titles, Authors, Clients	Abbreviation
1.	Stanford Research Institute (SRI) Project M-5465, September, 1965 "Priority Analysis of Manned Orbital Research Applications", for Douglas Aircraft Co., MSSD	SRI
2.	International Business Machines, Federal Systems Division, NASw-1215, February 1966 "Orbiting Research Laboratories (ORL) Experiment Program", for NASA	IBM
3.	Cornell University, The Center for Aerial Photographic Studies, December 1967, "Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest, and Range Resources", for NASA/USDA	Corn.
4.	Westinghouse, Defense and Space Center, 7145A2, Dec. 1967 (Final Summary Report February 1968) "EROS Applications Benefit Analysis", for USDI	West.
5.	Planning Research Corporation, PRC R-1218, January 1968, "A Study of the Economic Benefits and Implications of Space Station Operations", for NASA	PRC
6.	General Electric Co., Missile and Space Division, March, 1968, "Final Report on the Space/Oceanographic Study", for National Council on Marine Resources and Engineering Development	GE
7.	Mathematica, GLM, September, 1968, "Cost Benefit Study of the Earth Resources Observation Satellite System: Grazing Land Management", for RCA, AED	Math.
8.	Mathematica, ECM, June, 1969, "Cost Benefit Study of the Earth Resources Observation Satellite System: Estuarine and Coastal Management", for RCA, AED	Math.

Document Titles, Authors, Clients	Abbreviation
9. Planning Research Corporation, PRC R-1224, November, 1969, "A Systems Analysis of Applications of Earth Orbital Space Technology to Selected Cases in Water Management and Agriculture", for NASA/Bureau of the Budget	PRC
10. Summer Study on Space Applications, National Academy of Sciences, National Research Council, January, 1969, "Useful Applications of Earth-Oriented Satellites", for NASA.	NAS

Of these documents, only in 5, 6 and 9 were both system costs and benefits analyzed in sufficient detail for the studies to be considered system cost/benefit studies. The others dealt with subsystems or with benefits alone. Documents 3 and 10 were excluded from the Interplan analysis chiefly because the documentation either did not identify the sensor platforms or was related to scientific disciplines rather than fields of application. Documents 5, 6 and 9 were the only ones that postulated operational time-frames for the applications studied. Documents 4, 5 and 9 were judged by Interplan to be of very high quality.

The documents varied in their quality, but the better ones defined the phenomena to be observed, the spectral bands to be used in sensing, the mode of sensing, the resolution and the frequency of observation.

4.2 Satellite System Costs, U.S.A.

The Interplan summary of four independent systems studies indicates that, in spite of differences in the kind, complexity, and program size of the seven satellite systems studied, the estimated system costs per satellite-year (exclusive of user costs) ranged from \$20 million to \$50 million. ("System" includes ground data facilities.)

4.3 Potential Satellite System Benefits, U.S.A.

Of the several hundred applications cited in the ten studies reviewed by Interplan, benefit estimates for 85 applications from eight studies were supported by sufficient discussion and documentation to be evaluated and compared. Each of the applications was placed in one of three classes depending on whether the proposed earth observations would yield

(1) the same information as now being used,
(2) better information than now being used, or
(3) new kinds of information.

In each information class, applications were grouped according to whether they required (a) mapping of static phenomena, or (b) monitoring of dynamic phenomena.

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

The benefit estimates that were considered valid order-of-magnitude estimates totalled $1.4 billion to be realized annually by the U.S. from implementation of 43 non-overlapping applications. The distribution of potential benefits ($ million per annum), across the three information classes and two application types, judged valid by Interplan, were as follows:

TYPE OF APPLICATION	CLASS OF INFORMATION SAME	BETTER	NEW	TOTALS
Mapping static phenomena	27	135	-	162
Monitoring dynamic phenomena	27	987	179	1,193
TOTALS	54	1,122	179	1,355

Tables 1, 2, 3, 4, 5 and 6 at the end of this paper show the breakdown of applications by classes, validity, and study agency.

Five of the 43 non-overlapping applications accounted for one billion dollars of the total estimated benefits which were considered valid. These applications and the U.S. estimated benefits were:

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

Total U.S. annual benefits of 5 applications.......$1,058 million

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

4.4 Value of Studies in Directing R & D Activities

The scope of the studies reviewed by Interplan was limited. The estimated benefits were evidently potential benefits, which could be realized only if appropriate technology were to be developed. According to Interplan, "Since the scope of many of the studies was limited, the benefit estimates made for most of the applications were not supported by a definition of the chain of informational requirements which link the user benefits to technological developments. Therefore, integration of the benefit estimates for use in R & D planning is not presently possible....." Interplan concluded that "the R & D manager should have (1) a knowledge of what applications are desired by the real world of users, (2) an estimate of the economic benefits expected from these applications, and (3) a definition of the technological developments which are required for each of the applications and their cost and related time-frames.... Thus, a priority ranking based on the economic value of technological developments (as opposed to a priority ranking of the applications) could be evolved which could be used in conjunction with development costs, time-frames, and other noneconomic criteria to optimize the effectiveness of an R & D program."

