A PRELIMINARY ECONOMIC ASSESSMENT OF AGRICULTURAL LAND DEGRADATION IN ATLANTIC AND CENTRAL CANADA AND SOUTHERN BRITISH COLUMBIA

Prepared by:

THE DEVELOPMENT CONSULTING HOUSE (DCH)
67A Sparks St., Suite 200
Ottawa, Ontario

and

LAND RESOURCE RESEARCH INSTITUTE (LRRI)
Research Branch
Agriculture Canada
Central Experimental Farm
Ottawa, Ontario

for

REGIONAL DEVELOPMENT BRANCH AGRICULTURE CANADA

January, 1986

A PRELIMINARY ECONOMIC ASSESSMENT OF AGRICULTURAL LAND DEGRADATION IN ATLANTIC AND CENTRAL CANADA AND SOUTHERN BRITISH COLUMBIA

Principal Authors:

M.G. Fox, DCH
D.R. Coote, LRRI

Contributing Authors:
J. Dumanski
D. Hamilton
E. Huffman
C. Lok
J.A. Shields
K.D. Switzer-Howse
L.J.P. van Vliet

Contributors:

Soil Landscape Maps
C. Action
J-M Cosse-te
A. Eagle
F. Hender
H. Rees
C. Veer
C. Wang
K. Webb

Regional Interviews
R. Cotterill
D. Schroeter
M. van Lierop

Data Analysis
G. Butt
V. Kirkwood
S. Marshall
C.A. McGovern
M.A. McGovern
W. Mulcahy
D. Trant

Contribution 85-70, LRRI, Research Branch, Agriculture Canada

ACKNOWLEDGEMENTS

This report required input from a great number of individuals and agencies. Their contributions are hereby acknowledged. Assistance was received from members of Agriculture Canada's Regional Development Branch in British Columbia, Ontario, Quebec, Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland, particularly from J. Hansen, J. Oxley, and C. Pharo. The assistance of Statistics Canada and of many individuals with the provincial departments of agriculture in the study areas is also gratefully acknowledged. Those people who attended regional Nominal Group Process meetings and answered the questionnaires deserve our grateful recognition because without the data and experience that they provided this study could not have been completed. Assistance received from the Canada Soil Information System (CanSIS) and and the Agrometeorology Section of LRRI, as well as that from the British Columbia Soil Information System (BCSIS) and the Computer Aided Planning Assessment and Map Production (CAPAMP) system is also acknowledged. Finally, we wish to thank the various reviewers for their useful comments.

TABLE OF CONTENTS

LIST OF TABLES

NUMBER PAGE

NUMBER PAGE

LIST OF FIGURES

NUMBER PAGE

1.0 EXECUTIVE SUMMARY

The purpose of this study was to make preliminary estimates of the on-farm and off-farm costs of agricultural land degradation in Atlantic and Central Canada, and British Columbia excluding the Peace Region. The types of degradation examined are water erosion, wind erosion, acidity and soil compaction. The main costs which are estimated are the values of crop yield reductions, added inputs (fertilizers, pesticides, etc.) required to offset physical losses, and reduced crop quality. An attempt is also made to quantify the off-farm damage from agricultural land degradation in the study area.

The study was carried out in two parts. The first consisted of a procedure to estimate the location, area and severity of erosion, acidification and compaction within 16 subregions of the study area. Newfoundland, Nova Scotia and Prince Edward Island were each treated as separate subregions. Two subregions were created for New Brunswick , three each for Quebec and British Columbia, and five for Ontario. A large electronic data base of physical soil characteristics and land use in the study area was compiled to which standard 'models' of the degradation processes, expected to be operative in the study area, were applied. This exercise yielded the likely extent, location and severity of degradation in the subregions.

The second part consisted of estimating crop yield reductions and other economic costs of soil degradation under each type and class of degradation in each subregion. These estimates were obtained by analysing the opinions of a select group of experts in the provinces covered by the study. Questionnaires, group consensus meetings and telephone follow-ups were employed.

The results from both modules were then combined to derive estimates of the annual on-farm economic costs of soil degradation in each of the 16 regions of the study area. Water erosion was found to be the most economically-significant form of degradation in the study region as a whole, with current annual on-farm costs ranging from $156 to 218 million. Compaction was estimated to cost the industry almost $126 annually. The on-farm impacts of wind erosion and acidity were less significant with cost estimates of $11 and 9 million respectively. The total on-farm economic impact of all forms of degradation combined is estimated to be between $300 and 364 million per year. This total may be slightly high because a certain amount of overlap may have occurred in the assessment of yield losses attributable to different soil degradation processes.

The Southern Ontario Region generates the highest level of damage in three of the four degradation categories (it is second in acidity damage) with losses of between $55 and 93 million from water erosion, $8 million from wind erosion, $67 million from compaction and $1.3 million from acidification. The magnitude of damage in this region can be attributed to its large agricultural land base and high intensity of row cropping. The Western Ontario Region generated the second highest on-farm degradation costs mainly due to erosion ($47 to 51 million). Compaction and acidification problems cost the region approximately $3.3 million and $1.5 million respectively.

The on-farm costs of soil degradation are also relatively important in the St. Lawrence Region of Quebec ($30 million compaction, $9.3 to 11.3 million erosion, $1.1 million acidity); the Potato Belt Region of New Brunswick ($10.1 to 12.1 million erosion, $8.3 million compaction); the South Coastal Region of British Columbia ($7.5 to 12.5 million erosion); and Prince Edward Island ($5.0 to 5.4 million erosion, $8.9 million compaction).

Economic impacts were also expressed as an average cost-per-hectare of improved land and as a percentage of on-farm operating costs in each of the 16 regions. Unit area costs of water erosion are highest in the Potato Belt of New Brunswick , followed by Newfoundland, British Columbia South Coast and Southern Ontario. The Potato Belt also suffers the highest unit area compaction costs, followed by Southern Ontario, Prince Edward Island and the South Coastal Region of British Columbia Unit area wind erosion and acidity costs are relatively low in all regions. Expressed as a percentage of on-farm operating costs, soil degradation has highest impact on the agricultural industry in New Brunswick and Prince

Edward Island, where these costs exceeded 10 percent. Values for all other regions were less than 4 percent.

The off-farm economic impacts of agricultural land degradation could not be accurately disaggregated by region, nor could they be broken down into component parts. From unpublished data provided by the Ontario Erosion and Sedimentation Coordination Committee (ESCC), however, we estimate that the off-farm economic impacts of agricultural soil degradation may be as high as $91 million in that province. Extrapolations from United States data suggest that the off-farm impacts of agricultural soil degradation (primarily erosion) in the study area as a whole are approximately $111 million annually. According to our estimates, off-farm damages in the study area cost the nation more than the on-farm impacts of acidity or wind erosion, and nearly as much as soil compaction.

The results generated in this study suggest that the on and off-farm economic impacts of soil degradation in the study area are significant and are growing. The results are, however, only estimates. It must be recognized that many assumptions were made to obtain them and that they are, therefore, only an indication of the likely magnitude of problems.

2.0 INTRODUCTION

The degradation of agricultural land is a topic of growing concern to farmers and agricultural experts across North America. Two descriptive reviews of the nature, extent, and location of soil degradation in Canada have been published (Coote et al, 1981; Coote, 1983) and the Senate Standing Committee on Agriculture, Fisheries and Forestry (1984) published the results of hearings held across Canada on soil degradation. None of these documents contained any economic analyses.

Attempts to quantify the economic impact of agricultural land degradation have recently been made for the Prairies (PFRA, 1983; Anderson and Knapik, 1984). The Regional Development Branch (RDB), Agriculture Canada, required a similar assessment for Central and Eastern Canada and Southern British Columbia to assist in priorizing problem areas and appropriate mitigation policies. While economic analyses have been made in Ontario for erosion (Wall and Driver, 1982) and in Nova Scotia for several forms of degradation. (Jacques, Whitford and Associates, 1985) no comprehensive economic assessments for Eastern Canada and Southern British Columbia were available.

In February, 1985, ROB engaged the services of the Development Consulting House Ltd. (DCH) to prepare a report covering these remaining agricultural areas in Canada, who worked in cooperation with the Land Resource Research Institute (LRRI) of Agriculture Canada. While this report covers both physical and economic analysis resulting from this study, it should be noted that a more detailed report of the physical analysis will be prepared by LRRI after they have further refined the interim physical data which they prepared for this study.

The study had five major objectives (See Appendix C for Terms of Reference):

1) To estimate the physical location, extent and severity of water erosion, wind erosion, acidification and compaction in agricultural areas of Atlantic and Central Canada and British Columbia (excluding the Peace Region).

2) To estimate quantitatively how yields and input requirements of specific crop groups (corn, beans, small grains, potatoes, other row crops) in each province or region. are affected by varying levels of severity of each form of soil degradation.

3) To estimate the annual on-farm economic impacts of each form of degradation in the 16 regions of the study area and to identify on-farm measures (and their costs) taken to control soil degradation.

4) To estimate the annual off-farm economic impacts of agriculturally-induced soil degradation in the study area due to sedimentation, nutrient enrichment and non-point source chemical pollution of water bodies.

5) To provide a context for these estimates by discussing confidence levels which apply to these results; comparing them with published estimates; outlining knowledge gaps; and assessing the priority associated with filling these gaps.

The study area included the agricultural regions of Atlantic Canada, Ontario and Quebec, and British Columbia excluding the Peace River Region (the latter was covered by Anderson and Knapik).

This area was divided into 16 regions for separate economic analysis. These regions are displayed in Figure 2.1. They are:

1. Newfoundland, 2. Nova Scotia, 3. Prince Edward Island, 4. Southern and Eastern New Brunswick , 5. New Brunswick Potato Belt, 6. Northern Quebec and Gaspe Peninsula, 7. Eastern Townships of Quebec and Outaouais region, 8. St. Lawrence Lowlands of Quebec,

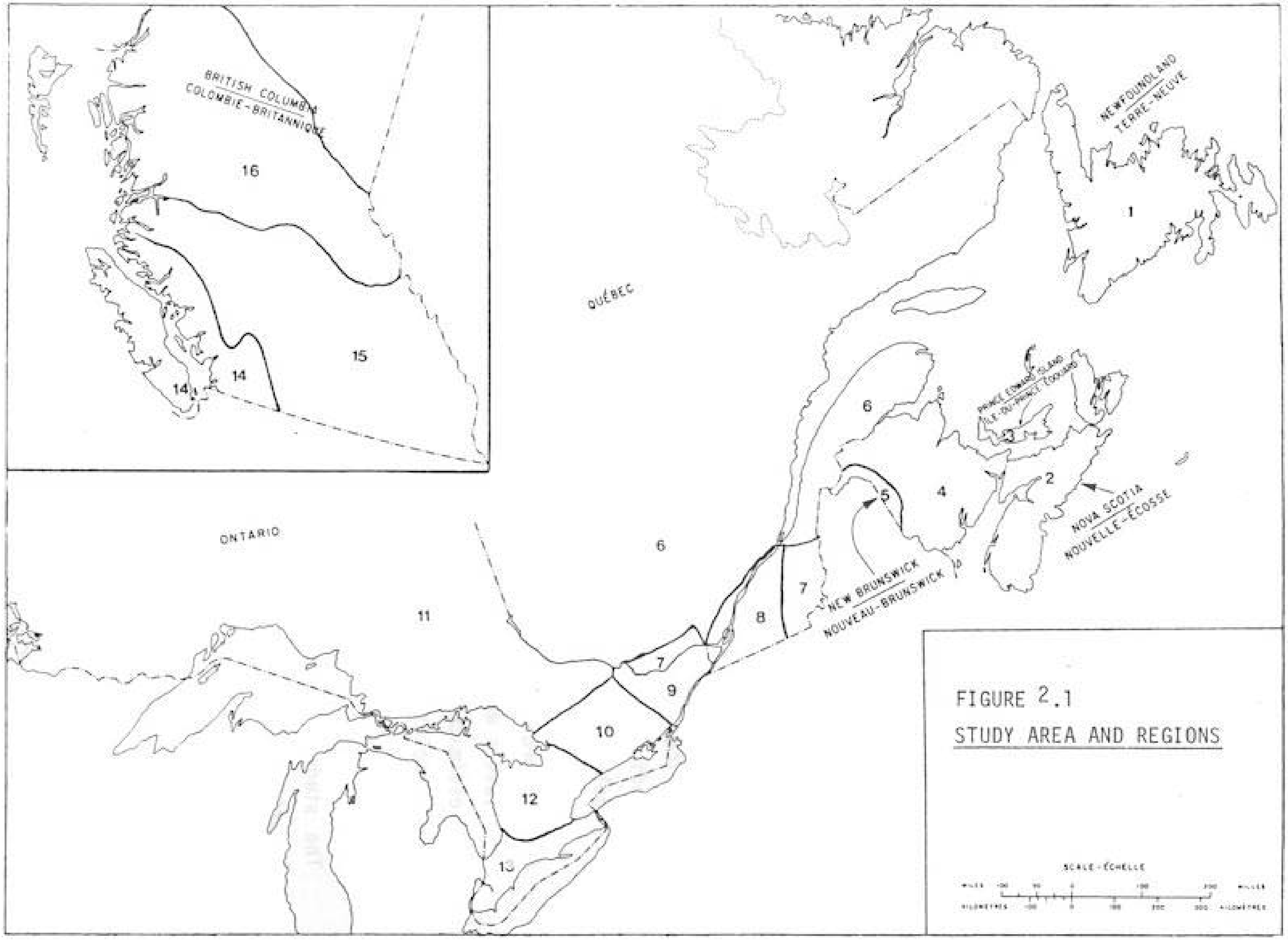

FIGURE 2.1
STUDY AREA AND REGIONS

9. Eastern Ontario, 10. Central Ontario, 11. Northern Ontario, 12. Western Ontario, 13. Southern Ontario, 14. South Coastal Region of British Columbia, 15. Southern Interior of British Columbia, and 16. Omenica Region of British Columbia.

The next chapter of this study (Chapter 3) is a brief summary of the methodology and results. Readers seeking more detailed information about the methodology employed are directed to Chapter 4. Results, for each form of degradation, by region, are described in Chapters 5 to 9.

