Radarsat Economic Review and Assessment

Executive Summary

Department of Energy, Mines and Resources
Government of Canada

April 1986

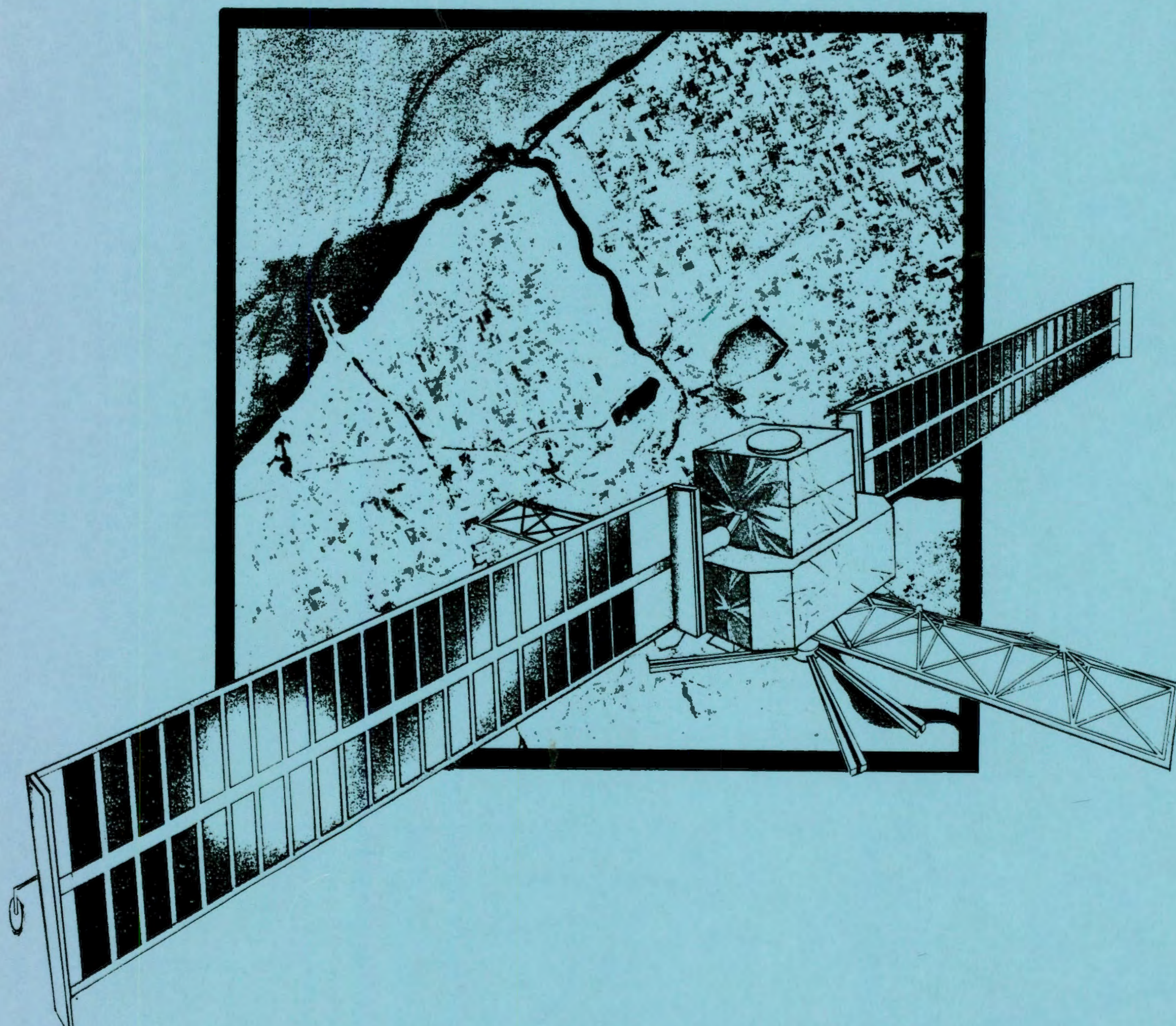

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TABLE OF CONTENTS

1. OBJECTIVES AND SCOPE OF THE STUDY

In spite of an involvement from the Canadian government in remote sensing since 1969, Canada must still rely on foreign satellites to obtain remotely sensed data information of its own territory. Radarsat will be the first Canadian remote sensing satellite. It will be launched in 1991 in order to provide valuable data for Canadian resource management and energy development needs.

A 1983 study on the economic advantages of Radarsat, prepared by Price Waterhouse and Associates[1], has concluded positively on the Radarsat program. However, this study was limited in scope and the characteristics of the satellite have significantly changed since 1983. There remained, therefore, a critical need for a more comprehensive study which would sustain and justify the heavy stream of investment of public funds associated with such a program. In 1984, the Government of Canada asked for such a comprehensive study and a reassessment of the overall economic feasibility of the Radarsat program.