Interplan made this judgment: "In view of the accomplishments of the past studies, no further cost-benefit studies on systems of applications are recommended at the prefeasibility level of development. However, work to develop an R & D decision model for use in planning ERS R & D activities is suggested and defined. This model would integrate (at the ERS system level) the findings of past and supplementary studies on benefits, costs and technologies required by all major applications studied". In other words, further cost-benefit studies should be related directly to specific technological developments (e.g., new sensors, new interpretation methods).

5. BENEFIT/COST ANALYSIS FOR THE CCRS

This section deals with (1) CCRS activities related to the National Policy, (2) assumptions, (3) potential benefits, (4) the time-frame for the stream of future benefits, (5) costs, (6) benefit/cost analysis under alternative strategies, and (7) non-quantified benefits and spin-offs.

5.1 Remote Sensing Related to Canada's National Policy

Based on published statements of the federal government, Canada's National Policy seeks to:

(1) safeguard sovereignty and independence,
(2) foster economic growth,
(3) ensure a harmonious natural environment,
(4) enhance the quality of life,
(5) promote social justice, and
(6) work for peace and security.

The remote sensing activities of the CCRS are designed to contribute directly to these six themes of national policy.

The CCRS seeks to contribute to the safeguarding of sovereignty and independence by providing technology, methods and organization to help develop and maintain central control of remotely sensed data for public use. This includes:

(a) maintaining agreements with NASA and other U.S. national space agencies for joint activities and Canadian participation in the control and distribution of data acquired by NASA satellites,
(b) promoting international agreements and cooperation in remote sensing, and
(c) in cooperation with other government agencies, developing and maintaining central facilities for data acquisition, data processing, data storage, data interpretation and distribution.

The benefits of the CCRS contribution to this theme of national policy cannot be readily measured in quantitative economic terms.

The CCRS seeks to contribute to the national policy theme of fostering economic growth by:

(a) promoting research and development and the diffusion of a new remote sensing technology in Canada, so that the nation will not become dependent on other countries for the growth of this new technology and related manpower skills, and
(b) satisfying the growing needs of Canadian resource management and energy management agencies by producing and distributing remotely sensed data, derived information and related consultant services in a centrally organized, timely and effective manner.

Fostering economic growth is primarily a matter of developing the Canadian economy. This theme embraces a wide range of economic, commercial and financial objectives in many fields. Remote sensing activities may generate economic benefits related to mineral exploration, expediting petroleum exploration, land use surveys, oceanographic surveys, ship navigation, monitoring sea ice and other natural hazards, flood control, agricultural crop inventories for marketing agency control, crop disease control, irrigation, wildlife management, forest management, ground transportation, hydro-electric power generation, major construction projects, outdoor recreation, and a variety of other resource management applications.

The CCRS seeks to contribute to the national policy theme of ensuring a harmonious natural environment by:

(a) satisfying the growing needs of environmental control agencies for remotely sensed data, derived information and related consultant services,and

(b) developing sensing devices and monitoring methods for measuring air, water and land pollution, on a national and international basis.

This theme embraces a wide range of governmental monitoring and environmental control activities having major legal implications. Remote sensing may generate tangible economic benefits and intangible benefits related to national aesthetics, quality of life, public health and social developments which are affected by environmental factors such as air pollution, water pollution, land pollution and degradation, traffic congestion, and crowding.

The CCRS seeks to contribute to the national policy theme of enhancing the quality of life by offering its remote sensing services to governmental agencies involved in resource and energy management and environmental control.

There seems to be no direct connection between the activities of CCRS and the national policy themes of promoting social justice and working for peace and security. However, the Centre's activities in developing and maintaining central control of remotely sensed data for public use, on the equitable basis that it is readily accessible to all possible users, tends to contribute indirectly to these national policies. Remote sensing will be helpful to the deployment of Canada's available resources - money, manpower, ideas and expertise, as well as natural resources - to the best advantage, so that Canada's impact on international relations and world affairs generally may be greater.

5.2 Assumptions

No specific studies of the benefits and costs of Canadian applications of remote sensing have been made. However, it is reasonable to assume that the order-of-magnitude of some of the Canadian potential benefits can be approximated by appropriate scaling of comparable U.S. potential benefits. The assumption consists of the selection of a 1:10 ratio (Canadian benefits/U.S. benefits), and is, of course, open to question. It simply reflects the approximate ratio of population.

It is also assumed that Interplan's evaluation of ten other major benefit/cost studies is generally acceptable as an initial basis for discussion of benefits and costs, and that at least some of the items in some of those reports are generally acceptable. The Interplan evaluations seem conservative.

It is also assumed that the estimated benefits are net, after taking account of incremental costs and savings of user agencies, related to interpretation, etc. In fact, many of the benefits estimated in the 10 reports evaluated by Interplan were cost savings related to user surveys, data gathering and decision processes (particularly in the "same" and "better" information classes).

It is also assumed that Canadian potential benefits of U.S. remote sensing activities would not be realized without the intervention of the CCRS. This assumption is open to questionning because some Canadian agencies would probably seek to obtain data and imagery directly from NASA or other U.S. agencies if the CCRS did not exist. However, it is believed that the rate of adoption of remote sensing technology and methods would be very slow in Canada relative to the U.S. without the research and development, promotional and educational activities of the CCRS. Potentially large incremental benefits of remote sensing in Canada are therefore attributed to the incremental activities of the CCRS.