3.0 SUMMARY AND RECOMMENDATIONS

3.1 ON-FARM COSTS OF SOIL DEGRADATION

Using soil data and maps at a scale of 1:500,000 (1:250,000 in Prince Edward Island), and 1981 Census of Agriculture data on land use matched to soil polygons at this scale, estimates were made of water erosion, wind erosion, acidification and compaction risk by applying estimation techniques described in Chapter 4, Section 4.1. Classes of erosion and compaction risk were selected by matching computed land areas in each class with observations of study participants in each region. Five crop groups were selected for the study region (see page 43) except in British Columbia where three crop groups were used. The area of each crop group in each erosion and compaction risk class was then tabulated. Yield reductions expected for each crop group in each risk class were then applied to these tabulated areas to determine the estimated value of foregone production. Costs of acidification were computed from the estimated need for lime to prevent further acidity development in soils that are sensitive or moderately sensitive to acidification (see Chapter 4, Section 4.2).

3.1.1 Location and Extent of Soil Degradation

The areas most seriously affected by water erosion are the Western and Central regions of southern Ontario, the Potato Belt of New Brunswick and central Prince Edward Island. Row crop production on silty and loamy soils with relatively steep slopes is most susceptible. In all other regions, small areas with high erosion risk are found for certain crops, mostly on steeper slopes. The area of these high-risk areas is greatest in Nova Scotia and the St. Lawrence Region of Quebec. It is very small in Newfoundland, Eastern and Northern Ontario and the Omineca region of British Columbia.

Significant areas of moderate wind erosion risk are found in Southern, Central and Eastern Ontario, and the St. Lawrence region of Quebec. Isolated moderate wind risk areas occur in the Outaouais region of Quebec, south of Quebec City, and in Prince Edward Island , Nova Scotia and Newfoundland, but in each of these regions land areas affected are very small. No areas with a high risk of wind erosion are found in the study region.

Areas with high risk of soil compaction and structure deterioration are widely dispersed. The fine textured soils of Southwestern and Eastern Ontario, the St. Lawrence region of Quebec and the Lower Fraser Valley of British Columbia appear to be very susceptible; so also are other soils such as the loamy and sandy loams of the New Brunswick Potato Belt, Prince Edward Island and the Annapolis Valley of Nova Scotia, when used intensively for crops with machinery inputs.

The acidification agricultural soils occurs when the deposition of acidifying inputs, such as fertilizers or atmospheric emissions, exceeds the buffering capacity of these soils. High acidification risk on sensitive and moderately sensitive soils occurs mainly in Southern Ontario, Southern Quebec, the Potato Belt of New Brunswick, the Annapolis Valley of Nova Scotia, and western Prince Edward Island. Many other areas, such as Eastern Ontario and Southern British Columbia, are subjected to large amounts of acidifying inputs, but the dominance of non-sensitive soils with high buffering capacity precludes an acidification problem in the short-term.

3.1.2 Yield Reduction Factors

Estimates of crop yield reductions due to water erosion and soil compaction were obtained from agriculturalists and farmers in each of the 16 regions by way of a series of highly structural group meetings and questionnaires. These subjective estimates were critical to the economic analysis. A review of experimental data on yield reduction factors is provided in the sections on erosion and soil compaction (Chapters 5 & 7).

Objective data on yield reductions due to degradation processes in each region are very scanty and are not sufficient to judge the accuracy of the yield reduction factors estimated by study participants.

Table 3.1 displays the range of yield reductions (percentage) expected for different classes of water erosion which were estimated by study participants. For row crops, values around 15 percent on moderately eroded soil and 30 percent on severely eroded soil were common. Estimates for corn and soybeans grown in rotation with forages were slightly lower, and for potatoes in rotation (especially with forage) were significantly lower. Yield reduction estimates for small grains, mostly spring grains, averaged 12 percent on moderately eroded soil and 27 percent on severely eroded soil. Experimental values in the literature are comparable or slightly higher when similar crops are considered (e.g. corn, barley and potatoes).

An examination of yield reductions caused by erosion across regions, reveals relative consistency with the singular exception of small grains in British Columbia, where the estimate was about half the Eastern Canada average. No individual region gave consistently high or low yield reduction estimates when compared with study area averages Table 3.2 provides a summary of yield reductions caused by soil compaction and structural deterioration. Yield reduction averaged for all crops were estimated to be about 3 percent on compacted sandy soils, 15 percent on compacted loamy soils and 25 to 30 percent on compacted clayey soils. Reduction of soybean yields tended to be higher than average, and of small grains tended to be lower. None of the values obtained for this study are inconsistent with the few experimental data available in the study region (primarily corn on loamy and clayey soils).

A regional analysis of yield reduction values due to compaction indicates that estimates for the Quebec St. Lawrence region tended to be much higher than those of other regions on loamy and clayey soils. It was not possible to determine whether such high estimates reflected an unrealistically high level of concern with the problem in this region, or a real difference in the severity of the problem, relative to other regions, caused by soil type and tillage practices.

3.1.3 Economic Impacts

Table 3.3 provides a compilation of the annual on-farm economic costs of soil degradation calculated for each of the 16 study regions. Water erosion was found to be most economically-significant in the study region as a whole, with impacts ranging from $156 to 218 million annually. However, compaction, even when impacts were estimated only on land with a severe compaction risk, accounted for $126 million in annual on-farm costs. Very little is known about the actual extent of compaction and its effects on crop yield, but the results of this study suggest that it imposes significant costs on the agricultural industry in the study area.

Acidity and wind erosion were both found to cause considerably less damage than water erosion, with annual impacts of $9 and 11 million respectively. Acidity is the best understood of the four degradation problems from the perspective of extent, severity and means of mitigation. Costs of controlling acidity were found to be highest in the Western Ontario, Southern Ontario and Quebec St. Lawrence Regions ($1.5, 1.3 and 1.1 million respectively). These figures are based on the costs of neutralizing acidity with lime only in soils sensitive and moderately sensitive to acidification. It should be, recognized that non-sensitive soils may also become more acid in the future and expenditures for lime to neutralize acidity in these soils could eventually increase to three times the current estimates in some regions of Central Canada.

TABLE 3.1 Percentage Yield Reduction Due To Soil Erosion Estimated By Study Participants[1].

	YIELD REDUCTION FACTORS (%) [2]								
	P.E.I.	N.B.(2).	QUEBEC			ONTARIO		B.C.(3)	Average[4]
Crop			North	E.T./Out.	St. L.	E & C	S& W		
Corn Mono.	-	[20][3]	[12 - 20] [6 - 15]	15- 40 (10-20)	15-33 (10-25)	15-40 (5-30)	12.5-30 (6-20)	12.5-37.5	14-36
Corn Rot. w/Forage	-			10-30 (10-20)	-	12-32	10-25	-	11-29
Soybean Mono.	-	-	-	-	15-40	10-35 (NA-25)	20-25	-	15-42
Soybeans Rot. w/Forage	-	-	-	-		7.5-30	17.5-45	-	12-38
White Beans		-	-	-	-	-	30-NA	-	30-NA
Potato Mono.	-	15-30 (8-20)	-			-	-	-	15-30
Potato - Grain	10-20	8-20		15-40 (10-30)	15-40	-	-	-	9-20
Potato - Grain - Forage	5-15	5-15	-	--	—	-	-	-	5-15
Tobacco	5-10		-	-	15-40	-	15-NA	-	12-25
Vegetables	20-NA	20-NA	15-20 (8-15)	-	15-40	-	15-NA	17.5-30	17-30
Spring Grain	10-25	-	8-20 (3-6)	13-28	13-30	20-30 (5-7)	10-30 (NA-15)	5-15	12-27
Fall Grain	-	-	-	-	-	-	10-25 (NA-12.5)	-	10-25

[1] Regions not listed either could not provide yield reduction factors (Nfld., N. Ont.) or were not polled (N.S.)

[2] Paired figures are yield reduction estimates for moderately and severely eroded soils, respectively. Values are based on no extra fertilizer being used to compensate for yield loss, except the lower values shown in parentheses which assume extra fertilizer is added. NA - Not Assessed.

[3] Brackets indicated where crop rotation unspecified.

[4] Does not include figures in brackets or regions where responses were unavailable.

TABLE 3.2. Yield Reduction Factors Due To Soil Compaction, As Estimated By Study Participants.

	YIELD REDUCTION FACTORS (%)[2]									
	Nfld	P.E.I.	N.B.(2)	QUEBEC			ONTARIO		B.C.(3)	Average
Crop				North	E.T./Out.	St. L.	E & C	S& W		
Corn	-	-	-	7.5-22.5-32.5	5-10-NA	0-15-35	0-10-25	2.5-10-20	0-7.5-12.5	2-12-25
Soybeans	-	-	-	-	-	0-25-60	10-17.5-25	2.5-10-25	-	4-18-37
White Beans	-	-	-	-	-	-	-	5-15-25	-	5-15-25
Potatoes	-	5-15-NA	10-20-NA	5-20-30	5-10-NA	0-15-NA	-	-	-	5-16-30
Tobacco	-	-	-	-	-	-	-	2.5-10-NA	-	2-10-NA
Vegetables	10-25-NA	-	10-30-40	3-20-30	-	NA-NA-50	-	2.5-10-20	0-7.5-12.5	5-18-30
Small Grains	-	5-15-NA	-	3-15-30	2.5-7.5-NA	0-10-35	0-5-10	2.5-10-20	0-7.5-12.5	2-10-22

[1] Regions not listed either could not provide yield reduction factors (N. Ont.) or were not polled (N.S.).

[2] Three figures in column are yield reduction estimates for sandy, loamy and clayey soils, respectively. Estimates assume no measures taken to compensate for yield loss.

TABLE 3.3. Summary Of Annual On-farm Costs Of Soil Degradation.

	Water Erosion		Wind Erosion		Acidity		Compaction	
REGION	$000	Rank[1]	$000	Rank	$000	Rank	$000	Rank
Newfoundland	730 -860	13	< 1	-	94	16	<1	-
Nova Scotia	4,130 -9,931	7	< 1	-	247	12	1,216	7
P.E.I.	4,972 -5,395	8	102	4	834	5	8,926	3
New Brunswick Potato Belt	10,129 - 12,063	3	< 1	-	238	13	8,296	4
South & East New Brunswick	629 -746	14	< 1	-	180	14	<1	-
Quebec St. Lawrence	7,073 -9,059	6	2,216	2	1,090	3	30,458	2
Quebec E. Twp/ Outaouais	4,298 -4,643	9	< 1	-	712	6	<1	-
Northern Quebec	3,041 -3,363	10	23	5	870	4	<1	-
Eastern Ontario	2,274 -2,485	11	348	3	380	9	797	8
Central Ontario	7,855 - 10,383	4	< 1	-	168	15	79	9
Northern Ontario	145 -427	15	< 1	-	452	8	<1	-
Western Ontario	46,630 - 51,202	2	17	6	1,466	1	3,350	6
Southern Ont.	54,646 - 92,841	1	7,984	1	1,267		266,773	1
B.C. South Coast	7,474 - 12,457	5	< 1	-	495	7	6,000	5
B.C. Southern Interior	1,262-1,871	12	< 1	-	339	10	<1	-
B.C. Omineca	274	16	< 1	-	339	10	<1	-
TOTAL (x 1000)	$155,562 -218,000		$10,690		$9,171		$125,895	

[1] Based on average of range.

[2] Range in Nova Scotia includes estimates made using two alternative sets of yield reduction factors (see tables 5.2 (a) and 5.2 (b)).

Of all the of soil degradation processes examined, wind erosion is probably the most variable from year to year, and is, therefore, the most difficult to assess in economic terms. Our analysis suggests that the Southern Ontario Region incurs the greatest wind erosion damage ($8.0 million/yr), followed by Quebec St. Lawrence ($2.2 million/yr).

An examination was made of the collective impacts of all forms of degradation by region. Southern Ontario is the region most severely affected by soil degradation, other than acidification, because of its large agricultural land base and a high intensity of row cropping. Here water erosion causes annual on-farm damages valued at between $55 and $93 million. Damages due to compaction, wind erosion and acidification are $67 million, $8 million and $1 million respectively. The Western Ontario Region is next in terms of the total damage, largely as a result of high costs of water erosion ($47 to 51 million annually).

Other regions in which the economic impact of soil degradation is high are the St. Lawrence Region of Quebec ($30 million compaction, $9.3 to 11.3 million erosion, $1.1 million acidity); the Potato Belt Region of New Brunswick ($10.1 to 12.1 million erosion, $8.3 million compaction); the South Coastal Region of British Columbia ($7.5 to 12.5 million erosion, $6.0 million compaction); Central Ontario ($7.9 to 10.4 million erosion), and Prince Edward Island ($5.0 to 5.4 million erosion, $8.9 million compaction). None of these results were surprising from the perspective given to us by study participants, with the possible exception of South Coastal British Columbia. In this region, the high calculated cost of erosion damage is as much a reflection of high crop prices in the province as it is of any physical or land use factor.

The magnitude of degradation impacts in a region is a function of the severity of the process and the geographic extent over which the process occurs. The values described above may not provide, therefore, an accurate picture of the importance of degradation problems in regions with relatively small agricultural land bases or small total areas. To clarify this situation, Table 3.4 shows the economic impacts of soil degradation in each study region, expressed per hectare of improved land.

The unit area costs of water erosion are highest in the Potato Belt of New Brunswick, followed by Newfoundland, British Columbia South Coast and Southern Ontario. The Potato Belt Region also suffers the highest unit area compaction costs, followed by Southern Ontario, Prince Edward Island and the South Coastal Region of British Columbia Unit area wind erosion and acidity costs are relatively low in all regions.