Essentially, the objective of the present study was to assess the desirability of the Radarsat program from an economic point of view. Therefore, an attempt has been made to assess the costs associated with the program and to estimate, for each potential area of application, quantifiable benefits arising from the enhanced information provided by Radarsat. A cost-benefit analysis has subsequently been performed. The present study also examines benefits which, although unquantifiable, constitute part of the economic justification of the Radarsat

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(1) Price Waterhouse, "Radarsat Economic Review and Assessment", September, 1983

program. Furthermore, an impact analysis of Radarsat industrial benefits, quantifiable spin-offs, job creation and regional benefits has been conducted. Since market studies of future Radarsat products are not required by the terms of reference, the present study does not present a financial analysis of the Radarsat program but instead demonstrates its overall economic benefits to Canadian society.

2. OVERALL APPROACH

The cost-benefit methodology that has been adopted follows the procedures used by such institutions as the World Bank and the Government of Canada Treasury Board. The economic feasibility of the Radarsat Program is measured, through a cost-benefit analysis, by the following common set of indicators: discounted net present value (NPV), the benefit-cost ratio (B/C ratio) and the internal rate of return (IRR).

The analysis conducted is a "with" and "without" project comparison, which implies that only incremental costs and benefits have been accounted for. The "without project" situation exists now and will continue to exist until the year 2001 if Radarsat is not launched in 1991. The "without project" situation therefore takes into consideration competition from other satellites.

The benefit assessment represents the best effort to arrive at an order of magnitude that is based on empirical justifications. The estimation procedure can be considered, if anything, conservative rather than optimistic. Following the assessment of benefits and costs over the time horizon of the Radarsat Program, a cost-benefit analysis has been performed based on realistic assumptions. Simulations and sensitivity analyses have also been performed to take into consideration the uncertainty that exists in a number of aspects of the Radarsat Program and in factors bearing on a final decision.

3. RADARSAT PROGRAM

Radarsat is a space program currently underway which aims to place a Canadian satellite in an inclined polar orbit by 1991. This remote sensing satellite is to provide data for resource management and energy development needs. The program is being carried out under the auspices of the Department of Energy, Mines and Resources.

The Radarsat satellite will be in a sun-synchronous polar orbit at a nominal altitude of 1004 km with an inclination of 99.49°. The orbital period will be approximately 105 minutes with an ascending mode at 21:44 local time. The initial satellite design lifetime is five (5) years and, with planned in-orbit servicing, this could be extended by an additional three (3) to five (5) years.

Radarsat will have four (4) sensors: synthetic aperture radar (SAR), Radarsat Optical Sensor (ROS), scatterometer (SCAT) and an advanced very high resolution radiometer (AVHRR).

The Radarsat Program will provide timely information to agencies and organizations involved in the management of resources, monitoring of the environment and improving navigation safety.

Geology, forestry, agriculture, hydrology, cartography, fishing, oil and gas and shipping sectors will all benefit from Radarsat applications.

4. RADARSAT COSTS

The overall direct costs to Canada resulting from Radarsat activities include the Radarsat Program costs as well as the incremental costs that users will incur in order to use Radarsat data.

Total costs to Canadians for the period from 1986 to 2001 are expected to be $575 million, consisting of $550 million for program costs and $25 million for cost to users. Program costs have been estimated in 1985 Canadian dollars.

4.1 PROGRAM COSTS

Total incremental costs, after deducting foreign participation of $225 million, are expected to amount to $550 million ([1]). These costs will be disbursed during Phases C/D/E - that is, between the last quarter of 1986 and the end of 2001.

For the purposes of the cost-benefit study, only incremental costs have been taken into consideration since these costs are the best estimate of the Radarsat program's impact on the Canadian economy. ERS-1 and Phase B costs of $78 million have therefore been excluded as these costs have already been incurred or committed to contractors. Ice Information Centre (IIC) costs have also been excluded. The IIC will be operational with or without Radarsat.

([1]) Because SPAR revised costs estimates were to be made available only in November 1986, the analysis had to be performed on the preliminary cost estimates. Preliminary cost estimated were believed to be within 10% of revised costs. This was confirmed by SPAR by November 1985. The total program costs including operating costs was revised at $610 million.

Estimates of direct costs for the Radarsat program have been derived from the RPO's data source. Cost breakdowns such as Canadian/foreign content and labour/material/other were obtained from previous Radarsat studies and discussions with RPO representatives.

Program costs have been estimated in 1985 Canadian dollars and include engineering, manufacturing, procurement expenditures and project administration profits.

4.2 COSTS TO USERS

<u>The total incremental cost to Radarsat data users from 1991 to 2001 will be $25,0 million</u>. This amount comprises: 1) $9,3 million for users that will already have the required facilities (regardless of Radarsat) and who will need to incur minor incremental costs to receive Radarsat data; and 2) $15,8 million for new remote sensing users who will need to purchase and maintain systems to receive Radarsat data.(1)

In order to derive the incremental user cost estimates, it was necessary to determine the unit cost per user (existing and newly created) for receiving and using Radarsat data. The incremental average unit costs for existing remote sensing users are $108,500 for a large system, $41,500 for a medium-size system and $17,000 for a small system. For new users, the average unit cost for a small system would be $525,600 (includes capital and operating costs).