It is also assumed that the timing of the flow of future benefits will depend on the levels of sustained activities of the CCRS. If the CCRS activity levels are increased in the early years, the potential benefits will be achieved earlier in time. There are limitations, of course, on the rates of adoption of innovations. But Canadian experts in the field of remote sensing generally agree with the idea that benefits can be achieved earlier, particularly if greater promotional and educational efforts are made concerning data interpretation methods.

5.3 Potential Benefits

The potential benefits of CCRS and related remote sensing activities in Canada are estimated to be 1/10 of $1.4 billion, or $140 million per year, based on the estimates of U.S. potential benefits shown in Tables 1 through 6.

It should be noted that this estimate is based on only a subset of possible applications - the ones that were specifically documented in eight of the ten major U.S. studies mentioned earlier, then judged by Interplan to be "valid", then selected to be indicative of benefits in Canada. It does not include, for example, applications which were judged to be invalid in the U.S. for a variety of reasons, but which might be valid in Canada. It does not include possible applications in the "new information" class, which were overlooked in the ten U.S. studies but are known to be potentially beneficial in Canada (e.g., ice thickness monitoring in the St. Lawrence Seaway and coastal waters).

The figure of $140 million per year seems to be a plausible middle estimate of potential Canadian benefits, based on extrapolation of admittedly incomplete U.S. estimates. A figure of $250 million per year would be optimistic, while $25 million per year would be pessimistic. However, a range from $25 to $250 million per year seems to reflect the uncertainties involved.

Expert testimony can be obtained from a variety of sources to support the existence of potential benefits. For example, the Chairman of the Surveys and Mapping Committee of the Canadian Petroleum Association has written to the National Advisory Committee on Surveys and Mapping as follows:

> "In order to effectively preserve our ecology in many parts of northern Canada it has become extremely important to have 'real time' data on existing conditions. A dynamic mode of data retrieval would make it possible to utilize existing trails, airstrips, clearings, seismic lines, and installations for many geophysical operations. Published maps are often found inadequate for these purposes since they are normally based on aerial photographs which are ten years old. In addition, the slow delivery of contact aerial photo prints which normally takes from 5 to 6 weeks provides little value during the seismic field data acquisition periods.
>
> "We therefore urge that the National Advisory Committee on Surveys and Mapping investigate the feasibility of launching a low flying (200 miles high) artificial satellite capable of mapping the earth semi-annually. In this regard, we would further ask that strong consideration be given towards the implementation of a retrieval centre which could make the data available to the user shortly after acquisition."*

The needs expressed in this letter can be met at least partly by the activities of the Canada Centre for Remote Sensing. The potential benefits to the petroleum industry are evident.

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* Private communication, CCRS Project Files

5.4 Time Frame for Stream of Future Benefits

The report on "Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest and Range Resources", by the Centre for Aerial Photographic Studies, Cornell University, December, 1967 (for NASA) indicated that it would take time - at least to 1975 - to develop sensors and interpretation methods to realize full potential benefits for applications of remote sensing in the "same" and "better" information classes.

It is estimated that the full potential benefits for Canadian applications may not be achieved in Canada until as late as FY 1986/87, given the present level of sensor and interpretation development in Canada. Even this would depend on CCRS sustaining a moderate budget growth to allow for normal technological developments and renewals.

However, it is estimated that the full potential benefits could be reached in Canada as early as 1976/77, given an accelerated rate of sensor and interpretation development in the formative years FY 1973/74 through 75/76. Without such accelerated research and development at home, at an early date, Canada would probably have to be satisfied to import technology at a later date and to learn to use what becomes available. The time-lags for the diffusion of a new technology and the learning processes of users could be reduced by perhaps fifteen years under an accelerated domestic research and development strategy.

To facilitate subsequent benefit-cost analyses related to alternative research and development and promotional strategies, the following postulates are made:

(1) The stream of Canadian benefits starts at a rate of zero at the beginning of FY 1972/73 and increases approximately linearly to the full potential rate of x million dollars per annum in some target year. Thereafter the rate remains approximately constant at x million per annum until FY 1991/92. The planning time-frame is 20 years.

(2) The stream of benefits depends on the stream of research and development expenditures and the promotional activities of the CCRS. Thus the target year for achieving the full potential rate of benefits can be moved forward by increasing expenditures on the appropriate activities.

For example, if the target year is 1976/77, and the full potential rate of benefits is $250 million per year, the following stream of annual benefits is assumed ($ million):

72/73	73/74	74/75	75/76	76/77	77/78	....	91/92
50	100	150	200	250	250		250

The corresponding present value, discounting at 10% for 20 years, is about $1.6 billion.*

Using the above postulates, any 20-year stream of annual benefits, from 1972/73 through 1991/92, can be discounted to a present value to facilitate the comparison of alternatives. Figure 2 gives approximate present values corresponding to various potential rates of benefits and various target years.

5.5 CCRS Incremental Costs

Under the agreement with NASA, data from the ERTS satellites will be freely available to the Canadian ground receiver. The incremental costs to Canada for the CCRS system of data acquisition, data handling and data interpretation are estimated to be about $6.2 million per year (at FY 1972/73 level). This is inclusive of the airborne remote sensing and satellite remote sensing programs, which are integrated for both research and development purposes and production-distribution purposes. But it is exclusive of user costs, which are generally accounted for in the estimates of cost savings included in the benefit estimates.