On average the regions where soil degradation has the largest total economic impacts are those where the impact per hectare is also high, relative to all other regions. There are several anomalies, however. For example, we estimated that the on-farm economic impacts of water erosion in Southern Ontario were as high as $93 million per year, almost 8 times greater than the $12 million estimated for the New Brunswick Potato Belt or the British Columbia South Coastal region. On a per hectare basis, however, the on-farm impacts of water erosion in the New Brunswick Potato Belt are as much as 2.5 times the impact for Southern Ontario and almost twice that for the British Columbia South Coastal region. The large per hectare values for Newfoundland reflect a very small agricultural land base and relatively high valued potato and vegetable crops grown in areas of high erosion risk.

To obtain another indication of the relative importance of soil degradation to the agricultural industry in each province, the costs of soil degradation were expressed as a percentage of 1984 on-farm operating costs (defined by Statistics Canada). For each case the more conservative estimates of soil erosion, compaction and acidification were used. In New Brunswick and Prince Edward Island the annual costs of soil erosion, acidification and compaction represent over 10 percent of annual operating costs in these provinces. The percentages for the remaining provinces are much lower, falling between 2.4 percent and 3.2 percent.

TABLE 3.4. Annual Cost Of Soil Degradation Per Hectare Of Improved Land.

	Water Erosion		Wind Erosion		Acidity		Compaction	
REGION	$/ha	Rank[1]	$/ha	Rank	$/ha	Rank	$/ha	Rank
Newfoundland	74 -87	2	-	-	10	1	-	-
Nova Scotia	23 -56	5	-	-	1	8	7	6
P.E.I.	24 -26	7	1	4	4	2	43	3
New Brunswick Potato Belt	129 - 153	1	-	-	3	3	102	1
South & East New Brunswick	6 -7	11	-	-	2	5	-	-
Quebec St. Lawrence	7-9	10	2	2	1	8	30	5
Quebec E. Twp/ Outaouais	8-9	9	-	-	1	8	-	-
Northern Quebec	2	14	< 1	5	1	8	-	-
Eastern Ontario	3-4	12	1	3	1	8	1	8
Central Ontario	21-28	8	-	-	< 1	16	<1	9
Northern Ontario	1	15	-	-	2	5	-	-
Western Ontario	29 -32	6	< 1	5	1	8	2	7
Southern Ont.	36 -61	4	5	1	1	8	44	2
B.C. SouthCoast	52 -86	3	-	-	3	3	41	4
B.C. Southern Interior	3 -4	12	-	-	1	8	-	-
B.C. Omineca	1	15	-	-	2	5	-	-

[1] Based on average of range.

Caution must be exercised in adding the economic impact estimates of each type of land degradation. This is because of the overlap that may have occurred when study participants attempted to estimate the yield losses due to each degradation process. Such an overlap would be particularly likely with wind and water erosion and compaction, where the occurrence of one phenomena would be expected to affect the other. An analysis of soil areas in which both severe compaction and either moderate or severe water or wind erosion occurred showed that the area of overlap amounted to less than 4 percent of the total area affected by both processes in all regions except Nova Scotia, where it affected 11 percent of the total area. Overlap of areas with both moderate or severe wind and water erosion never occurred. Thus, only in Nova Scotia may there be a significant overestimation of economic impact of all forms of degradation when totals of each process are added. When considering totals for all regions combined, the overestimation is probably not significant.

3.1.4 Future Changes in the Cost of Soil Degradation

Change in the future on-farm economic impacts of soil degradation are dependant on a number of future trends:

- Rate of increase of the total cultivated area;
- Change in farm management practices, especially with regard to tillage and soil amendments;
- Change in the area of various row crops planted, subject to changing market forces (some of which are influenced by government policies and programs);
- Long term climatic change.

While it was beyond the scope of this project to model these phenomena, we were able to estimate the change in the economic impact of water erosion over the next 5 years using forecasts made by study participants of the projected change in area of each class of erosion. Insufficient data and time constraints precluded a similar analysis for wind erosion, acidification and compaction.

Table 3.5 summarizes these forecasts for each region except Newfoundland and Nova Scotia. It displays the added cost attributable to the increase in eroded land area based on applying the changes equally to all crops assessed. Although the results were calculated using the high end of the range of current water erosion costs as a baseline, we do not feel that the results overestimate the dynamics of the situation because they ignore observed trends toward more erosive (and higher value) crops at the expense of small grains and forage.

The total increase in annual costs of degradation is calculated at $15.6 million in five year's time, an average increase of 7.5 percent for the regions assessed. The highest increases are predicted to occur in Western Ontario ($2.7 million), Southern Ontario ($2.6 million) and the New Brunswick Potato Belt ($2.5 million). The latter is predicted to suffer the highest rate of increase in water erosion costs (20 percent) as a result of the rapid rate of deterioration of agricultural land in the region, including land actually being retired from agriculture as a result of erosion damage.

3.2 OFF-FARM IMPACTS

The off-farm economic impacts of agricultural land degradation could not be accurately estimated for each region, or quantitatively disaggregated by type of off-farm effect. It was possible, however, to make some rough estimates of the potential off-farm economic impacts based on extrapolations from a recent United States study (Clark *et al,* 1985) and using unpublished estimates for Ontario provided by the Ontario Erosion

TABLE 3.5. Estimated Change In The Annual Cost Of Water Erosion In A Five Year Time Span (1984-89).

	% Cultivated Land Predicted to Change Erosion Classes'		Annual Cost in Millions of 1984 Dollars		
REGION	'Little' to 'Moderate'	'Moderate' to 'Severe'	1984	1989	5-Year Difference
P.E.I.	2.5	2.5	5.4	5.6	0.2
N.B.Potato Belt[3]	15	20	12.0	14.9	2.9
South & East N.B.	2	4	0.7	0.7	---
Northern Quebec	15	5	3.4	3.8	0.4
Eastern Townships/ Outaouais	12	5	4.6	5.8	1.2
St. Lawrence	3	2	9.1	10.7	1.6
Eastern Ontario[4]	10	10	2.5	4.4	1.9
Central Ontario[4]	10	10	10.4	12.2	1.8
Northern Ontario	3	1	0.4	0.5	0.1
Western Ontario[5]	1	2	51.2	53.9	2.7
Southern Ontario[5]	1	2	92.8	95.4	2.6
B.C. Southern Coast	2.5	2.5	12.5	12.8	0.3
B.C. Southern Interior	< 1	< 1	1.9	1.9	---
B.C. Omineca	< 1	< 1	0.3	0.3	---
Total[6]			207.2	222.9	15.7

[1] Based on study participant responses

[2] Based on 'high' 1984 water erosion estimates

[3] Five year difference includes estimate of 5% of severely eroded land would go out of production in this time period, as predicted by study participants

[4,5] Single response for combined regions applied to both regions individually

[6] Does not include Newfoundland and Nova Scotia, for which no 5 year predictions were obtained

and Sedimentation Coordination Committee. Using the former study, we suggest that the off-farm economic impacts of soil degradation in the study area, primarily due to reduced water quality and increased flooding, probably exceed $90 million, and may exceed $110 million, each year (see Chapter 9 for more details).

The significance of off-farm damage from agricultural land degradation can be seen when compared with on-farm costs. According to our estimates, off-farm damages in the study area cost the nation much more than acidity and wind erosion combined, and nearly as much as soil compaction. For this reason it is important to consider the off-farm costs when estimating the total economic impact of soil degradation.

3.3 RECOMMENDATIONS FOR FURTHER STUDY

Our review of the literature on the economic impacts of soil degradation from an economic perspective suggests that very little actual data are available upon which to base water erosion, wind erosion and compaction damage estimates in any of the study regions. Some data on crop yield reduction due to water erosion are available for Ontario, New Brunswick and Nova Scotia, and limited compaction data are available for Ontario and Quebec. We could find no studies which have attempted to quantify the added costs of time, machinery and labour as a result of degradation by erosion or compaction. These would have been very helpful. The only data that could be obtained on off-farm economic impacts apply only to the province of Ontario, and these estimates are unpublished. Therefore, it is critical that the estimates provided in this report be considered as very tentative.

In order to refine the estimates of on and off-farm economic impacts of soil degradation made here, we would suggest that the following work needs to be done:

1) The compilation of an improved data base on the location and extent of soils affected by various degrees of past erosion and compaction, using field observations rather than predictive models of erosion rates;

2) Long-term monitoring of soil degradation processes in the field to calibrate and improve methods of estimation and to detect changes in soil quality;

3) Studies of the effects of compaction and structural deterioration on yields of all major crops and soil types;

4) Studies of the effects of water erosion on yields of vegetables, small fruits and tobacco, calibrated to soil types and soil loss rates;

5) More detailed empirical investigations into the off-farm impacts of agricultural land degradation in Atlantic Canada, Quebec and British Columbia;

6) A study of long-term yield reductions due to wind erosion in southwestern Ontario;

7) Case studies of the incremental time, effort and machinery costs required to cultivate fields affected by sheet, rill and gully erosion and soil compaction.

4.0 METHODOLOGY

4.1 LOCATION AND EXTENT OF SOIL DEGRADATION RISK

Soil degradation results from an interaction between the manner in which the soil is used, and the physical and chemical characteristics of that soil. A variation in either the nature of the soil or the methods of land use will result in different processes and rates of degradation.

Since data on the actual state of soil degradation in Canada are incomplete, the determination of the physical extent and severity of soil degradation within the study area was based on the risk of degradation, assuming that current land use practices will continue in the future. The degree and extent that current cropping patterns are likely to be degrading the soil were examined. It was assumed that the risk of soil degradation, as calculated here, was an accurate proxy for the amount of degradation which has occurred. Unit area values were then multiplied by the areas of land in each crop/degradation risk class combination to determine on-farm economic impacts.

To determination the amounts and location of the area affected by degradation a large electronic data base of physical soil characteristics and land use was compiled to which standard 'models' of the degradation processes, expected to be operative in Atlantic Canada, Central Canada and British Columbia were applied. Estimates of the degree and area affected by wind and water erosion, acidification and soil compaction were derived. A detailed explanation of the methodology is presented in the following sections.

4.1.1 <u>Development of the Data Base of Physical Soil Characteristics</u>

Generalized maps depicting relatively uniform soil landscapes at scales ranging from 1:1,000,000 to 1:250,000 were prepared for each province. These maps were compiled from the hest available soil surveys in each province. The most common mapping scales of the source documents were 1:63,360 or 1:50,000, but ranged from 1:25,000 to 1:250,000. In a few northern areas soil survey maps were unavailable, and the generalized maps were compiled from Canada Land Inventory (CLI) soil capability maps.

The map areas depicting soil landscapes are called soil polygons. These polygons show major soil properties such as soil development, soil texture, parent material, surface form and slope gradient. Soil development is indicative of natural fertility, drainage and pH. Soil texture influences moisture storage capacity, availability of moisture to plants and susceptibility to erosion and compaction. Slope gradient and slope length influence susceptibility to water erosion. The soil parent material integrates aspects of surficial geology, mode of deposition, texture and surface form.

The information contained in each soil polygon on the generalized soil landscape maps was coded into a computerized data base. For example, the property 'soil texture' was coded into classes of sand, sandy loam, loam, clay loam, and clay, which depict corresponding plant available water capacities of 50, 100, 150, 200 and 250 mm. Similarly, slope gradient was coded in classes of 1-3%, 4-9%, 10-15% and 16-30%. Surface form classes included level, undulating, hummocky, rolling or dissected (See table 4.1). All information was coded for the dominant soil landscapes which occupy more than 40% of each polygon and for subdominant landscapes which occupy less than 40% but more than 15% of each polygon.

Additional information, required to apply the Universal Soil Loss Equation (USLE), the Wind Erosion Equation (WEE) and the interpretive schemes developed to depict acidification, compaction and structure deterioration was collected and coded into the data base. This

TABLE 4.1 Generalized Soil Landscape Property Classes And Their Codes Used In The Extended Legend.

SOIL DEVELOPMENT	
A	Brown Chernozemic
B	Dark Brown Chernozemic
C	Black Chernozemic
D	Dark Gray Chernozemic or Dark Gray Luvisolic
E	Gray Brown Luvisolic
F	Gray Luvisolic
G	Brown Solonetzic
H	Dark Brown Solonetzic
I	Brunisolic Gray Luvisol
J	Black Solonetzic
K	Gray Solonetzic
L	Melanic Brunisol
M	Eutric Brunisol
N	Sombric Brunisol
O	Organic Cryosol
P	Dystric Brunisol
Q	Humic Podzol
R	Regosol
S	Static Cryosol
T	Turbic Cryosol
U	Gleysolic
V	Ferro Humic Podzol
W	Humo Ferric Podzol
X	Fibrisol
Y	Mesisol
Z	Humisol
2	Folisol

NON-SOIL MATERIALS	
R1	Soft Rock Undiff.
R2	Hard Rock Acidic
R3	Hard Rock Basic
R4	Hard Rock Undiff.