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(1) Totals do not necessarily add due to rounding.

Next, it was necessary to determine the number of new and existing users that Radarsat would attract. Of the total of 453 existing systems, 5 are large sized, 45 are medium sized, and 403 are small sized. All 30 newly created users are expected to purchase and maintain small systems. Total users of Radarsat digital data was estimated to be 483 in Canada.

Finally, unit costs were applied to the projected number of users in order to arrive at estimates for total cost to users.

5. BENEFITS ASSESSMENT

Total economic benefits of Radarsat for all Canadians are expected to reach $1,9 billion (in non-discounted terms) over the 1991 and 2001 period. These benefits include cost savings in alternative data acquisition, cost savigs in operating costs of end-users such as oil and mining companies, increased value-added production activities and valuation of increased forecasting accuracy.

5.1 ICE AND OCEANS ECONOMIC BENEFITS

The unique combination of sensors (SAR, RSCAT, ROS AND AVHRR) comprising Radarsat's payload makes the satellite particularly interesting for both operational and research applications to a variety of ice and oceans activities. The choice of sensors and orbit configuration underline the fact that Radarsat was originally designed primarily for northern applications. This was a reflection of the early 80's optimism for future Arctic offshore oil and gas development and related shipping activities.

The ice and oceans information to be gathered by the Radarsat sensors is to provide direct input into major Canadian ice analyses and marine forecasts prepared by intermediate users such as AES. In some cases the data may be directly accessed by the end-user. The primary sensor, the SAR, will provide data on ice types and ice features such as ridges and icebergs, as well as data on ocean wave spectra. The SAR ice imagery will be integrated into AES Ice Central's ice analysis and forecast system for all ice-infested Canadian waters.

The Radarsat scatterometer will provide wind vector measurements that will be used by AES and CFWS to improve day 1 and 2 marine weather forecasts, which together with the SAR observation of the surface wave field will input into the DND METOC sea state forecasts. AVHRR data on sea-surface temperatures, ocean thermal fronts, warm and cold core rings and regions of upwelling will also be used by DND METOC in the preparation of ocean surface features analyses.

The expected improvements to ice analyses and marine forecasts will provide benefits to those industries that require timely, accurate and complete information on ice and weather conditions in Canadian northern and East Coast waters. Major potential benefactors are the offshore oil and gas industry, fishing industry and general commercial shipping sector. In addition to increasing the safety of offshore drilling operations, fishing and general shipping activities, Radarsat will provide benefits in terms of cost-savings in the current operating expenditures of these three industries.

Total benefits for ice and ocean applications between 1991 and 2001 amounts to $178 million ($61,8 million for weather application and $116,2 million for ice applications).

5.2 AGRICULTURE BENEFITS

Agriculture is an important facet of the Canadian economy as indicated by projected 1985 total farm receipts at $20,2 billion. Wheat is the most important crop for Canadian agriculture, representing $4,0 billion in cash receipts in 1984 and constituting the principal export commodity. In 1985, total agricultural exports were expected to range between $9,5 and $9,7 billion.

Therefore, the importance of agriculture, and more specifically grain exports, is crucial in helping to maintain a good trade balance with Canada's economic partners. This situation, however, could be improved if Canada had access to better intelligence information regarding crop conditions around the world.

Crop forecasts for Canada and its major trading partners are currently conducted by various government agencies, however, forecast errors are frequent and sizeable in nature. Based on present experience, it is assumed that the increased use of remote sensing techniques, and more specifically Radarsat, would significantly reduce the forecast errors thereby leading to potentially large economic benefits for Canadian society. Furthermore, the Canadian controlled Radarsat would provide Canadians an early access to crop-related data and a more timely data compared to foreign satellites.

The assessment of economic benefits has been based on the value of information to be available.

Radarsat imagery could furthermore be utilized as a monitoring tool for crop conditions. The <u>potential benefits</u> can consequently be seen as resulting from <u>better management of re-</u>

sources and increased production. Government departments and agencies, in this sense, could use satellite imagery to assess crop damages due to natural disasters such as floods and droughts in order to give prompt assistance to afflicted farmers. Radarsat benefits for agriculture applications in 1992 have been estimated to be $33,2 million. The total benefits for the period from 1991 to 2001 has been evaluated at $684,3 million. These benefits are conservative since they do not include benefits which could occur from the reduction in forecasting of foreign crop. These later benefits have not been quantified because they were judged to be too speculative.

5.3 GEOLOGY BENEFITS

In mineral and petroleum exploration, advances in remote sensing technology which facilitate more efficient and extensive exploration are likely to produce significant benefits in terms of reductions in exploration costs and increased rates of discovery. Despite the general tendency within the sector to employ more traditional exploration techniques, mining and petroleum exploration activities are sufficiently competitive and involve considerable capital expenditures that there exists a strong economic incentive for individual firms to experiment with new techniques and information systems such as Radarsat.