The following analysis deals with various cases based on various CCRS alternative budgeting strategies.

In all cases, the budget starts at $6.2 million for FY 1972/73, jumps to Y million in FY 1973/74, and then increases at about 4 percent per annum. Using this postulate, the present values of future budgeted costs of CCRS would be approximately as follows (discounting at 10 percent per annum over a 20-year planning interval):

Strategy	1973/74 Budget Cost (Y)	Approximate Present Value of Future Costs
A	$ 6.5 million	$ 75 million
B	10.0	115
C	12.0	140

---

* Let $B_1, B_2, \ldots, B_{20}$ be annual benefits. Let i be the interest rate. The present value P.B. is given by

$$P.B. = \frac{B_1}{(1+i)} + \frac{B_2}{(1+i)^2} + \frac{B_3}{(1+i)^3} + \ldots + \frac{B_{20}}{(1+i)^{20}}$$

$$P.B. = \sum_{k=1}^{20} B_K / (1+i)^k$$

5.6 Benefit-Cost Analysis for CCRS

The following analysis deals with various alternative cases, based on the postulated flows of benefits and costs described in 5.4 and 5.5.

CASE 1 - PESSIMISTIC: The full potential benefits in this case are assumed to be only $25 million per annum. The benefit/cost ratios corresponding to budget strategies A, B and C, and to various target years for realizing the full potential benefits, are shown in Figure 3.

CASE 2 - MIDDLE ESTIMATE: The full potential benfits in this case are assumed to be $140 million per annum (the extrapolation of estimated U.S. benefits). The benefit/cost ratios corresponding to budget categories A, B and C, and to various target years, are shown in Figure 4.

CASE 3 - OPTIMISTIC ESTIMATE: The full potential benefits in this case are assumed to be $250 million per annum. The benefit/cost ratios corresponding to budget categories A, B and C, and to various target years, are shown in Figure 5.

It is not possible to predict the flow of benefits resulting from any particular budget strategy. However, by varying parameters it is possible to examine the implications of various assumptions.

Given the budget cost A, it seems unlikely that the full potential benefits would be realized until about 1986/87. In this case, the following results are calculated (in $ millions):

	Pessimistic	Middle	Optimistic
1973-74 Budget Level	6.5	6.5	6.5
Present Value of Costs	75	75	75
1986-87 Target Year Benefits	25	140	250
Present Value of Gross Benefits	90	500	900
Present Value of Net Benefits	15	425	825
Benefit/Cost Ratios	1:1	7:1	12:1

Given the budget cost B, it seems likely that the full potential benefits could be realized by 1981-82 (five years earlier than with budget cost A). The following results are calculated (in $ millions);

	Pessimistic	Middle	Optimistic
1973-74 Budget Level	10:0	10:0	10:0
Present Value of Costs	115	115	115
1981-82 Target Year Benefits	25	140	250
Present Value of Gross Benefits	125	700	1,250
Present Value of Net Benefits	10	585	1,135
Benefit/Cost Ratios	1:1	6:1	11:1

Given the budget cost C, it seems likely that the full potential benefits could be realized by 1976-77 (five years earlier than with budget cost B). The following results are calculated (in $ millions):

	Pessimistic	Middle	Optimistic
1973-74 Budget Level	12.0	12.0	12.0
Present Value of Costs	140	140	140
1976-77 Target Year Benefits	25	140	250
Present Value of Gross Benefits	160	900	1,600
Present Value of Net Benefits	20	760	1,460
Benefit/Cost Ratios	1:1	6:1	11:1

If these assumptions are deemed to be plausible, it appears that the larger budget levels are justified since they generate benefits earlier and thus increase the present values of benefits.

5.6 Non-Quantified Benefits and Spin-Offs

Many potential applications have not been identified and their corresponding benefits have not been estimated, particularly in the "new" information class. The benefits related to the MORL manned satellites, for example, seem to be greatly underestimated. The entire field of environmental pollution seems to have been overlooked or underestimated in the U.S. studies cited (perhaps because the studies were carried out about 1966-68, before pollution became a hot political issue).

Spinoff benefits to Canadian industries involved in the development of new remote sensing technology have not been taken into account in the quantitative analysis. The CCRS is actively engaged in contract developments which could lead to the spawning of a unique Canadian capability in science, engineering and manufacturing of fine instruments.

All things considered, the quantitative estimates of benefits may be conservative.

6. SELECTED REFERENCES

1. NASA, Third Annual Earth Resources Review (MS-03742), NASA Spacecraft Centre, Houston Texas, December, 1970. (Three volumes on Geology and Geography; Agriculture, Forestry and Sensor Studies; Hydrology and Oceanography.)

2. CCRS, Resource Satellites and Remote Airborne Sensing for Canada, Reports No. 1 to 14, Canada Centre for Remote Sensing, Ottawa, Ontario, 1971-72. (Fourteen reports of working groups, titled as follows):

    1. Report of the Program Planning Office
    2. Agriculture and Geography
    3. Atmospheric Constituents
    4. Cartography and Photogrammetry
    5. Forestry and Wildlands
    6. Geology
    7. Ice Reconnaissance and Glaciology
    8. Water Resources
    9. Satellite and Ground Station Engineering
    10. Sensors
    11. Airborne Program
    12. Data Handling
    13. Observables and Parameters of Remote Sensing
    14. Remote-Sensing Devices.