CALCAREOUS CLASSES	
0	Non
1	Weakly
2	Strongly
3	Extremely

WATER TABLE DEPTH	
1	0-2m
2	2-3m
3	>3m
4	0-1m
5	1-2m

TEXTURE GROUPS AND TEXTURAL CODES FOR PARENT MATERIAL OR SURFACE	
SD	Sand Group Includes:
S	Sand
LS	Loamy Sand
FS	Fine Sand
GS	Gravelly Sand
VFS	Very Fine Sand
LFS	Loamy Fine Sand
LVFS	Loamy Very Fine Sand
GLS	Gravelly Loamy Sand
CB	Cobbly
SL	Sandy Loam Group Includes:
FL	Fine Sandy Loam
SL	Sandy Loam
GSL	Gravelly Sandy Loam
CBSL	Cobbly Sandy Loam
LM	Loam Group Includes:
VL	Very fine Sandy Loam
CBL	Cobbly Loam
GL	Gravelly Loam
CBGL	Cobbly Gravelly Loam
GFL	Gravelly Fine Loam
L	Loam
SL	Silt Loam
GSIL	Gravelly Silt Loam
CL	Clay Loam Group Includes:
VCL	Very Fine Sandy Clay Loam
CL	Clay Loam
SICL	Silty Clay Loam
SCL	Sandy Clay Loam
C	Clay Group Includes:
C	Clay
GSIC	Gravelly Silty Clay
SIC	Silty Clay
SC	Sandy Clay
HC	Heavy Clay

DRAINAGE CLASSES	
E	Excessive
R	Rapid
W	Well
I	Imperfect
P	Poor
V	Very poor

COMPACTED OR CONSOLIDATED LAYER	
B	Basal Till
C	Compacted Mat. (Anthropogenic)
D	Duric
F	Fragipan
O	Ortstein
P	Placic
R	Rock

GENETIC ORIGIN OF PARENT MATERIAL	
A	Alluvial
B	Bog
C	Colluvial
D	Residual
E	Eolian
F	Fluvioglacial
H	Marsh
L	Lacustrine
M	Morainal
N	Fen
O	Organic Undifferentiated
R	Rock
S	Swamp
T	Anthropogenic
U	Undifferentiated
W	Marine
11	Fibric Sphagnum
21	Mesic Sedge
22	Mesic Woody Sedge
23	Mesic Woody Forest
24	Mesic Brown Moss
25	Mesic Spagnum
26	Mesic Moss Forest
30	Mesic Moss Forest
31	Humic Sedge
32	Humic Woody Sedge
33	Humic Woody Forest
34	Humic Brown Moss

DEPTH TO COMPACTED OR CONSOLIDATED LAYER	
1	0-50 cm
2	50-100 cm
3	> 100 cm

SURFACE FORM	
Mineral Soils:	
D	Dissected
H	Hummocky
I	Inclined
K	Knoll and Kettle
L	Level
M	Rolling
R	Ridged
S	Steep
U	Undulating
V	Veneer
T	Terraced
Organic Soils:	
B01	Bog Palsa
B04	Bog Domed
B05	Bog Polygonal Peat Plateau
B06	Bog Lowland Polygon
B07	Bog Peat Plateau
B08	Bog Northern Plateau
B09	Bog Atlantic Plateau
B13	Bog Basin
B14	Bog Flat
B15	Bog String
B16	Bog Blanket
B17	Bog Bowl
B18	Bog Slope
B19	Bog Veneer
F01	Fen Northern Ribbed
F07	Fen Shore
F08	Fen Collapse
F11	Fen Slope
F13	Fen Horizontal
M01	Marsh Estuarian High
M02	Marsh Estuarian Low
M06	Marsh Stream
M11	Marsh Shallow Basin
M14	Marsh Shore
S01	Swamp Stream
S03	Swamp Peat Margin
S04	Swamp Basin
S05	Swamp Flat

SLOPE LENGTH	
1	0-100 ft
2	100-500 ft
3	500-1000 ft
4	>1000 ft

Slope %	
4	4-9%
10	10-15%
16	16-30%
31	31-61%
61	61+%

SOIL OR LANDSCAPE INCLUSIONS	
A	Acid Surface Soil
BL	Blanket
BS	Bedrock Soft
BR	Bedrock Hard
C	Clay substrate
CA	Calcareous Surface Soil
D	Sandy Marine Mat.
E	Eroded Knolls
ES	Eroded Slopes
G	Sandy Lm. Morainal Mat.
GL	Gleyed
ID	Imperfect Drainage
L	Melanic Brunisol
LI	Lithic
LM	Lm. Morainal Till
M	Eutric Brunisol
ML	Marine Clay Loam Mat.
MP	Moss Peat
N	Sombric Brunisol
O	Organic
OC	Organic Cryosol
OT	Ortstein
P	Dystric Brunisol
PD	Poorly Drained
PP	Poorly Drained Peaty
R1	Soft Rock Outcrop - Undifferentiated
R2	Rock OutCrop Acidic
R3	Rock OutCrop Basic
R4	Hardrock Outcrop - Undifferentiated
RD	Rapidly Drained
SA	Saline
SC	Static Cryosol
SG	Sandy Glaciofluvial
SP	Steep
ST	Stoney
T	Till Substrate
TC	Turbic Cryosol
TE	Terric
V	Veneer
WD	Well Drained
WE	Wind Erosion
X	Fibrisol
Y	Mesisol
Z	Humisol
11	Fibric Sphagnum
21	Mesic Sedge
23	Mesic Woody Forest

information included such variables as depth to bedrock, drainage, slope length and compact layers. These more detailed data sets were prepared for over 2,700 polygons containing agricultural land. Organic soils were not included in this analysis as there are as yet no suitable procedures for determining erosion, compaction or acidification rates in these soils. Other soil specific variables were extracted from existing electronic data bases, such as those maintained by the Canada Soil Information System (CanSIS) and the British Columbia Soil Information System (BCSIS). Wherever possible mean values from two or more representative soil profiles were used. Where no representative detailed site data existed in these files, the original soil survey reports were used to identify the dominant soil series for each polygon, and available data was extracted from published tables. For some polygons, however, data were available only from generalized sources such as topographic and capability maps, or from knowledgeable individuals in the region.

4.1.2 Development of the Data Base of Agricultural Land Use Practices

Information on the area of crops, and groups of crops representative of crop rotations, in each soil polygon was obtained from the census of Agriculture (1981) by linking census Enumeration Areas (EA's) with soil polygons. This link was established by overlaying Federal Electoral District maps, which contain EA boundaries and numbers, onto the appropriate soil landscape map and creating a computer file listing the EA(s) corresponding to each polygon. In addition, a generalized (1:7.5 M) map from the National Atlas of Canada, 5th Edition, showing 'agricultural land' areas was used to obtain an estimate of the area of each polygon that currently is used for field cropping or pasture (personal communication , C. Gosson, Energy Mines and Resources Canada, Ottawa). The following conventions were following in creating the data file:

1) Only the 'agricultural' portions of the EA's and polygons were considered in assigning EA's to polygons;

2) EA's were assigned to the soil polygon in which the largest portion of their area occurred;

3) If no EA's were assigned to a polygon containing agricultural land, the data from that EA with the largest portion of its area in that polygon was used to indicate land use percentages;

4) Polygons with no agricultural land were excluded.

The EA/Polygon files were submitted to Statistics Canada for keying and statistical analysis. Polygons with less than 10 farms were grouped with other similar map units to maintain confidentiality. The area of crops and other agricultural land use types were calculated for each polygon in each province, and expressed as a percentage of the agricultural land in each polygon. The following crops, crop groups and land use types were evaluated: (1) nursery crops; (2) tree fruit; (3) small fruit (berries and grapes); (4) vegetables; (5) potatoes; (6) sugarbeets; (7) tobacco; (8) grain corn; (9) ensilage corn; (10) beans (soybeans, field beans, field peas, sunflowers); (11) fall grain (rye, wheat); (12) spring grain (oats, barley, wheat, buckwheat, rye, flax, canola); (13) alfalfa; (14) hay; (15) summerfallow; (16) sod; (17) root crops; (18) improved pasture; (19) other improved land; (20) woodland; and (21) other unimproved land (rangeland, native pasture). The area and percentage distribution of each of these categories was used in calculating the risk/potential class for each type of soil degradation for each polygon.

Polygons that are predominantly CLI class 7 soils were assumed to be non-agricultural unless census data indicated the presence of at least 10 farms.

Correction Factor for 'Agricultural Land'

Agricultural land areas were estimated by multiplying soil polygon areas by estimates of the percentage of each polygon area that is 'agricultural', obtained by overlaying polygon boundaries on maps of 'agricultural land'. Agricultural areas estimated in this way did not always correspond to the area of farmland reported in each region through the Census of Agriculture (Statistics Canada). Several reasons exist for these discrepancies. Most important among these is the generalized nature of the agricultural land maps. Rounding errors in estimating percent agricultural land may also have contributed to area differences.

Errors were found to be small in regions with large areas of intensive cropping and few woodlots. Where much farm land is wooded, errors are greater. In some regions (e.g. northern Ontario) many small cleared areas appear not to have been included, so crop areas computed from soil polygon areas tended to be less than census values. In most regions, however, areas computed from 'agricultural land' tended to be larger than census values.

In order to bring results as close as possible to Statistics Canada values, a correction factor was required, specific to each region. A correction factor based on 'row-crops' was chosen, as errors in this group of crops are of greatest significance in terms of the economic analysis. Most values were between 0.8 and 1.1. The greatest difference to be corrected was encountered in Newfoundland, resulting in a correction factor of 0.18 and suggesting that much of the land classified as 'agricultural' in this province is not used for agriculture.

4.1.3 Interpretations of Soil Degradation Risk

Interpretations of risk of water and wind erosion, acidification, and compaction/soil structure deterioration were made for each polygon. Procedures and criteria for each interpretation are described below.

Water Erosion

The assessment of water erosion risk was based on the Universal Soil Loss Equation (USLE). Attempts were made to rate polygons in terms of their erosion risk under average annual conditions of rainfall and snowmelt runoff.

The USLE is an equation of the form: A= RKLSCP (Wischmeier and Smith, 1978). Each factor was estimated as follows:

K= Rr + Rs where:

R= Rainfall erosivity, modified to include a snow melt factor as follows:

Rr = computed rainfall factor using Ateshian (1974) estimation for non-snowfall months (R = 0.373 p2.2, where p = 2 yr, 6 hr rainfall in mm)

Rs = snowmelt factor from the sum of monthly precipitation (in mm) for December through March, provided that the average 30 yr normal monthly snowfall is at least 10 cm. The months of November and April were also included if the mean monthly snowfall exceeds 25 cm.

In an area of southern British Columbia where mean annual snowfall is less than 100 cm, only those months with snowfall greater than 20 cm were included. This modification was made to correct an apparent overestimation of Rs in that region when the 10 cm snowfall criterion was used.

R was computed for 116 climate stations in eastern Canada, and 113 in British Columbia having rainfall intensity (tipping bucket) records. Values were plotted on maps and iso-lines drawn. Polygon values were interpolated from the iso-lines.

K = soil erodibility, estimated from Wischmeier and Smith's (1978) monograph wherever soil particle size and organic matter data were available. Where these were not available, estimates were based on similar texture classes in the same province or region. The 'soil structure' modification used by Wischmeier and Smith was not used in eastern Canada as reliable data could not be obtained for most polygons. The 'soil permeability' modification was simplified to 3 classes (instead of 6) and was estimated from the texture class of the most restrictive horizon in the profile. 'Structure' and 'permeability' classes were estimated from soil clay content and texture class, respectively, for British Columbia polygons.

L = length of slope. Estimates of slope length were provided by soil survey personnel for all polygons except those in Ontario, Quebec and British Columbia. In Ontario 'L' was estimated by interpreting slope class and landform (Shelton *et al.*, 1984). In Quebec, the same slope class and landform values were used as in Ontario, except with 'rolling' landform where the longer slopes of the Atlantic provinces were used. In British Columbia 'L' was assigned on the basis of landforms without modification by slope class. It was based on an estimate of the average length of slopes within the polygon, and was recorded in four classes:

1) <30 m (100 ft); L = 15 m (50 ft)
2) 30 - 150 m (100 - 500 ft); L = 90 m (300 ft)
3) 150 - 300 m (500 - 1000 ft); L = 225 m (750 ft)
4) >300 m (1000 ft); L = 300 m (1000 ft)

In British Columbia, polygons with steep slopes are frequently encountered which contain small amounts of agricultural land located on flat valley bottoms Dominant slopes in such polygons are unrepresentative of the agricultural portion. To partially correct for this problem, polygons with 10 percent or less of their area in agricultural land use were assumed 'flat' for the purpose of calculating erosion risk.

S = slope gradient (%); assumed to be the mid-point of the polygon slope class unless other data were provided.

C = cropping factor; the proportion of the expected soil loss compared to that from bare fallow (value 1.00). The cropping factor (C) was calculated for each crop and land use type in each of the crop rotations common to a region. The procedure as outlined for the USLE was followed, using expert opinion to identify best estimates, and interpolations for Canadian conditions where necessary.

For the purpose of calculating water erosion, Atlantic Canada, Central Canada and Southern British Columbia were divided into 16 regions based on cropping practices and mean monthly rainfall distribution. Common crop rotations (eg. monoculture grain corn; silage corn-silage corn-cereal-grain-hay-hay; potato-potato-cereal grain-potato; etc.) were established for each region on the basis of field surveys and consultations with specialists in the region . Growth stages for each crop in each rotation were identified through literature reviews and farm management recommendations. The C-factor calculation, as outlined by Wischmeier and Smith (1978), was conducted on a mini-computer (D. Trant, Statistics Canada), and C-factors for each crop and rotation were calculated for each region. C-factor values ranged from 0.00 for continuous grass hay to 0.72 for continuous vegetables.

To produce a single C-factor for each crop, a weighted mean based on the proportion of area devoted to each rotation within a region was calculated. Using a farm typing program, a sample of several counties in each region was analysed, providing a representation of the distribution of crop rotations by area. C-factors for each crop were then multiplied by the appropriate proportion to give a weighted C-factor for each crop by region. These factors were multiplied by the proportion of crops in each polygon (as calculated through polygon Enumeration Area overlays), and summed to give a single polygon C-factor.

P = <u>the conservation practice factor</u>. This was considered to be 1.00, as there was no evidence that any polygons had been treated significantly (i.e. >25%) with conservation practices such as diversion terraces or strip cropping.

Five erosion risk classes based on matching output from the above analysis to observations of study participants (see section 4.2), were used in this study. They were applied to erosion risk values calculated using the USLE as follows:

Class	1 (slight)	0 - 2.5 t/ha/yr
"	2 (low)	2.5 - 10.0 " " "
"	3 (moderate)	10.1 - 25.0 “ ” “
"	4 (high)	25.1 - 50.0 " " "
"	5 (severe)	> 50.0 " " "

For the economic analysis, these classes were further collapsed into 3 more general classes (see Section 4.2.4.).