While aerial photography is currently the most widely used remote sensing tool in geology because of its spatial resolution and decided cost advantages over other systems, Radarsat SAR has the capability of providing enhanced information that is not available with current methods, specifically in areas which are simultaneously heavily forested and geologically complex.

<u>The total potential benefit from Radarsat to the geology sector has been estimated at $62 million to $68 million annually between 1991 and 2001</u> with approximately 55% of the benefit for any given year representing the net present value of earlier discoveries and 45% representing savings in exploration costs. <u>Total benefits for the period 1991 to 2001 have been evaluated at $516,3 million.</u>

5.4 FORESTRY BENEFITS

The current Canadian commitment to increase reforestation is strong and growing. One can predict that after 1990 there will be far more concern than there is today with site evaluation and the use of climatic and phenological data. The benefits that have been estimated for these programs would be highly speculative under present circumstances, but are reasonable for the period after 1990.

Revisions of forest inventory procedures will accompany the move towards intensive management, but abrupt changes are unlikely. Systematic updating of inventories is currently the practice in a minority of provinces, but most have recently made commitments to geographic information systems and major revision of inventory procedures. Large changes will take place in the next few years and Radarsat will have an excellent opportunity to play a significant role in replacing aerial photography with procedures that will come on line during the next ten years.

The growing attention to reforestation, silviculture and inventory will take place in spite of, or perhaps because of, the current depressed state of the Canadian forest industry. The recent decline of the industry has been more than a cyclical phenomenon and its causes include the lack of adequate forest management. This fact has now been realized and has given rise to increasing demands for information about the forest. The economic importance of such information is recognized and this bodes well for the future of resource-oriented satellites such as Radarsat.

The total potential benefits of Radarsat to the forestry sector are therefore estimated at $ 14,7 million annually. There are three main types of benefits that can be anticipated: i) data acquisition cost savings in forest inventory and updating and biophysical surveys (representing a potential annual benefit of $11,7 million); ii) increased survival rates of new plantings of reforestation programs due to more comprehensive site evaluations (representing an increased standing forest value of $1,8 million annually); and iii) construction and maintenance cost savings through better forest road location (representing an annual benefit of $1,2 million). <u>Total benefits for the period 1991 to 2001 have been estimated at $115 million.</u>

The above benefits have been estimated based on three main assumptions: i) the Radarsat Optical Sensor (ROS) is equivalent or better than the Landsat Thematic Mapper (TM); ii) even if the performance of the ROS is equivalent to TM, there are significant benefits of having access to a Canadian rather than a foreign system (ie. product costs); and, iii) in the evaluation of benefits the main approach is to recognize Radarsat benefits in those cases where SAR data is potentially more efficent/useful or where there exists an important link of ROS to SAR.

5.5 OTHER APPLICATION BENEFITS

A systematic search was undertaken to identify other potential applications of Radarsat which would provide quantifiable benefits to Canada. Such benefits would accrue from the sale of Radarsat products and from services provided by Canadian firms.

Three general fields were identified, based on a review of literature, as having potential for applications of remote sensing technology. They were:

1) water resource management;
2) cartography; and,
3) soil moisture determination.

Information needs in each field were studied and specific applications were then evaluated, according to the capabilities of Radarsat and other competitive information gathering systems (eg. satellites, airborne radar, land surveys, etc.)

The capability of Radarsat's SAR sensor to extract data despite inclement weather, particularly cloudiness, gives the proposed satellite a clear advantage over other systems. This advantage will be translated into tangible benefits for Canada in three specific applications:

1) surface runoff forecasts required for the management of hydro-electric power reservoirs;

2) land use mapping, at a scale of 1: 250 000, in countries subject to frequent cloud cover; and,

3) revision of topographic maps (1:250 000) for cloud covered countries.

The potential benefits of other applications such as general topographic and land use mapping, or in the determination of soil moisture will be limited. Other satellites, specifically SPOT and Landsat TM, are technically better suited to map topography and land use in countries where cloudy conditions are less frequent, such as Canada. Radarsat's sensors will not penetrate the soil to sufficient depth to provide quantitative data on soil moisture.

The potential benefit of Radarsat for the most promising applications was estimated at $33.2 million/year (i.e. water resources management, mapping and mapping revisions). Total benefits for the period from 1991 to 2001 for these applications is expected to be $266,7 million ($249,7 million for water resources management, and $17,0 million for mapping). Improved surface runoff forecasts will allow more efficient management of Canadian reservoirs for the production of hydroelectric power, resulting in an estimated annual benefit of $28 million (1991) to $35 million (2000). In order to realize this benefit existing reservoir management models would have to be modified before the proposed satellite is launched to accept Radarsat data. The benefits of Radarsat in land use mapping and in revising topographic maps of cloud covered lands were estimated at $1.2 million and $0.49 million per year, respectively.