3. NASA, A Survey of Space Applications, NASA SP-142, 1967.

4. LISTING OF BENEFIT/COST DOCUMENTS IN SECTION 4.1.

TABLE 1 - POTENTIAL BENEFITS, MILLION DOLLARS PER YEAR, FOR APPLICATIONS YIELDING "SAME" INFORMATION AS NOW EXISTS IN MAPPING (STATIC PHENOMENA), U.S.A.

Code No.	Description of Application	U.S. Annual Benefits	Satell. Prog.	Judged Validity*	Study Agency
1	U.S. mineral exploration	12.5	EROS	V	West.
2	U.S. Continental shelf	2.0	EROS	V	West.
3	U.S. regional geology	0.2	EROS	V	West.
4	U.S. small scale and metallogenic mapping	0.3	EROS	V	West.
5	Brazil geologic mapping	1.3	EROS	V	West.
6	Military geologic mapping	0.5	EROS	V	West.
7	Topographic mapping	0.5	EROS	V	West.
8	Land use mapping	5.6	EROS	V	West.
9	Cadastral surveys	0.3	EROS	V	West.
10	Geographic, general	1.6	EROS	V	West.
11	Hydrologic	2.1	EROS	V	West.
12	Selected regional maps, small-, medium-, and large-scale	3.5	MORL	I	IBM
13	Land Survey	1.0	MORL	I	IBM
14	Site, facilities, and population surveys	5.5	MORL	I	IBM
15	Changes in settlements	1.0	MORL	I	SRI
16	Oil and mineral exploration	1.0	MORL	I	IBM

SUMMARY

11 valid EROS mapping applications with $26.9 million annual U.S. benefits.

5 invalid mapping applications.

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* V means "valid" and I means "Invalid", as judged by Interplan.

TABLE 2 - POTENTIAL BENEFITS, MILLION DOLLARS PER YEAR, FOR APPLICATIONS YIELDING "SAME" INFORMATION AS NOW EXISTS IN MONITORING (DYNAMIC PHENOMENA), U.S.A.

Code No.	Description of Application	U.S. Annual Benefits	Satell. Prog.	Judged Validity	Study Agency
17	Croplocation-identification	1.0	MORL	V	IBM
18	Crop vigour and yield	20.0	MORL	V	IBM
19	Waterfowl breeding	0.2	EROS	V	West.
20	Wetlands, Columbia and Colorado River Basins	1.1	EROS	V	West.
21	Ocean surface phenomena	4.0	MORL	V	SRI
22	Coastal study and development	1.0	MORL	V	SRI
23	Urban air pollution	0.6	EROS	I	PRC
24	Water pollution	6.6	EROS	I	PRC
25	Discover ecological relationships	1.0	MORL	I	IBM
26	Earthquake prediction	75.0	MORL	I	IBM
27	Volcanic eruption predict.	1.0	MORL	I	IBM
28	Flood warning	20.0	MORL	I	IBM
29	Snow and ice prediction	15.0	MORL	I	IBM
30	Soil conditions survey	40.0	MORL	I	IBM
31	Arid area survey	4.0	MORL	I	IBM
32	Pollution in rivers, streams	15.0	MORL	I	IBM
33	Fisheries and fish location	100.0	MORL	I	IBM
34	Navigation hazards	75.0	MORL	I	IBM
35	Industrial disposal monitoring	60.0	MORL	I	IBM
36	Tidal wave warning	40.0	MORL	I	IBM
37	Ocean effects on beaches	50.0	MORL	I	IBM
38	Disaster damage assessment	25.0	MORL	I	IBM

SUMMARY

2 valid EROS monitoring applications with $1.3 million annual U.S. benefits.

4 valid MORL monitoring applications with $26.0 million annual U.S. benefits.

16 invalid monitoring applications.

TABLE 3 - POTENTIAL BENEFITS, MILLION DOLLARS PER YEAR, FOR APPLICATIONS YIELDING "BETTER" INFORMATION THAN NOW EXISTS IN MAPPING (STATIC PHENOMENA), U.S.A.

Code No.	Description of Application	U.S. Annual Benefits	Satell. Prog.	Judged Validity	Study Agency
39	Expediting petroleum expl.	125.0*	EROS	V	West.
40	Mineral exam, public lands	0.45	EROS	V	West.
41	Road const. on public lands	0.1	EROS	V	West.
42	Road const. on Indian lands	0.05	EROS	V	West.
43	Avoidance of sea losses	9.0**	EROS	V	PRC
44	Inc. efficiency in oil expl.	3.9	EROS	I	PRC
45	Inc. efficiency in min. expl.	42.0**	EROS	I	PRC
46	Reduce road const. costs	114.0	EROS	I	PRC
47	Estuarine survey	0.6	EROS	I	Math
48	Catalogue soil fertility and environmental char.	100.0	MORL	I	SRI
49	Grazing land conditions	0.1	EROS	I	Math
50	Location and Identification of forest resources	3.0	MORL	I	IBM
51	Forest vigour and yield	300.0	MORL	I	IBM
52	Land boundary survey for tax assessment	8.0**	EROS	I	PRC

SUMMARY

5 valid EROS mapping applications with $134.6 million annual U.S. benefits***

9 invalid mapping application

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* Includes Canada with U.S.A.