<u>Wind Erosion</u>

The assessment of wind erosion risk was based on a generalized mean annual risk estimate using the Wind Erosion Equation (WEE) developed by the United States Department of Agriculture to estimate wind erosion risk in the Great Plains region (Woodruff and Siddoway, 1965). The WEE reduces a great quantity of detailed research results to a simple annual estimate based on the relationship between soil erodibility (a function of soil texture and moisture), surface roughness and wind speed. Soil moisture and wind speed were combined into a 'climate factor' (C) and expressed as (Lyles, 1983):

$$C = 386 \frac{\overline{U}_z^{\,3}}{[\sum_{i=1}^{n} 10(P-E)_i]^2}$$

where U_z is the average annual wind speed (m/s) at 9.1 m above ground level, i represents months, and (P-E) is the monthly Thornthwaite precipitation evaporation index, estimated as follows:

$$(P-E) = 11.5\,[\,(P/2.54)\,/\,(1.8\,T + 22)]^{10/9}$$

where P is monthly precipitation (cm) and T is the mean monthly temperature (Celsius) and must be $\geq$ -1.7 degrees.

The 'C' factor relates sites to conditions at Garden City, Kansas (value 100), where the wind erodibility studies were carried out.

'C' values were computed for 104 climate stations in Eastern Canada, and 33 in southern British Columbia having wind speed data. Iso-lines were drawn and polygon values interpolated from these lines. In British Columbia 4 zones of wind 'C' values were mapped, and polygons assigned to the most appropriate zone.

Wind erodibility of dry soils was based on percent dry aggregates >0.84 mm in diameter. This percentage was estimated for seven soil textural groups from tabulated data by surface texture prepared in North Dakota, Ohio and New York - the closest United States states with available information. From the percent dry aggregates >0.84 mm, erosion rates were obtained from a table prepared by Woodruff and Siddoway (1965).

The effect of crop residues on the soil surface was also taken into account when calculating wind erosion risk classes. When wind erosion occurs in eastern Canada, it is often during the winter-spring period, as observed in Ontario (Fitzsimons and Nickling, 1982). Crop residue estimates were made from Census of Agriculture EA data. They included residues remaining after fall tillage, and assumed to cover fields during the winter-spring period.

Crop residues from different crop types at harvest, reduced by expected tillage operations, were computed and a mean annual crop residue was obtained for 11 crop groups. Erosion reduction factors were estimated by crop group and applied to the unadjusted wind erosion risk for each polygon. The mean 'reduced' wind erosion rate appropriate for the soil type and climate factor of each polygon was then computed. Classes of wind erosion risk were established similar to those used for water erosion.

Acidifying Inputs to Soils

Man-induced soil acidity inputs (in kg. of calcium carbonate ($CaCO_3$) equivalent per hectare per year) were computed for current fertilizer nitrogen use and acid rain using procedures of Coote, *et. al.* (in press). They were derived using estimates of N use (type of fertilizer and application rate per unit area), and atmospheric deposition. Fertilizer use by province was derived from the Fertilizer Institute Canada. Distribution of fertilizer use within each province was calculated by crop type, employing average ratios of N use from crop to crop (based on fertilizer recommendations published by Ontario Ministry of Agriculture and Food) to estimate the distribution of the total use among the crops grown. Atmospheric input was derived from data complied from the Canadian Network for Sampling Precipitation (CANSAP).

Soil Acidification Risk:

Soil sensitivity to acidification was estimated according to criteria established by Wang and Coote (1981). It defines sensitivity to change in soil base status according to exchangeable bases present in the surface soil (at field pH) as follows:

sensitive	- <6 meq/100 gm
moderately sensitive	- 6-15 meq/100 gm
non-sensitive	- >15 meq/100 gm

Soils in each polygon were rated using available soil survey information. Where data were not available, a relationship between pH (in water) and base saturation (permanent charge) was used to estimate exchangeable bases from a known cation exchange capacity (CEC) or from a CEC estimated from texture and organic matter content.

Risk of Soil Structure Deterioration and Compaction

Three soil characteristics for which data are reasonably reliable and widely available (texture, drainage class and organic carbon content) and an estimate of the impact of tillage and machinery were used to make this interpretation. Five classes of susceptability separate soils into high, moderate and low susceptibility to 'compaction' were derived, (Table 4.2) which reflect the importance of soil moisture, organic matter and clay content in soil compaction (De Kimpe *et al.* 1982; Gameda *et al.*, 1983; Battison *et al.*, 1984; Kay *et al.* 1984) as well as numerous observations of soil structure deterioration when heavy equipment is used on clay soils under wet conditions (e.g. Raghavan *et al.*, 1977; McKyes *et al.*, 1980). Organic carbon is given a lower level of importance in the matrix as available data on this factor are the least reliable of the three.

The type and frequency of tillage and traffic associated with an 'average' cropping system (e.g. a corn-oats-hay-hay rotation) was evaluated. Cropping systems employing more frequent tillage (e.g. continuous corn) also tend to result in lower soil organic matter levels (Groenevelt *et al.*, 1983; Coote, 1983). Tillage and traffic impacts of various cropping systems were estimated from the frequency and type of each equipment pass, weighted by time of year to account for soil moisture. Haymaking and cereal grain harvesting equipment, and post-emergence spraying, were considered to have litle effect on compaction because conditions are ususally dry and the soil is not disturbed. The harvesting of silage corn, potatoes or sugar beets was considered to be more damaging to soil structure as soil conditions are often moist, loads are heavy and distance between wheel tracks is reduced. Plowing, spring seedbed preparation and inter-row tillage are intermediate in their impact on soil structure.

An index of the type, weight and frequency of tillage and machinery traffic was computed for each polygon using cropping information from EA data. 'High' values of this index increased the risk of compaction by one class, and 'low' values decreased it by one class, compared with the moderate values obtained for many intermediate crop rotations (Table 4.2).

4.2 ECONOMIC ASSESSMENT OF FARM LEVEL IMPACTS

The analytic procedure used to assess the on-farm economic impacts required estimates of crop yield reduction associated with each type of and class of soil degradation. Few data of this type are published in the literature. To obtain estimates of degradation-induced yield loss and other economic effects we decided to poll the opinions of a selected group of experts in each region of the study area. The methods used in obtaining these estimates and in conducting the economic analysis are described below.

TABLE 4.2. Risk Of Soil Structure Deterioration And Compaction.

		Frequency and weight of tillage and traffic								
		High			mod.			low		
	Drainage:	Poor	Imp.	Well	Poor	Imp.	Well	Poor	Imp.	Well
Texture	O.C.									
sandy	>2%	H	M	M	M	L	L	L	VL	VL
sandy	<2%	H	H	M	M	M	L	L	L	VL
loamy	>2%	H	H	M	M	M	L	L	L	VL
loamy	<2%	VH	H	H	H	M	M	M	L	L
clayey	>2%	VH	H	H	H	M	M	M	L	L
clayey	<2%	VH	VH	H	H	H	M	M	M	L

4.2.1 Delineation of Regions

Sixteen regions were delineated: two in New Brunswick , three in Quebec and British Columbia and five in Ontario. Newfoundland, Nova Scotia and Prince Edward Island were each treated as a single region. These regions are shown in Figure 3.1.

4.2.2 Method of Obtaining and Analyzing Participant Response

Information on the economic impacts of soil degradation was collected by subjecting regionally representative groups of agricultural specialists to a series of questionnaires, group consensus meetings and telephone follow-ups. Each group included soil and water program managers, pedologists, soil and crop specialists, agricultural representatives, research scientists and farmers with an active interest in soil degradation issues. Group members were confirmed in advance by telephone to ensure sufficient representation. The number of participants in each group varied from 7 to 14. Many individuals who were unable to attend meetings contributed questionnaires and/or provided opinions on particular aspects of the degradation problem. A list of the study group participants is provided in Appendix A.

We obtained our data using a technique known as the Nominal Group Process. The NGP is a modified form of the Delphi Technique, which uses several iterations of a questionnaire-feedback cycle to obtain group concensus from participants who are working on the problem individually (Linstone & Turoff 1975). A questionnaire was completed by each group member. The information thus obtained was summarized by the consultant and formed the basis of discussion at the subsequent group meeting. The questionnaire helped participants prepare for the meeting by letting them know in advance what would be discussed. Participants had the opportunity to review reference materials and case reports, or to consult with other members of their staff or organization prior to the meeting. The meeting served to clarify misunderstandings and to obtain a consensus.

Actual group meetings were held during March and April at central locations within the province or region. Six full day meetings were held, covering 12 of the 16 regions:

Meeting Location	Regions Covered
Vancouver, British Columbia	Lower Mainland South Interior Omineca
Guelph, Ontario	Southern Ontario Western Ontario
Ottawa, Ontario	Eastern Ontario Central Ontario
Montreal, Quebec	St. Lawrence Eastern Townships/Outaouais
Fredericton, New Brunswick	Potato Belt South and East New Brunswick
Charlottetown,P.E.I.	Prince Edward Island

Northern Ontario, Northern Quebec, Newfoundland and Nova Scotia were covered in a different manner due to constraints on the study budget. Information from Northern Ontario, Northern Quebec and Newfoundland was obtained from an initial questionnaire and follow-up telephone interviews.

In Nova Scotia, a provincial soil degradation study was in progress at the time our study began. Economic impacts obtained from this other study (Jacques, Whitford and Associates, 1985) were used here, supplemented with data from surrounding regions obtained in this study.

4.2.3 Questionnaire

A questionnaire was developed for each study region (except Nova Scotia). Questions were organized by degradation/limitation parameter. An additional section covered the respondent's background and comments on the questionnaire.

The actual wording of questions was developed following pretesting in Ontario and Quebec, and meetings with Land Resource Research Institute personnel responsible for the physical aspects of the study. A sample questionnaire is provided in Appendix B.

4.2.4 Estimation of Economic Impact of Water and Wind Erosion

To calculate the economic impact of wind and water erosion four farm-level effects were examined: (1) loss of yield; (2) added fertilizer input to partially offset yield loss; (3) increase in cullage, resulting in a loss of marketable product (applied to potatoes only); and (4) added tillage and other input costs. NGP participants were asked to estimate these the farm-level effects on soils that had been eroded to varying degrees. These effects were applied to land areas under row and field crops with moderate and severe erosion risk, based on the predicted annual rate of soil loss. (Refer to Section 4.1.3).

We acknowledge the potential problem of equating erosion risk classes, based on predicted soil loss rates with existing states of erosion. It was necessary to make this assumption because of the paucity of empirical data on the amount of agricultural land affected by various degrees of erosion in Canada. To calibrate our results, field definitions of 'little or none', 'moderate' and 'severe' erosion were included on the questionnaire and NGP participants were asked to estimate the percentage of cropland under each of the erosion categories. The areas in each risk class were found to correspond reasonably well with NGP-derived estimates of existing erosion when the following definitions were used:

Historical Erosion Class	Annual Soil Loss	Risk Class(es)
Little or none	0 - 10 t/ha/yr	1,2
Moderate	10 - 25 " " "	3
Severe	>25 " " "	4,5

These definitions were therefore used in estimating land areas affected by erosion in the economic analysis.

The calculations used to derive estimates of the economic impact of water and wind erosion are explained below. Unless otherwise noted, it was assumed that a given severity class of erosion would have the same effect on crop yields regardless of whether it was caused by water or wind.

<u>Yield Reductions</u>

The equation used for calculating the economic impact of yield loss (IEy) due to water and wind erosion is:

$$IEy = \sum_{c=1}^{n} B_c \left(Y_{c,m} L_{c,m} + Y_{c,s} L_{c,s}\right) \qquad (1)$$

where:

c = type of field crop or crop group. The crops were grouped differently from region to region according to the amount of crop grown and similarities in their erosivity.

B_c = baseline farmgate economic yield ($/ha); typically the most recent provincial value of production of a crop, divided by the hectarage planted in that year, as reported by Statistics Canada. In cases where the baseline was felt to be unusually high or low, the most recent two years of data were averaged.

Y = yield reduction factor (%) for moderate (m) and severe(s) erosion. This was determined in each region through the NGP meetings or questionnaire/follow-ups. Data gaps were filled in using deflation factors estimated in adjacent regions.

L = number of hectares of land with a moderate or severe erosion risk. The physical model provided 'L' for 5 crop groups, typically (except in British Columbia):

- corn
- beans
- potatoes, tobacco, vegetables combined
- spring grain
- fall grain

In many regions, crops in the first three categories were disaggregated further to account for differences in 'B_c or in 'Y', where economic impact 'I' in the region would significantly change as a result.

Crop breakdowns were based on data specially provided by Statistics Canada. These data were provided by crop type and rotations for randomly selected census divisions within the study area. The data were used, to estimate ratios Of crops within groups, and to estimate the percentage of a crop under, a given type of rotation (e.g. continuous potatoes; potatoes in rotation with grain; potatoes in rotation with grain and forage).

Fertilizer Input

The equation used to calculate the cost of exta fertilizer required to partially offset yield reduction caused by erosion (IE_f) is:

$$IE_f = \sum_{c=1}^{n} (f_{c,m} L_{c,m} f_{c,s} L_{c,s}) \qquad (2)$$

where:

f = value of fertilizer input ($/ha) for a given crop and level of erosion to partially compensate for loss of yield.

Other variables are as defined in Equation (1).

This equation places an economic value on the loss of fertilizer requirements only when it is reasonable to assume that more than the normal dosage of fertilizer would be used to compensate for yield loss on eroded land. It does not place an inherent economic value on fertilizer loss with eroded soil unless it would result in an economic penalty to the farmer.

Estimates of added fertilizer inuputs and corresponding reductions in the yield loss factor to account for the portion of lost yield which would be 'brought back' by the extra inputs of fertilizer were obtained from the questionnaires and NGP meetings. Participants were much less inclined to generalize about fertilizer inputs than they were about yield loss factors; therefore there are many data gaps. In two provinces Prince Edward Island and British Columbia, participants noted that over-fertilization was already occuring and that additional fertilizer would not likely ameliorate yield loss due to erosion. Because of these problems and uncertainties, we elected not to fill in any data gaps. For crops where estimates of "f" were made, we compared the economic impact with and without the fertilizer. When the economic impacts were higher with incremental fertilizer than without it, fertilizer was not used in the equation.

Loss of Marketable Product

The economic equation used for calculating the economic value of crop quality reduction due to erosion (IE_m) is:

$$IE_m = 0.1\ B_p\ [L_{p,m}\ (1-Y_{p,m}) + L_{p,s}\ (1-Y_{p,s})] \qquad (3)$$

where:

B_p = baseline farmgate economic yield for potatoes (\$/ha);
L_p = hectares of eroded land on which potatoes are grown, and
Y_p = yield loss factor (%) for potatoes on eroded land.