5.6 OTHER QUANTIFIABLE BENEFITS

There are other benefits that do not relate to specific applications but are quantifiable benefits that arise from the Radarsat program. These are the cost savings to users and net benefits from foreign sales.

5.6.1 Cost savings to users

These are costs that will no longer be incurred by individuals and organizations involved with remote sensing after Radarsat is implemented. Hence, they are included as benefits since they are savings for the Canadian society.

Total cost savings to users has been estimated at $109,4 million for the 1991-2001 period, consisting of $31,7 million for the substitution to foreign satellites, and $77,7 million for the substitution to airborne acquisition.

5.6.2 Global market

Radarsat will have wide application for foreign users of satellite imagery as well as for Canadian users. The orbit of the satellite will allow for complete global coverage within a period of 16 days, with more frequent coverage provided for the mid-latitudes and the north (3 day sub-cycle). Some of the major potential users of Radarsat will be from application areas such as forestry, geology, cartography, ice (oil and gas, shipping and fishing industries), agriculture, water resources and oceans. Users will require data from varying combinations of Radarsat's four sensors (ie. SAR, ROS, Scatterometer and AVHRR). For example, the SAR sensor is expected to provide useful information on ice characteristics. Geology and forestry users, on the other hand, will find data from both the SAR and the ROS sensors most valuable. Ocean studies will be able to apply data from all four sensors to generate a unique combination of information on sea state.

As a result of global sales and distribution of Radarsat data, opportunities will arise for companies selling Radarsat data-related products and services (ie. equipment, software and services).

Sales by Canadian companies have been evaluated at $334,6 million during the 1991-2001 period. These sales are broken down into $95,5 million in data, $74,6 million in equipment, $31,5 million in software and $133,0 million in services.

Sales in Canada are expected to be $155,9 million while export sales will be $178,7 million (Canadian content of export sales is expected to be $160,1 million).

The social net value added benefits is evaluated at $85,3 million. The social net value added benefits are evaluated from the difference between the Canadian content of exports sales and the social value of production costs.

6. COST-BENEFIT ANALYSIS

The benefits and costs assessed in previous chapters have to be modified in order to reflect the real costs and benefits of the Radarsat program for the Canadian society. Therefore, some corrections had to be performed in order to take into account social distortions (or externalities) prevailing in an imperfect market situation.

6.1 RESULTS OF COST-BENEFIT ANALYSIS

Base Case Scenario

The results of the cost-benefit analysis on the base case (see Table 6.1) indicate, first of all, the Radarsat program to be economically viable as the value of the benefits ($621,9 million) exceed the costs ($338,0 million) producing a positive net cash flow of $283,8 million with a cost-benefit ratio of 1,84. Furthermore, the internal rate of return has been assessed at 21 percent, more than double the standard acceptable rate of return for a capital investment typically considered economically viable from a Canadian standpoint.

The following assumptions were used for the estimation of the base case scenario.

1) Annual market penetrations are:

1991	1992	1993	1994	1995	1996 to 2001
20%	30%	40%	60%	80%	100%

2) In the area of ice and ocean applications, for the base case it is assumed that Radarsat information contributes to 60% of the data that is not present in order to complete the ice information system, and to 20% of the information that is missing in order to have a reliable weather forecast system.

3) The life of the satellite is expected to be 10 years (five years before re-servicing and five years after re-servicing).

Table 6.1

COST-BENEFIT ANALYSIS FOR RADARSAT PROGRAM

BASE CASE

(millions of 1985 dollars)

	COST	BENEFITS	NET CASH FLOW
1985	-	0	-
1986	13,1	0	-13,1
1987	75,7	0	-75,7
1988	76,3	0	-76,3
1989	75,9	0	-75,9
1990	75,8	0	-75,8
1991	38,9	24,4	-14,5
1992	33,1	88,2	55,2
1993	32,9	109,7	76,8
1994	33,1	149,3	116,3
1995	33,0	191,4	158,4
1996	33,1	222,5	189,4
1997	11,7	228,7	217,0
1998	11,7	233,4	221,78
1999	11,6	237,7	226,1
2000	11,7	242,3	230,6
2001	7,9	163,1	155,2
NPV (10%) =	338,0	621,9	283,8
		B/C =	1,84
		IRR =	21%

4) The social discount rate, calculated by G.P. Jenkins[1], is 10%. This rate is widely used by economist in reference to industrial projects financed by public funding in Canada.

5) Risk factor of 20% over the replacement cost of the satellite in case of failure.

6.2 COST-BENEFIT SIMULATIONS

The implementation of a cost-benefit analysis is based upon a comparison of a "with project" case (Radarsat) and a "without project" case (status quo). In order to provide additional information for this analysis, a series of simulations were carried out utilizing the base case scenario. These simulations constitute the sensitivity analysis of the project, and can be classified in two main groups as follows:

1) simulations within the base case;

2) simulations within high case and low case scenarios.

6.2.1 Simulations within the Base Case

The findings of the cost-benefit analysis under the base case were subsequently tested for their sensitivity to changes in four parameters.