** World benefit

*** Includes about $15 million of petroleum exploration benefits for exploration in Canada, and about $7 million of sea-loss-avoidance benefits in U.S. world sea traffic.

TABLE 4 - POTENTIAL BENEFITS, MILLION DOLLARS PER YEAR, FOR APPLICATION YIELDING "BETTER" INFORMATION THAN NOW EXISTS IN MONITORING (DYNAMIC PHENOMENA), U.S.A.

Code No.	Description of Application	U.S. Annual Benefits	Satell. Prog.	Judged Validity	Study Agency
53	Minimize flood damage	305.5	EROS	V	PRC
54	Recreation reservoir control and improved navigation	6.5	EROS	V	PRC
55	Increased hydropower	94.1	EROS	V	(PRC & (West
56	Improvements in irrigation, navigation, cloud control	373.5**	EROS	I	PRC
57	Irrigation forecasting				
	Pacific northwest	44.8*	EROS	V	PRC
	U.S., 33 mill. acres	282.0	EROS	V	PRC
58	Detection of faulty irrig. and reclam. practices (1.6 mill. acres)	12.0*	EROS	V	West.
59	Detection of losses of irrig. water, runoff (40 mill. acres)	319.0*	EROS	V	West.
60	National park operations	8.0	EROS	V	West.
61	State recreation develop.	17.0	EROS	V	West.
62	State recreation ops.	15.0	EROS	V	West.
63	Soil and watershed conserv.	1.5	EROS	V	West.
64	Indian land management	0.2	EROS	V	West.
65	Forest fire detection	15.0	EROS	V	PRC
66	Forest fire damage assess.	3.0*	MORL	V	IBM
67	Range management				
	Bureau of Land Manag.	0.5*	EROS	V	West.
	Public and private land	1.8	EROS	V	Math.
68	Wheat rust detection	146.3	EROS	V	PRC
69	Small grain fungi stresses	84.9	EROS	V	PRC
70	Forest insect infestation loss reduction	9.0	EROS	V	PRC

continued.......

TABLE 4 (continued)

Code No.	Description of Application	U.S. Annual Benefits	Satell. Prog.	Judged Validity	Study Agency
71	Reduction of all crop disease and infestation	4,533.0	EROS	I	PRC
72	Location mosquito breeding	2,906.0**	EROS	I	PRC
73	Search and rescue	38.0**	EROS	I	PRC
74	Control of solid-waste related diseases	189.0**	EROS	I	PRC
75	Detecting epidemic diseases in animals	1,350.0**	EROS	I	PRC

SUMMARY

14 valid EROS monitoring applications with $986.8 million annual U.S. benefits.

9 invalid monitoring applications.

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* Benefits marked with a single asterisk overlap with other estimates and are not added in the total. They are shown because they are considered valid, though overlapping.

** Benefits to many countries, including U.S.A.

TABLE 5 - POTENTIAL BENEFITS, MILLION DOLLARS PER YEAR, FOR APPLICATIONS YIELDING "NEW" INFORMATION IN MONITORING (DYNAMIC PHENOMENA), U.S.A.

Code No.	Description of Application	U.S. Annual Benefits	Satell. Prog.	Judged Validity	Study Agency
76	Predictions of southeast Asian rice yield	45.3	EROS	V	PRC
77	World wheat production forecasts***				
	- for U.S. commodity Credit Corp and farmer cost reduction	113.7	EROS	V	PRC
	- for U.S. Agribusiness	0.2	EROS	I	PRC
	- for producer options	78.0	EROS	I	PRC
78	Ship routing economies	8.0	MORL	V	SRI
79	Increased U.S. Tuna Catch	12.0	EROS	V	GE
80	Monitoring fishing and international agreements	74.0	EROS	I	GE
81	Increase catch of Albacore Tuna	388.0**	EROS	I	PRC
82	Increase catch of all fish	3,880.0**	EROS	I	PRC
83	Crop predictions	11,300.0**	EROS	I	PRC
84	Prediction food-grain crops	22.0	EROS	I	PRC
85	Evaporation mapping	400.0	MORL	I	IBM

SUMMARY

3 valid EROS monitoring applications with $171.0 million annual U.S. benefits.

1 valid MORL monitoring application with $8.0 million annual U.S. benefits.

6 invalid applications.

** World benefit.

*** Assumed to be made available to other countries, including Canada.

TABLE 6 - POTENTIAL BENEFITS, MILLION DOLLARS PER YEAR, SUMMARY OF "VALID" ANNUAL U.S. BENEFITS FROM TABLES 1, 2, 3, 4, 5.