Other variables are as defined in Equation (1).

This equation was added to the economic loss calculation as a result of the NGP meetings in New Brunswick and Prince Edward Island, where participants noted that burnout from fertilizer addition to combat erosion was resulting in a 5 to 15 percent additional cullage of gross potato yields. Although no other regions noted this problem, it may not have been documented due to the low importance of potatoes relative to other crops outside of New Brunswick and Prince Edward Island. We therefore elected to apply a 10 percent cullage loss factor to eroded potato lands in all regions.

Added Tillage and Other Costs

This factor was used to account for all other economic impacts which were difficult to quantify, including:

1) Need to recontour fields or fill in gullies

2) Removal of stones exposed by eroded soil

3) Maintenance/repair of drainage outlets

4) Added machinery costs, including fuel, labour and depreciation

5) Replacement of pesticides lost with eroded soil.

To cover these losses, we assumed a 5 percent increase in the cost of production would occur on severely eroded soil on which crops were grown. This is a conservative assumption based on the results of the New Brunswick meeting, where it was agreed that costs of production on all eroded land were an average of 5 to 10 percent higher than on non-eroded land.

In applying this increase, costs of production figures were taken from the 1985 series published by the Province of Ontario. In the case of potatoes, costs from each province (except Newfoundland and Nova Scotia) were taken from McGiffin (1983).

Adjustments to Equation

An analysis of our initial calculations revealed that the results are very sensitive to the quantity of high value crops, such as tobacco, vegetables and potatoes, assumed to be grown on eroded soil. This was of particular concern in Southern Ontario, where tobacco and vegetables were found on about 15 percent of the potentially moderately and severely eroded crop land, but generated over 50 percent of the economic impact. The anomally occurred because of the assumption in the calculations of the physical extent of erosion that all crops are grown on 'average' slope conditions for the polygon in which they are located. In fact, some of these high value crops, especially vegetables, will be grown in the flatter areas.

To take this phenomenon into account we simulated the assumption that vegetables and tobacco were indeed grown in flatter areas (we know that potatoes are not, especially in New Brunswick and Prince Edward Island). Where high-value crops were grown we downgraded the 'severely eroded' area to 'moderately eroded', and the 'moderately eroded' area to 'little or no erosion'. The actual economic impact is likely to fall within the range of output provided by the two scenarios. In the case of wind erosion, which is not determined by slope values, no adjustment in the equation was made.

4.2.5 Estimation of Economic Impact of Acidification

To estimate the economic impact of acidification due to nitrogen fertilizer use and acid precipitation we calculated the value of lime required to neutralize these acid inputs (IA). The equation format is:

$$IA = PL\,(R_f + R_a)/1000 \qquad (4)$$

where:

P = unsubsidized price of lime in the region ($/tonne). This was obtained from the questionnaires and NGP meetings.

L = hectares of improved land on soils which are sensitive or moderately sensitive to acidification.

R_f = average dosage of lime required to neutralize annual fertilizer induced acidification on improved land in the region (kg/ha).

R_a = average dosage of lime required to neutralize annual acid precipitation on improved land in the region.

The equation was applied only to soils which are sensitive or moderately sensitive to acidification. However, it should be recognized that some soils presently capable of buffering acid inputs may eventually require lime once their buffering capacity is exceeded.

4.2.6 Estimation of Economic Impact of Soil Compaction and Structure Deterioration

The economic impact of soil compaction and structure deterioration is the most difficult degradation parameter to estimate reliably, due to the lack of empirical data on crop yield reductions. Recognizing this fact, we chose a simple and conservative method for estimating its economic impact (IC). The equation format used is:

$$IC = \sum_{c=1}^{n} B_c\,(Y_{c,s}\ L_{c,s} + Y_{c,l}\,L_{c,l} + Y_{c,k}\ L_{c,k}) \qquad (5)$$

where:

B_c = baseline farmgate economic yield for crop c ($/ha).

Y_c = yield loss factor (%) due to compaction for crop c, grown on sandy (s), loamy (l) or clayey (k) soils. These data were obtained from the questionnaires and NGP.

L_c = hectares of land in crop c with 'high' or 'very high' compaction/structure deterioration potential on sandy, loamy or clayey soils (see Section 4.1.3).

Because row crops in a proper rotation with forage would improve the ability of the soil to resist compaction, we reduced yield loss factors by 50 percent for the portion of the row crop grown in rotation in each region.

4.2.7 Economic Impact of Limitations Imposed by Naturally-Occuring Subsurface Compact Layers

It was not possible to estimate total economic impact of naturally occuring subsurface compact layers (e.g. fragipans, ortstein layers, etc.) with any degree of accuracy due to the limited knowledge on the extent of their occurence and effect on crop yields. Instead, we estimated from the physical data base, the percentage of improved land in each region where soils with naturally-occuring compact layers less than 1 m deep predominate. In addition, some information on the location of compact layers in agricultural areas and methods to ameliorate the problems they cause was provided in the questionnaires and NGP. This information is presented in the body of the report.

4.3 ASSESSMENT OF OFF-FARM IMPACTS

An in-depth estimate of the off-farm effects of agricultural land use is a major research effort beyond the scope of this study. Although it is sometimes possible to quantify short-term changes in the environment, some of the more complex and long-term effects of land degradation are difficult to isolate from other processes, and are difficult to measure and cost. In most cases the damages are not well-documented, or are the result of a number of land use activities, as well as natural phenomena. The assignment or apportionment of costs to agricultural land degradation cannot be done without more data.

The discussion of off-farm economic impacts in Chapter 9 describes the principal resource or economic activities affected. Problems encountered from land degradation are described and, whenever possible, an estimate of the commercial value of the affected resource, the extent of damage and the nature and cost of corrective measures is noted.

A literature review and telephone interviews with key individuals were the main sources of off-farm impact information. A computer search of the Canadian Environment (CENV) data base from 1970 to the present and of the Aqualine data base from 1960 to the present was conducted to facilitate the literature review. Data on the value of an economic activity potentially affected by agricultural land degradation was obtained from appropriate government departments.

The cost of implementing control or compensation measures and the damage attributed to agricultural land degradation is relatively site-specific. Data on these control measures were only available for the Great Lakes region in Ontario, the only location in the study area where anyone has attempted to calculate the off-farm economic impact of erosion and sedimentation. Ontario costs were not extrapolated to other regions because the factors used to derive these costs are quite specific to the Great Lakes region's land, water and population base.

The fact that the Great Lakes Basin is a relatively closed system with a large agricultural land base is very significant to the estimation of economic effects of agricultural erosion. In contrast, the effects of sedimentation on water quality in British Columbia are mainly due to logging activities, thus making it difficult to calculate economic impacts attributable to agricultural land use practices. In the case of all coastal provinces, most of the agricultural runoff is deposited in tidal estuaries or the ocean where factors such as tide and wave action play an important (and site-specific) role in the distribution of agricultural sediments, nutrients and pesticides. These factors have not been studied in Canada to date.

A discussion includes a comparison of the situation in the study area with that found in the United States , where an attempt was made by the Conservation Foundation to quantify the national off-farm economic cost of agricultural soil erosion (Clark et al., 1985). To obtain an order-of-magnitude estimate of the off-farm damage attributable to agriculture in our study area, we calculate the average amount of off-farm damages per unit area of row crop in the United States. This number was multiplied by the row crop area in our study area after adjustments for base year and the United States -Canada exchange rate were made. While the area under row crops is only one of several major factors determining the amount and cost of damage, our estimate provides a good indicator of the relative magnitude of the problem which can be used until more Canadian data are generated to provide a more accurate estimate.

5.0 WATER AND WIND EROSION

5.1 OVERVIEW OF THE PROBLEM

Water erosion is the most widespread and recognized form of agricultural land degradation in Canada, and has recently attracted much national attention as a result of Federal Government Senate Committee hearings. The types of water erosion covered in this study are those caused by rainfall runoff and snowmelt, primarily sheet and rill erosion.

Compared with water erosion, wind erosion is a more localized phenomenon. It is associated with low or variable rainfall, high wind speeds, open vegetation cover and topsoil possessing a high proportion of coarse grained materials or fine aggregates. Though most commonly considered a Western Canada problem, there are several places in Central and Eastern Canada where the combination of soil, crop and weather conditions have created a moderate wind erosion hazard. Unfortunately, there is little documentation on the economic effects of this phenomenon.

The extent, severity and economic impact of water and wind erosion are presented together in this section. The results are tabulated by region under the province in which it is found. The locations of areas with moderate and severe risk are shown in Figures 5.1 and 5.2.

Agriculturally-induced streambank and shoreline erosion are not covered in this study, but are undoubtedly responsible for significant economic losses in specific areas within study regions.

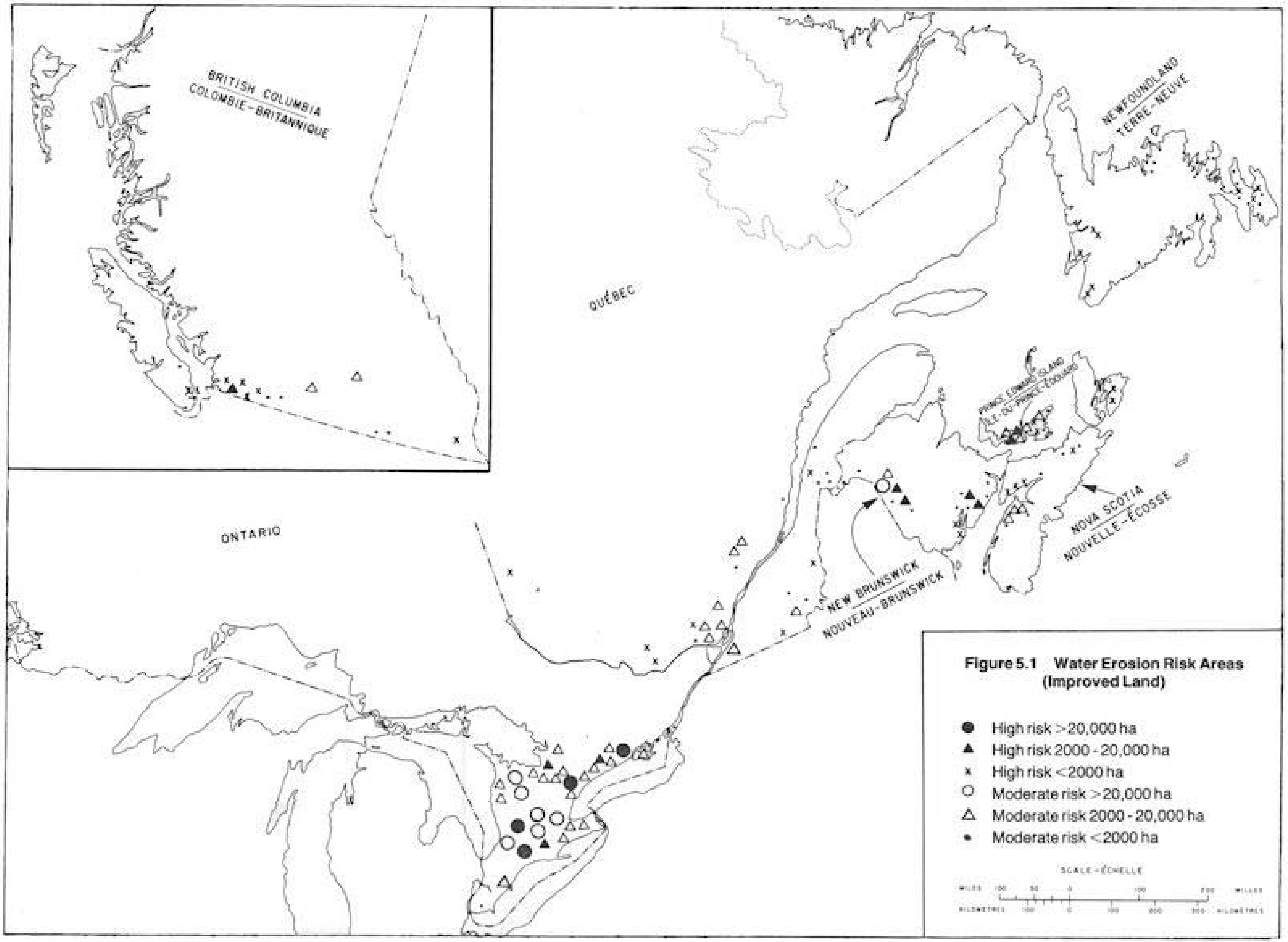

Figure 5.1 Water Erosion Risk Areas (Improved Land)