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(1) Jenkins, G.P., Capital in Canada: Its Social and Private Performance, 1965-1974, Discussion Paper N° 98, Economic Council of Canada, Ottawa, 1977.

The first simulation indicates that the cost-benefits estimates are sensitive to discount rates. When the discount rate is assumed to be 5%, the discounted net cash flow is $629 million and the B/C ratio is 2,53 (see Table 6.2). When the discount rate is assumed to be 15%, the discounted net cash flow falls to $106 million while the B/C ratio falls to 1,39 indicating that the project is still economically viable.

The second simulation indicates that, under an oil tanker scenario for transporting the oil from the Beaufort Sea to the East Coast [1], the net cash flow, the B/C ratio and the internal rate of return results are not significantly affected.

The third simulation indicates that the market penetration of 100% instead of a gradual penetration rate would increase the net cash flow by approximately 50%. The internal rate of return increases to 28% while the B/C ratio jumps from 1,84 to 2,29.

The last simulation within the base case indicates that, in case of failure at the time of launch, the replacement costs and a six-month delay would decrease the net cash flow by less than 5% while the B/C ratio and the internal rate of return would fall to 1,74 and 20% respectively.

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(1) Oil tanker benefits are assessed through the savings in operating cost for cargo tanker according to the number of voyage days required to transport the oil produced and the number of days saved per voyage. Based on the general shipping survey this last figure has been assessed to be 2.8 days while the savings in operating cost is assumed to be $40,000 per voyage.

Table 6.2

COST BENEFIT SIMULATIONS FINDINGS
AND
SENSITIVITY ANALYSIS
BASE CASE
($ million of 1985)

	Base Case	Base Case with change in the discount rate		Base Case with oil tanker scenario	Base Case with 100% market penetration	Base Case with failure
Discount rate	10%	5%	15%	10%	10%	10%
NPV Benefits	$ 621,9	1061,4	378,6	630,5	774,4	640,1
NPV Costs	338,0	432,4	272,6	338,0	338,0	367,8
NPV Net Cash Flow	283,8	629,0	106,1	292,5	436,3	272,4
B/C Ratio	1,84	2,53	1,39	1,87	2,29	1,74
IRR:	21%	21%	21%	21%	28%	20%

6.2.2 Additional Simulations

A cost benefit analysis was also carried out utilizing both favorable and unfavorable scenarios. The assumptions underlying these scenarios are outlined below for each scenario.

High Case Scenario

1) A faster market penetration, where the annual rates are assumed as follows:

1991	1992	1993	1994	1995
30%	40%	60%	80%	100%

2) A higher Radarsat contribution to the complete information system used for ice and ocean benefits assessment. The contribution rates for the ice and weather applications are 72 and 24 percent respectively.

3) The life of the satellite after re-servicing has been extended from 5 years to 7 years.

4) Additional savings obtained through Radarsat concerning the potential charge to the users of International Polar Orbiting Meteor Satellite System [1] (IPOMSS). These new benefits, valued at $10 million, have been evenly distributed over the years 1992 and 1993.

5) The social discount rate is 10%.

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(1) IPOMSS is considering charging Canada a fee for the provision of spaceborne remote sensing data services. If so, it is expected that Radarsat will avoid this fee through an exchange agreement.

Unfavorable Scenario (Low Case) Assumptions:

1) A slower market penetration, where the annual rates are assumed as follows:

	1991	1992	1993	1994	1995	1996	1997
Market penetration rate	10%	20%	30%	40%	60%	80%	100%

2) A lower Radarsat contribution to the complete information system used for the ice and ocean benefits assessment. The contribution rates for ice and weather applications are 48 and 16 percent respectively.

3) The life of the satellite after re-servicing has been reduced from 5 years to 3 years.

4) The flow of costs has been raised by 10 percent.

5) The social discount rate remains at 10 percent.

6) A failure of the satellite is assumed meaning an additional cost of 58 million dollars for the year 1992 and total benefits values delayed by six months.

Results

Table 6.3 below indicates the findings of the cost-benefit analyses for the high and low case scenarios.

Table 6.3
COST BENEFIT SIMULATION FINDINGS
LOW AND HIGH CASES
(million of 1985 $)

	High Case	Low Case	Base Case
Discount rate	10%	10%	10%
NPV Benefits	767,2	414,1	621,9
NPV Costs	342,7	399,6	338,0
NPV Cash Flow	424,6	14,5	283,8
Cost-Benefit Ratio	2,24	1,04	1,84
IRR (internal rate of return)	23%	11%	21%

For the high case scenario, the results of the cost-benefit analysis indicate a NPV totalling $424,6 million, representing an increase of 50 percent from the base case estimate. The C/B ratio and the internal rate of return are 2,24 and 23% respectively.

For the low case scenario, results indicate that the Radarsat program would still constitute an economically viable project with a NPV of $14,5 million, a cost-benefit ratio of 1,04 and an IRR of 11 percent.