GROSS ANNUAL BENEFITS, MILLION $	CLASS OF INFORMATION Same	Better	New	ROW TOTALS
EROS mapping	26.9	134.6	-	161.5
EROS monitoring	1.3	986.8	171.0	1,159.1
MORL monitoring	26.0	-	8.0	34.0
COLUMN TOTALS	54.2	1,121.4	179.0	1,354.6

NUMBER VALID APPLICATIONS	CLASS OF INFORMATION Same	Better	New	ROW TOTALS
EROS mapping	11	5	-	16
EROS monitoring	2	13	3	18
MORL monitoring	4	-	4	8
COLUMN TOTALS	17	18	7	42

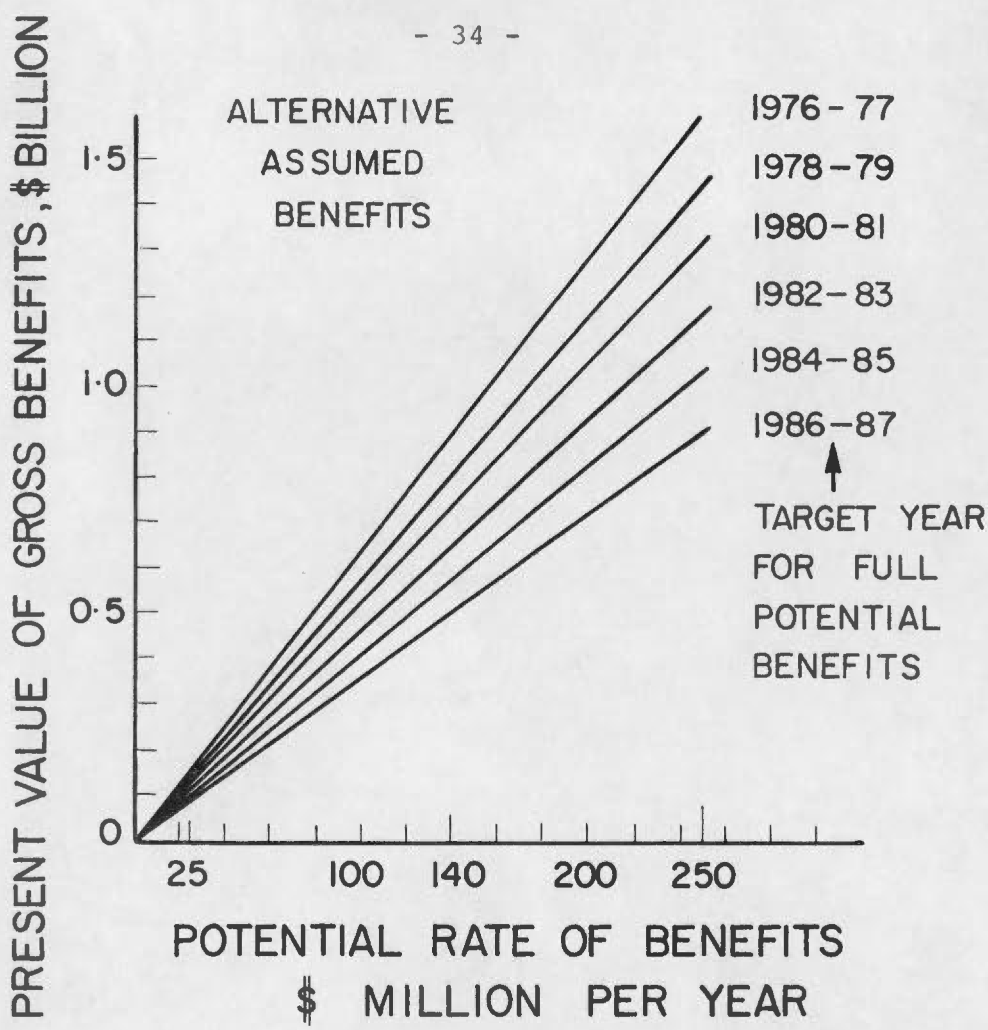

Figure 2

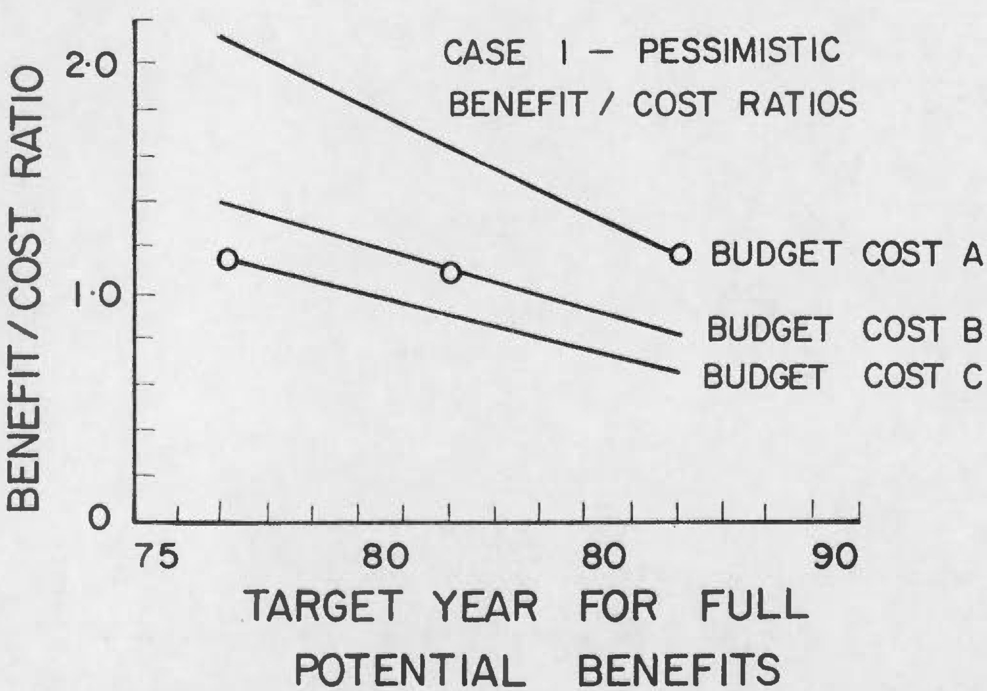

Figure 3

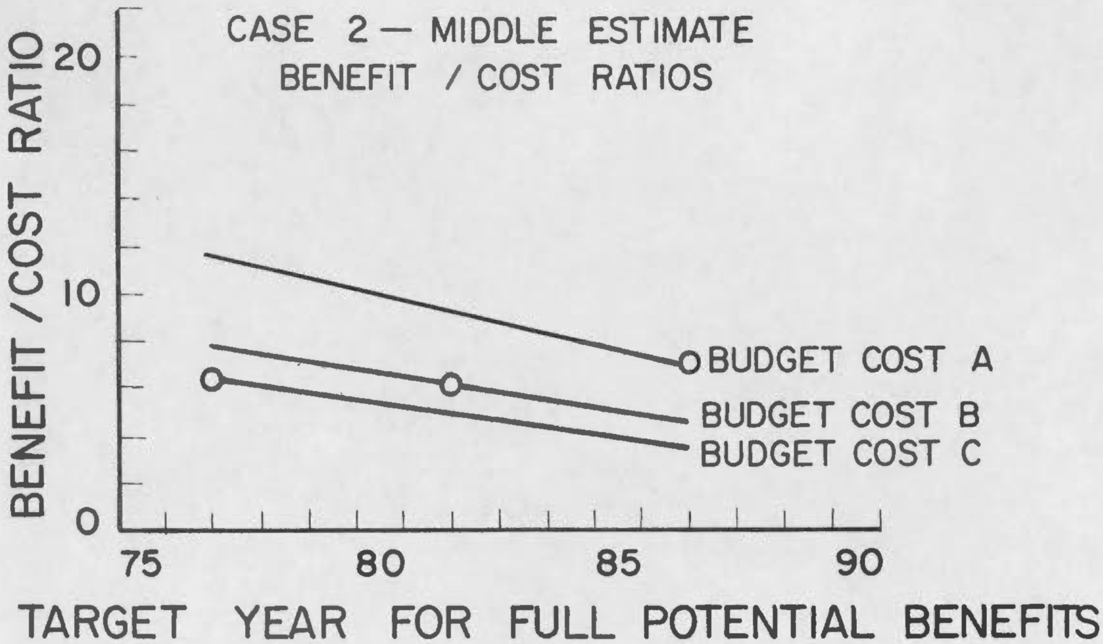

Figure 4

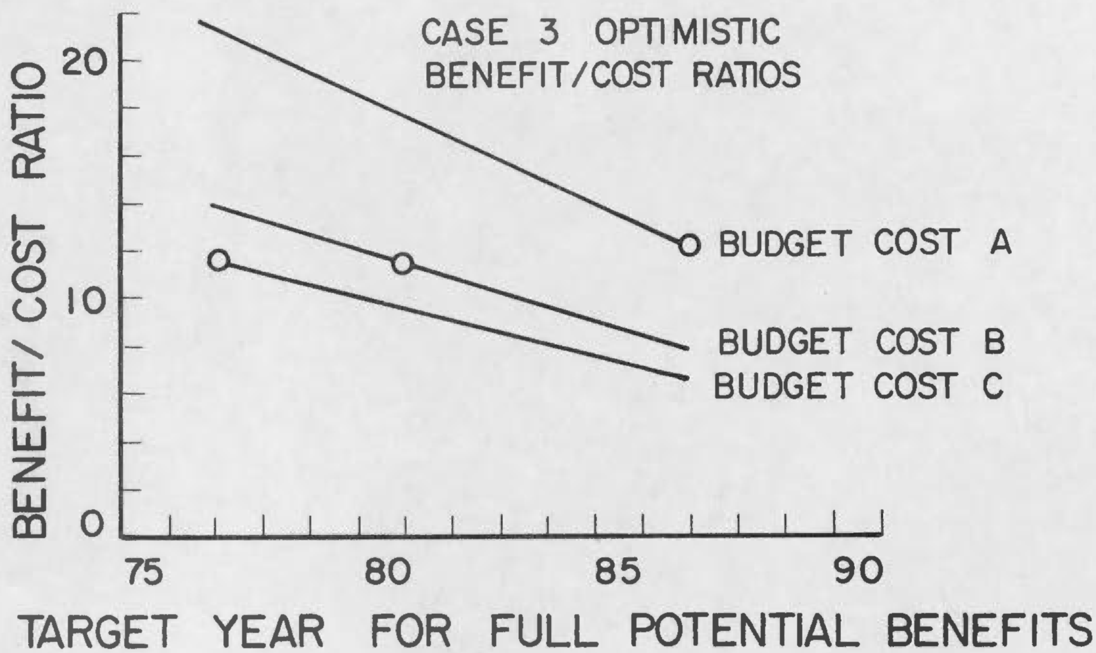

Figure 5

610
572-8712