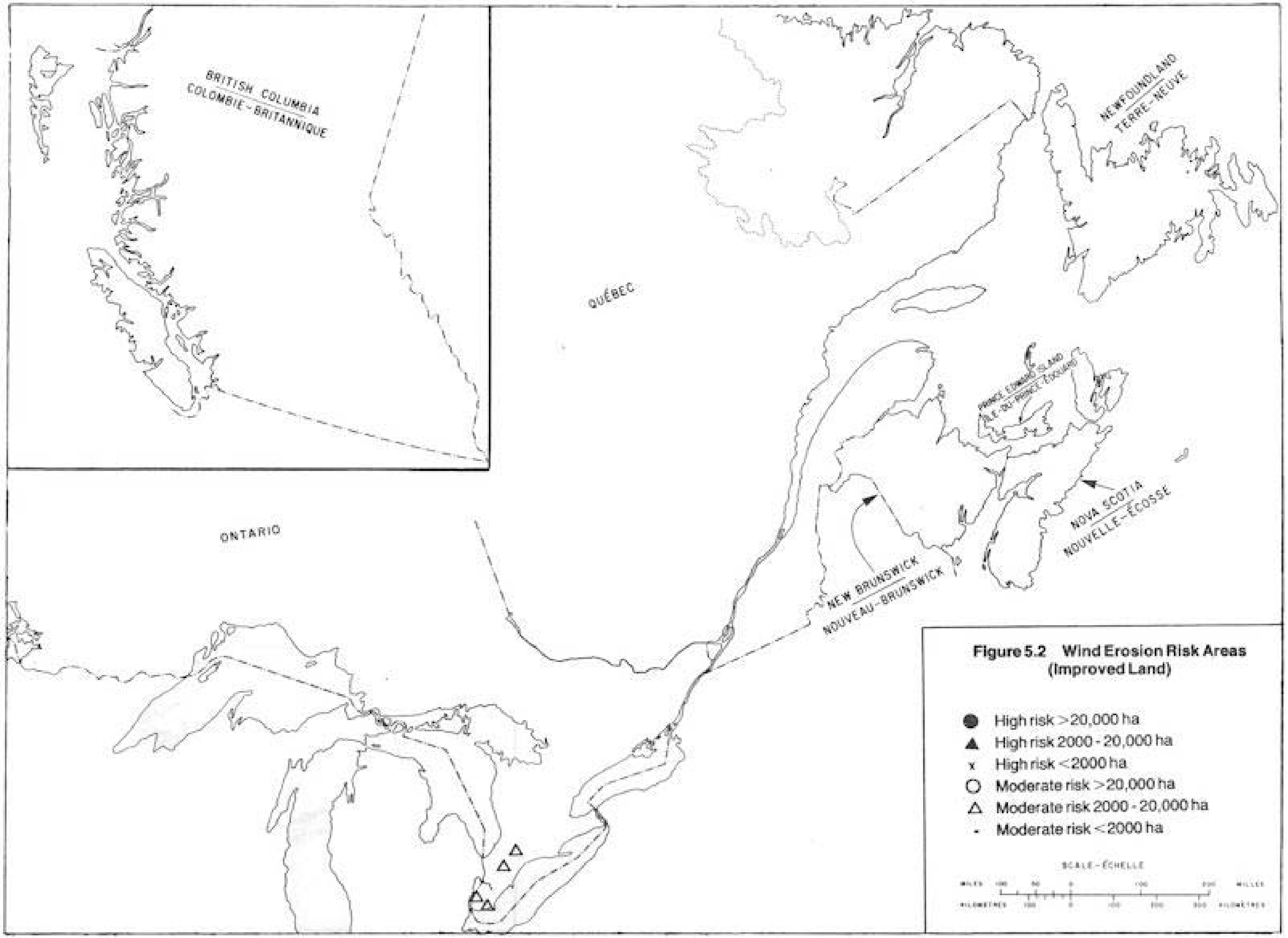

Figure 5.2 Wind Erosion Risk Areas (Improved Land)

5.2 NEWFOUNDLAND

5.2.1 Extent and Severity

Several soil areas to the north of St. John's and in the Conception Bay area have a very high potential for water erosion. Only small portions of these areas are cleared and cultivated, however, so actual soil losses are probably low. The more agriculturally valuable soils in this area have low water erosion risk, because slopes are flatter. Major crops include potatoes and vegetables. Where the risk of erosion is high on mineral soils, it is primarily because of steeper slopes. Most of the province's livestock and hay are located in this part of the province. Some organic soils are also used for agriculture, but no degradation estimates were made for these soils.

East of Corner Brook, in the Humber River Valley, and in the Codroy Valley in the southwest, potato production (and cabbages in the Humber River Valley) contributes to some high potential erosion rates on steeper land. However, the small percentage of farmland in the overall area involved indicates that flatter slopes, and thus lower erosion rates, are more probable than those used in the analysis.

Very few areas in the rest of the province, have significant water erosion. Where high potential is found, it is primarily because of steep slopes which are unlikely to be cultivated in areas where small percentages of the landscape are farmed. Potatoes and vegetables are the chief crops involved where erosion risk is noted. An example is the potato production on fairly steep slopes (15 percent) in the Lethbridge area. The high rainfall erosivity values in Newfoundland also contribute to these high risk values.

There are few significant wind erosion problems on mineral soils in Newfoundland, as the two areas with moderately high wind erosion risk have very little cleared land. Climatic factors affecting wind erosion are relatively high compared with other regions, so the potential for wind erosion cannot be ignored.

5.2.2 Economic Impact

Soil erosion on agricultural land in Newfoundland is generally not considered to be a problem, and has not been the subject of quantitative research. It is not surprising, therefore, that the study participants were unable to provide estimates for crop yield loss or other economic impact factors. For this reason it was necessary to use yield loss factors from neighbouring provinces in order to calculate economic impact estimates. The results, shown in Table 5.1, estimate the annual on-farm cost of erosion to be between $730,000 and $860,000. Most of this occurs on land growing potatoes and vegetable crops.

A recent submission to the Standing Senate Committee on Agriculture, Fisheries and Forestry (Stewart and Sudom, 1984) notes that commonly-practiced tillage and cropping methods which aid in the removal of excess water tend to exacerbate erosion. These include fall mouldboard plowing and spring seeding on poorly drained soils, typically in the direction of the slope. The benefits of rapid water removal made possible by the resulting furrows is considered by farmers to outweigh the negative impact of erosion because dry periods in the growing season are short and soils normally have adequate moisture supply for growing the crop.

Fortunately, crop rotations with forage are normally employed, primarily to control diseases. Stewart and Sudom (1984) note that it is normal for five or more years of hay or pasture to follow a few years of vegetable grown on a given parcel of land.

Wind erosion does not appear to be a problem in Newfoundland; this conclusion was borne out by both the questionnaire responses and the physical study results. Where it has occurred, overgrazing of livestock has sometimes been a causative factor (Stewart and Sudom, 1984).

TABLE 5.1. Estimated Annual Cost Of Water Erosion in Newfoundland.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD[1] LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD[1] LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
PTV													
potatoes	3000	10	0	0	20	300	0	50	180	0	72	15	267
vegetables (a)[2]	5500	20	400	0	20	0	0	50	440	0	0	0	440
(b)	5500	20	100	0	20	400	0	50	550	0	0	20	570
SPRING GRAIN	390	10	300	0	25	100	0	13	21	0	0	1	23
Total Of All Crops - Low Estimate Using (a)									$1,191	$0	$72	$36	$1,300
Extra With Vegetables Assumed Randomly Distributed Within Polygons									$110	$0	$0	$20	$130
High Estimate Using (b)									$1,301	$0	$72	$56	$1,430

1. Yield reduction factors from P.E.I.
2. (a) low and (b) high estimates assume high-value crops grown on flat and average slopes, respectively; 'severe' erosion downgraded to 'moderate'; 'moderate' downgraded to little'. See section 4.2.4.

5.3 NOVA SCOTIA

5.3.1 Extent and Severity

Compared with the rest of eastern Canada, water erosion risk appears to be relatively minor throughout Nova Scotia with only a few exceptions. Moderately high erosion rates are expected in the north-eastern part of the Annapolis Valley (Cornwallis valley) around Kentville, where vegetables, potatoes, grain corn and cereals are grown; and in the lower Annapolis Valley in the Kingston area. Flat slopes keep the erosion potential at a moderate level. Some areas with fairly high erosion potential occur north of the Minas Basin in the Lakelands-Parrsboro-Moose River area, but the small size of the agricultural land area precludes a serious problem at present, and the cultivated land is generally limited to the flatter landscape positions.

A high risk is also noted in a small area just southwest of Sydney (Cape Breton Island), where mixed dairy farming occurs under fairly steep, erodible conditions with high climatic erosivity. Some vegetable production also takes place on the flatter slopes. Most of the other agricultural areas of Nova Scotia such as the Northumberland shore and the Cobequid shore show low erosion risk because current cropping practices are dominated by relatively low risk forage and cereal grains. There has also been a trend for corn production to decline in recent years (Coote, 1984). Should more intensive practices become common, however, a significant erosion problem would develop, especially on the longer and steeper valley slopes.

These observations appear to be consistent with those of Jacques, Whitford and Associates (1985) who conclude that where soils tend to be erodible, non-erosive crops are usually grown, and vice versa. Thus the overall frequency of conditions leading to severe erosion risk is very low, and most areas were classified as having 'low erosion risk' according to the definitions employed here.

Wind erosion does not appear to be a significant problem anywhere in Nova Scotia. Even in the sandy soils of the Annapolis Valley, only one soil polygon showed a 'low' wind erosion risk. Climatic risk factors throughout the province are very low.

5.3.2 Economic Impact

In Nova Scotia, little empirical research on the effects of erosion on crop yields or on soil loss rates has been done. Our estimate of economic impact for this province is, consequently, very speculative. Unpublished soil erosion data obtained from J. van der Leest at Truro (personal communication, Nova Scotia Dept. of Agric. and Marketing) do not include yield effects. They do show that the fertilizer value of soil lost from corn grown up and down a 9 percent slope on fine sandy loam soil averaged $20/ha/yr, compared with $13 when grown across the slope; losses from permanent grassland were only $7/ha/yr.

As noted in the discussion of methodology (Section 4.2.2), no questionnaires or meetings were used in Nova Scotia because a local study on soil degradation was already underway (Jacques, Whitford and Associates, 1985). We used the yield reduction factors from this study in our economic impact model, and compared the results with those which would be obtained using the more conservative factors generated in neighbouring provinces from our NGP meetings and questionnaires.

The results, displayed in Table 5.2 (a & b), estimate the annual on-farm cost of water erosion to be between $4.1 and 9.9 million, depending on the yield deflators used and the distribution of high value crops on sloped land within a soil polygon. The annual economic estimate made by Jacques, Whitford and Associates ranges from $2.6 to 15.7 million, with $4.5 million suggested as a point estimate. This is very close to our estimate with yield reduction factors from neighbouring provinces, although the means of obtaining it are somewhat different.

TABLE 5.2 (a). Estimated Annual Cost Of Water Erosion In Nova Scotia Using Yield Reduction Factors From Provincial Study (Jacques, Whitford And Assoc., 1985).

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	1000	30	600	0	50	800	0	23	580	0	0	18	598
silage	840	30	1000	0	50	1300	0	23	798	0	0	30	828
								16	50	0	0		
BEANS	1000	20	0	0	50	100	0	16	50	0	0	2	52
OTHER ROW CROPS													
potatoes	3300	25	200	0	50	1600	0	80	2,805	0	314	128	3,247
tobacco (a)[1]	9100	25	200	0	50	0	0	110	455	0	0	0	455
(b)	9100	25	0	0	50	200	0	110	910	0	0	22	932
vegetables (a)	3600	20	1600	0	50	0	0	50	1,152	0	0	0	1,152
(b)	3600	20	200	0	50	1600	0	50	3,024	0	0	80	3,104
SPRING GRAIN	390	25	8700	0	40	1200	0	13	1,035	0	0	16	1,051
FALL GRAIN	480	10	2500	0	20	0	0	13	120	0	0	00	120
Total Of All Crops - Low Estimate Using (a)									$6,995	$0	$314	$194	$7,502
Extra With High Value Crops Assumed Randomly Dist Within Polygons									$2,327	$0	$0	$102	$2,429
High Estimate Using (b)									$9,322	$0	$314	$296	$9,931

1. See footnote 2, table 5.1

TABLE 5.2 (b). Estimated Annual Cost Of Water Erosion In Nova Scotia Using Yield Reduction Factors From Ontario And Prince Edward Island Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN [1]													
grain	1000	12	600	0	30	800	0	23	312	0	0	18	330
silage	840	12	1000	0	30	1300	0	23	428	0	0	30	458
BEANS [1]	1000	12	0	0	40	100	0	16	40	0	0	2	42
OTHER ROW CROPS[2]													
potatoes[3]	3300	5	200	0	15	1600	0	80	825	0	512	128	1,465
tobacco (a)	9100	5	200	0	10	0	0	110	91	0	0	0	91
tobacco (b)	9100	5	0	0	10	200	0	110	182	0	0	22	204
vegetables (a)	3600	20	1600	0	20	0	0	50	1,152	0	0	0	1,152
vegetables (b)	3600	20	200	0	20	1600	0	50	1,296	0	0	80	1,376
SPRING GRAIN	390	25	8700	0	25	1200	0	13	456	0	0	16	472
FALL GRAIN	480	10	2500	0	25	0	0	13	120	0	0	0	120
Total Of All Crops - Low Estimate Using (a)									$3,425	$0	$512	$194	$4,130
Extra With High value Crops Assumed Randomly Dist Within Polygons									$235	$0	$0	$102	$337
High Estimate Using (b)									$3,660	$0	$512	$296	$4,467

Yield reduction factors from:

1. Ontario (Average)
2. P.E.I.
3. See footnote 2 to table 5.1

The costs of practices used for controlling water erosion in Nova Scotia were not elaborated upon in the Jacques, Whitford study. Techniques recommended by the provincial government include contour farming, strip cropping, cover crops, conservation tillage and grassed waterways. It was noted that aerial seeding of fall cover crops (winter wheat and rye) have been successfully undertaken, albeit to a limited extent.

With respect to wind erosion, our physical model output suggests that the current potential for moderate to severe erosion on cultivated lands is too small to quantify. However, the Jacques, Whitford study does note that approximately 10,500 ha of moderate risk soils of the Cornwallis and Nictaux Series have been cleared for agriculture in the Annapolis-Cornwallis valley. About 2,000 ha of these soils have been rendered unusable due to previous wind and water erosion.

5.4 PRINCE EDWARD ISLAND

5.4.1 Extent and Severity

The greatest water erosion risk in Prince Edward Island is found in a band across the central part of the province from Cavendish-North Rustico in the north to Crapeau-New Haven in the south, and includes the Eliot (West) River basin. Longer and steeper slopes in this region are primarily responsible, as cropping intensity is not as great as in many areas elsewhere in the province. Other areas of high risk occur in the eastern part of Queens County and are again associated with longer and steeper slopes. This area also produces a significant amount of tobacco. Much of the rest of Queens County has moderate water erosion risk, except for the level land from around Charlottetown to the north coast, which has a generally low risk.