7. RADARSAT UNQUANTIFIABLE BENEFITS AND IMPACTS

The Radarsat program is anticipated to have a long-lasting socio-economic impact on all regions of Canada. The cost-benefit analysis of the Radarsat program has dealt only with quantifiable benefits. Aside from these quantifiable benefits, there are potentially many other benefits which are not easily quantifiable.

Several unquantifiable benefits have been identified and examined for this report. These benefits have been grouped under five main headings: Canadian Sovereignty, environmental management, technological spin-offs, national pride and foreign aid.

Radarsat, as a Canadian-owned and operated surveillance satellite, could play a strategic surveillance role and could demonstrate that Canada is guarding its northward and seaward reaches, including the 200 mile fishing limit and the waters of the Arctic. Radarsat would offer an inexpensive solution for maintaining adequate surveillance in that area compared to icebreakers and aircraft costs (e.g. proposed Polar Class icebreaker alone will cost one-half billion dollars).

Environmental management will also be enhanced with Radarsat, in particular in the areas of resource inventories, resource capability assessments, resource use surveys, environmental impacts assessments, assessments of natural change and assessments of man-induced change.

The primary areas that will be affected by Canadian R & D for Radarsat are aerospace technology and production, information system, and model refinement and development.

The satellite will have the potential to generate valuable national pride in Canada's technological capabilities and expertises.

Remote sensing data from Radarsat could also benefit many foreign countries, in particular those whose economies are primarily resource-based. Images can be used to detect and prevent deforestation, develop irrigation schemes, monitor plant disease, assist graphical prospecting, locate water supplies, etc.

8. OTHER IMPACTS OF RADARSAT

Radarsat will create business opportunities for many Canadian companies which will result in an increase in sales of hardware, software and services in the area of remote sensing for an amount of $239,1 million ($201,6 million in Canadian content). Sales will be $74,6 million for hardware, $31,5 million for software and $133 million for services. The net benefit (before taxes) to these Canadian companies is expected to be $62,0 million.

Radarsat will also create export opportunities for Canadian firms involved in ground station and space-related areas. These companies are expected to increase their export sales by $325,6 million ($260,0 million for the space segment and $65,6 million for the ground segment). The net benefit before taxes of these exports is expected to reach $65,1 million.

A total of 9 141 person-years direct jobs will be created as a consequence of Radarsat. The remote sensing industry is to create 3 359 person-years jobs as a consequence of increased activities in sales, the space and ground segments industry is to create 3 708 person-years jobs as a consequence of increased exports, and the Radarsat program will create 2 074 person-years jobs during Phases C, D and E (between the last quarter of 1986 and the end of 2001). The regional distribution of job creation in Canada was calculated at 1 868 person-years in Western Canada, 3 424 person-years in Ontario, 3 654 person-years in Quebec and 195 person-years in Eastern Canada.

9. CONCLUSIONS

The major objective of this study was to evaluate the economic viability of the Radarsat program in terms of its ability to improve the economic welfare of the Canadian society. The critical question is whether the program should or should not be pursued by the Canadian government at the end of Phase B (third quarter of 1986).

The Cost-Benefit analysis conducted on quantifiable benefits leads to the conclusion that the program is economically viable. For the Base Case, the Internal Rate of Return is 21% giving a Net Cash Flow for the Canadian Society of $284 million with a discount rate of 10% and a Benefit-Cost ratio of 1,8. The Base Case scenario comes from purposely conservative estimates of the benefits.

Even in the case of a very unfavourable scenario (lower benefit realisation rate, shorter life and higher costs for the satellite, worst scenario in terms of launching risks) the Radarsat program comes out as definetely still economically viable with an internal rate of return of 11% and a cost-benefit ratio just over 1,0.

Total incremental costs to the Canadian government are expected to be $550 million, to be disbursed between the last quarter of 1986 and the end of the year 2001 (Phases C, D and E).

Total economic benefits of Radarsat for all Canadians are expected to reach $1,9 billion (over the period in non discounted terms). These benefits include cost savings in alternative data acquisition, cost savings in operating costs of end-users such as oil and mining companies, increased value-added production activities and valuation of increased forecasting accuracy. These benefits are broken down as follows:

1) The non discounted Radarsat agriculture benefits will total $684 million over the time-period. Agriculture benefits are calculated as the social gains associated with reductions in crop forecasting errors resulting from the combined used of the three following Radarsat sensors: SAR, ROS and AVHRR.

2) Radarsat geology benefits will amount to $516 million (non discounted) over the period.

3) It has been established that Radarsat (with the SAR) will bring significant efficiency gains in reservoir management. The total non discounted benefit has been estimated to be $250 million.

4) Radarsat (with the SAR and the scatterometer) will significantly enhance information on weather, sea-state and ice leading to valuable benefits for the offshore oil and gas industry, general shipping and ocean fishing. The cumulative non-discounted benefits with conservative estimates are likely to account for $178 million over the period.

5) Radarsat forestry benefits will amount to $115 million (non discounted dollars) over the period. The largest benefit will come from acquisition cost savings in forest inventory and updating; other benefits will come from reforestation due to better site evaluations and better forest road locations.

6) The use of Radarsat for topographical and land use maps at 1:250 000 will likely give a total non-discounted benefit of $17 million.

7) Total sales of Radarsat data products are expected to be $95 million during the operational phase (between 1991 and 2001). Data product sales were found to be a very small proportion of potential benefits that can be generated by Radarsat.

In addition to these quantifiable benefits, Radarsat will create business opportunities for many Canadian companies.

1) Radarsat will result in an increase in sales of hardware, software and services in the area of remote sensing for an amount of $239,1 million ($201,6 million in Canadian content).

2) Radarsat will create export opportunities for Canadian firms involved in ground station and space-related areas. These companies are expected to increase their export sales by $325,6 million ($260,0 million for the space segment and $65,6 million for the ground segment). The net benefit before taxes of these exports is expected to reach $65,1 million.

A total of 9 141 person-years direct jobs will be created as a consequence of Radarsat.

The regional distribution of job creation in Canada was calculated at 1 868 person/years in Western Canada, 3 424 person/years in Ontario, 3 654 person/years in Quebec and 195 person/years in Eastern Canada.

The Radarsat program is anticipated to have a long-lasting socio-economic impact in all regions of Canada.

In addition to the quantifiable benefits, several unquantifiable benefits have been identified and analyzed in this study. These benefits have been grouped under five major categories: Canadian sovereignty, environmental management, technological spin-offs, national pride and foreign aid.

Radarsat, as a Canadian-owned and operated surveillance satellite, could play a strategic surveillance role and could demonstrate that Canada is guarding its northward and seaward reaches, including the 200 mile fishing limit and the waters of the Arctic. Radarsat would offer an inexpensive solution for maintaining adequate surveillance in that area compared to icebreakers and aircraft costs (e.g. proposed Polar Class icebreaker alone will cost one-half billion dollars).

Environmental management will also be enhanced with Radarsat, in particular in the areas of resource inventories, resource capability assessments, resource use surveys, environmental impacts assessments, assessments of natural change and assessments of man-induced change.

The primary areas that will be affected by Canadian R & D for Radarsat are aerospace technology, information systems, and model refinements and development.

The satellite will have the potential to generate valuable national pride in Canada's technological capabilities and expertises.

Remote sensing data from Radarsat will also benefit many foreign countries, in particular the Least Developed Countries whose economies are primarily resource-based. Images can be used to detect and prevent deforestation, develop irrigation schemes, monitor plant disease, assist graphical prospecting, locate water supplies, etc.

10. RECOMMENDATIONS

Recommendation no 1: Research and development

The benefits estimated in this study are conditional to a strong research and development program of $50 - 75 million for various Radarsat applications which should precede the launching in 1991. This program should include Radarsat image simulation experiments with remote sensing systems. Also, in many domains of application, Radarsat imagery should be part of a comprehensive integrated information system as it is currently envisaged for agriculture, ice and weather.

Recommendation no 2: Market study

Since market studies of future Radarsat data were not within the scope of this study, the potential revenues for data sales were evaluated from assumptions made on future prices of Radarsat raw data and a qualitative analysis of its competitive edge over foreign satellites (Landsat, SPOT and others). Although we believe that those assumptions were realistic and scientifically defendable, it is important that, prior to the operational phase of Radarsat, a comprehensive study be conducted. This study should evaluate the price sensitivity of future end-users (both in Canada and abroad) and the major variables, other than price, that affect the demand for Radarsat data.

The knowledge of such information would enhance the chances of selling Radarsat data and it would also allow Canadian representatives to establish better policies concerning revenue sharing with foreign distributors.

Recommendation no 3: Commercial strategy

The present study and the interviews conducted among potential end-users in promising domains of applications (geology, forestry and even offshore activities) have clearly indicated the need for the Radarsat Project Office to increase its visibility and to help end-users to discover how Radarsat could be valuable to their activities.

Besides this awareness strategy, a strong commercial stragegy can be realized only if recommendations 1 and 2 are fully implemented and if the private intermediary users (service sector) were fully involved in all commercial efforts.

Recommendation no 4: Foreign aid

Many of the Third World countries have vast quantities of untapped natural resources which can be developed if greater access to remote sensing data from Radarsat is available.

Radarsat, through CIDA, could provide data to determine crop yield, monitor production, assess disaster damage, detect and prevent deforestation, develop irrigation schemes, monitor plant disease, assist graphical prospecting, locate water supplies and improve mapping.

Recommendation no 5: National visibility

Both the launch and reservicing of Radarsat will involve Canadian astronauts, with the title of mission specialist. These Canadian astronauts who will be involved with Canadian technology (Radarsat satellite) can be shown on TV, if possible during a special occasion such as Canada Day or New Year's Eve. This would generate valuable national pride in Canada and its capability to be innovative and internationally competitive.