In the east, Kings County has a few areas of moderate water erosion risk, mostly associated with steeper slopes. Cropping intensity is lower here than the rest of the province. Prince County, although it has the greatest area of potatoes, has no high or moderate water erosion risk areas because slope effects are generally low. It is noteworthy, however, that Prince Edward Island has few areas with very low risk of water erosion, and that because of the extent of potato production, the valleys of the Wilmot and the Dunk rivers in the southeast of Prince County are widely perceived as having erosion-related sedimentation problems.

While most of Prince Edward Island has 'very low' risk of wind erosion, a number of areas in Prince County, and two small areas in Kings County, fall into the 'low' risk category. Climatic factors range from very low in the east to moderate (by eastern Canadian standards) in the west. Only the most erodible fine sands and fine loamy sands appear to have significant risk values, even in Prince County.

5.4.2 Economic Impact

Water erosion in Prince Edward Island has been recognized as a serious problem for more than a decade, although there has been no attempt until now to quantify its overall economic cost. Stewart and Himelman (1975) compared erosion rates, runoff and nutrient loss on plots with potatoes, sod and bare soil, using two years of data. They reported a spring and fall nutrient loss valued at $28/ha for the potato plots on a 12 percent slope, relative to an $8/ha loss for the sod plots. These values are remarkably similar to those provided by van der Leest in Nova Scotia (See Page58). The differences in soil loss and runoff between potato and sod plots were even more marked.

More recently, studies were conducted at Charlottetown to determine yield reductions of barley and potatoes due to erosion. Erosion was simulated by the removal of 7.5 and 15 cm of the original 20 cm Ap horizon. Yield reductions of 13 and 27 percent for barley and approximately 10 and 30 percent for potatoes in a dry year were obtained. In seasons with adequate rainfall, yield losses were less pronounced and more easily corrected with higher applications of N fertilizer (Sadler, 1979 and 1982).

NGP participants had difficulty estimating the effects of various erosion levels on crop yields because they felt our definitions of erosion categories did not easily apply to Island soils with shallow A-horizons and because of a lack of an historical perspective on soil loss over time. Ultimately, the NGP group elected to use the definitions of moderate and severe erosion provided in the questionnaire (see Appendix B), but they felt that the amount of erosion implied in the definition of the lowest category could be significant in Prince Edward Island Nevertheless, no yield loss factors were assessed against this level, in order to retain a consistent methodology for the study.

Study participants declined to estimate incremental fertilizer inputs required to partially compensate for the effect of water erosion on crop yield. Many Island farmers appear to be already overfertilizing their crops and, therefore, additional fertilizer would not likely restore lost yields.

The annual on-farm cost of water erosion in Prince Edward Island is estimated in Table 5.3 to range from $5.0 to 5.4 million. Most of this amount represents yield reductions on potatoes and spring grains. In addition, a reduction in the percentage of marketable potatoes due to cullage accounts for up to 18 percent of the estimated cost. It is estimated that approximately 20 percent of the potato, tobacco and vegetable hectarage is land with moderate and severe erosion potential.

Study participants predicted that 2.5 percent of the cultivated land currently experiencing 'little or no erosion' would be in a state of 'moderate' erosion 5 years from now, and that a similar percentage would deteriorate from 'moderate' to 'severely' eroded. If this occurred in proportion to the current cropping pattern, it could result in an additional annual cost of up to $200,000 (in current dollars) in crop losses and other on-farm costs by the year 1990. 'Other costs' include added machinery and wear and tear to fill in gullies and work the soil; added fuel and time to detour around

TABLE 5.3. Estimated Annual Cost Of Water Erosion in P.E.I.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN[1]	730	12	200	0	30	500	0	23	127	0	0	12	139
BEANS[1]	630	12	0	0	40	100	0	16	25	0	0	2	27
OTHER ROW CROPS													
pot-grain-for	3100	5	2100	0	15	2500	0	80	1,488	0	1,277	200	2,965
pot, other	3100	10	200	0	20	200	0	80	186	0	105	16	307
tobacco (a)[2]	7200	5	300	0	10	0	0	110	108	0	0	0	108
tobacco (b)	7200	5	200	0	10	300	0	110	288	0	0	33	321
vegetables (a)	5000	20	200	0	20[3]	0	0	50	200	0	0	0	200
vegetables (b)	5000	20	200	0	20	200	0	50	400	0	0	10	410
SPRING GRAIN	310	10	6700	0	25	11000	0	13	1,060	0	0	143	1,203
FALL GRAIN	480	10	200	0	25	100	0	13	22	0	0	1	23
Total Of All Crops - Low Estimate Using (a)									$3,216	$0	$1,383	$373	$4,972
Extra With High Value Crops Assumed Randomly Dist Within Polygons									$380	$0	$0	$43	$423
High Estimate Using (b)									$3,596	$0	$I,383	$416	$5,395

1. Yield Reduction Factors from Ontario (average)
2. See footnote 2 in table 5.2
3. Set at moderate erosion level; vegatables not typically grown on severely eroded soil

impassable spots in fields; the total loss of production on parts of fields; and the maintenance of drainage outlets clogged with silt.

The amount of land in row or field crops subject to moderate or high wind erosion potential is estimated to be under 700 ha. The crops potentially affected are potatoes, spring grain and a small amount of tobacco (none of which is subject to high wind erosion potential). The annual on-farm cost of wind erosion is estimated at $102,000 (Table 5.4).

A number of measures to control erosion have been implemented in Prince Edward Island The most common practice is crop rotation, which is well suited to the mixed farming economy of the province. The underseeding, broadcast seeding or fall planting of cover crops is highly recommended, but is not commonly practiced on late-harvest potato varieties, slopes over 5 percent or areas subjected to gully erosion. Conservation tillage and residue management practices include fall chisel plowing (average cost: $45/ha), the use of a power harrow, and the retention of straw/stover from rye, barley or winter wheat. The practice of making temporary berms in the fall on sloping land (to retard soil movement) is being adopted by some farmers on a trial basis.

5.5 NEW BRUNSWICK

5.5.1 Extent and Severity

The province of New Brunswick is one of the most seriously affected by water erosion in Canada; most notably in the northwest part of the province known as the Potato Belt. In Carleton, Madawaska and Victoria Counties where most of the potatoes are grown, over half of the potential agricultural land has a slope of 5 percent or greater (Stewart, 1976). Further, it is estimated that less than one third of the potato-growing land in these counties is being properly rotated with forage, and that approximately 15 percent of this land is under continuous potatoes. Erosion is considerably less

TABLE 5.4. Estimated Annual Cost Of Wind Erosion in Prince Edward Island.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN [1]	730	12	0	0	30	0	0	23	0	0	0	0	0
BEANS[1]	630	12	0	0	40	0	0	16	0	0	0	0	0
OTHER ROW CROPS													
pot-grain-for	3100	5	200	0	15	0	0	80	31	0	59	0	90
pot, other	3100	10	0	0	20	0	0	80	0	0	0	0	0
tobacco	7200	5	0	0	10	0	0	110	0	0	0	0	0
vegetables	5000	20	0	0	20	0	0	50	0	0	0	0	0
SPRING GRAIN	310	10	400	0	25	0	0	13	12	0	0	0	12
FALL GRAIN	480	10	0	0	25	0	0	13	0	0	0	0	0
TOTAL OF ALL CROPS									$43	$0	$59	$0	$102

1. Yield Reduction Factors from Ontario (average)

serious in other agricultural areas of the province, due to a more diversified, livestock-based agriculture resulting in better soil management.

About 30 percent of the improved land area of the Potato Belt Region has moderate or high water erosion risk due to the large-scale production of potatoes and specialty crops like peas and beans. Potato production on steep slopes in the Grand Falls to Perth-Andover area results in the greatest erosion risk. Near Woodstock, the erosion risk is somewhat lower, (in spite of greater vegetable production than in the Grand Falls area) because dominant slopes are less steep, and more livestock and forage production occurs there.

In the northwest, (i.e. Madawaska County) water erosion risk is also lower than elsewhere in the Potato Belt because small grains and hay are more common, and fewer potatoes are grown.

In southern and eastern New Brunswick, water erosion seems to be a problem only around Sussex in Kings County. Sandy and loamy soils on steep slopes south of Sussex, and coarse textured soils north of Sussex, are particularly vulnerable. Cropping consists mainly of small grains, (mainly oats) and hay for dairy cattle. Some soils with a high risk of erosion, including those south of Moncton and east of Saint John, are not heavily cropped and consequently the risk is not currently of great concern. If vegetable production continues to increase in the coastal and river valley soils in Kent and Westmorland Counties, erosion rates in this region will rise.

No soils in this province have a significant wind erosion risk, mainly because climatic risks are low and soil properties are not highly conducive to wind erosion.

5.5.2 Economic Impact

More appears to be known about the physical and economic effects of water erosion in New Brunswick than in any other province in the study area except Ontario, as a result of several research projects on soil loss, fertilizer loss and the effects of mitigation measures. Experimental plots and studies of changes in cropping practices over time, have highlighted the seriousness of water erosion losses in the Potato Belt (see for example, Stephens, *et. al.*, 1982; Daigle, 1984). Unfortunately, little documentation exists on the effects of erosion on crop yields. Yield reduction factors used here were based, therefore, on the observations and experience of study participants.

Our estimate of the annual on-farm cost of water erosion in New Brunswick ranges from $10.1 to $12.1 million in the Potato Belt and $630,000 to $750,000 in the rest of the province (Tables 5.5 and 5.6). Approximately $9 million of this is attributable to the potato crop alone, with over $4 million accruing from the loss of marketable product. This estimate does not include lost production on former potato land no longer in production as a result of excessive erosion. This land, which includes parts of fields no longer worth seeding, entire abandoned fields, and land used for erosion control structures (terraces and grassed waterways); was estimated to constitute approximately 5 percent of the total cropland in the Potato Belt (some 3,000 ha).

Another concern, which is ignored in our calculations, is the strong dependance of the local economy on the potato crop. Agriculture is a major source of direct and indirect income to local residents, and potatoes appear to be one of the few crops which may be profitably grown (in quantity) in this region. Because of the important contribution of potato production and processing to the local economy, the effects of soil degradation on the potato industry pose a significant threat to the overall economic health of the region.

TABLE 5.5. Estimated Annual Cost Of Water Erosion in New Brunswick Potato Belt Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN [1]	730	12	400	0	30	100	0	23	57	0	0	2	59
BEANS [1]	630	12	300	0	40	100	0	16	48	0	0	2	50
OTHER ROW CROPS			15000			5200							
pot, contin	2500	8[3]	2000	37	20	700	37	80	750	100	600	56	1,506
pot-grain	2500	8	8Q00	0	20	2800	0	80	3,000	0	2,360	224	5,584
pot-grain-for	2500	5	3300	0	15	1200	0	80	863	0	1,046	96	2,005
vegetables (a) [4]	5600	20	600	0	20	0	0	50	672	0	0	0	672
vegetables (b)	5600	20	1700	0	20	600	0	50	2,576	0	0	30	2,606
SPRING GRAIN [2]	290	10	1700	0	25	2400	0	13	223	0	0	30	253
Total Of All Crops - Low Estimate Using (a)									$5613	$100	$4,006	$410	$10,129
Extra With Vegetables Assumed Randomly Dist. within Polygons									$1,904	$0	$0	$30	$1,934
High Estimate Using (b)									$7,517	$100	$4,006	$440	$12,063

Yield Reduction Factors from:

1. Ontario (S & E)
2. P.E.I.
3. Lower Yield Loss rates (%) reflect the use of fertilizer as an economical Yield restoration measure (See Table 2.1)
4. See footnote 2, table 5.1

TABLE 5.6. Estimated Annual Cost Of Water Erosion In New Brunswick South And East Region.

CROP/CROP GROUP		VALUE ($/HA)	MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
			YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN [1]		730	12	200	0	30	500	0	23	127	0	0	12	139
OTHER ROW CROPS														
potatoes		2500	5	200	0	15	100	0	200	63	0	69	20	151
vegetables	(a)[3]	5600	20	100	0	20[4]	0	0	50	112	0	0	0	112
	(b)	5600	20	100	0	20	100	0	50	224	0	0	5	229
SPRING GRAIN [2]		290	10	500	0	25	2400	0	13	189	0	0	30	219
FALL GRAIN		290	10	0	0	25	100	0	13	7	0	0	1	9
Total Of All Crops - Low Estimate Using (a)										$497	$0	$69	$68	$629
Extra With Vegetables Assumed randomly Distributed Within polygons										$112	$0	$0	$5	$117
High Estimate Using (b)										$609	$0	$69	$73	$746

Yield reduction factors from:

1. Ontario (S & E)
2. P.E.I.
3. See Footnote 2 in Table 5.1
4. Set at moderate erosion level; vegetables not normally grown on severely eroded soil.

Furthermore, the extent of erosion appears to be growing at a higher rate in the Potato Belt than in any other region. NGP participants estimated that 15 percent of the cultivated land currently experiencing little or no erosion would become moderately eroded in 5 years; 20 percent of the moderately eroded land would move into the severe category in the same time period, and an additional 5 percent of the severely eroded land would be removed from production. This scenario suggests that the annual on-farm costs attributed to water erosion would rise by $2.5 million (in constant dollars) in 5 years.

Fortunately, the climatic factors required to produce wind erosion problems are not present in New Brunswick. Wind erosion is not a concern except in isolated pockets of sandy soil. Since the physical analysis identified no polygons in the province subject to moderate or severe wind erosion risk, the economic impact would be too small to quantify.

Participants in the New Brunswick NGP meeting identified a number of problems frequently experienced by farmers as a result of erosion. These include:

- Loss of micronutrients (Bo, Mb, Zn) due to soil loss and runoff resulting in an added input costs of up to $30 per tonne of fertilizer used;

- Cultivation equipment working into subsoil material, due to loss of the surface layer, sometimes leading to excessive stoniness and even exposure of bedrock, and resulting in damage to machinery and added costs for stone removal;

- Loss of available rooting depth and water holding capacity, leading to increased runoff from rain and snowmelt, and increased susceptibility to drought even in brief dry periods;

- Increased pesticide requirements to replace losses due to erosion and runoff, resulting in 5 - 10 percent added spraying costs;

- Soil deposition in depressions and ditches, requiring removal;

- Need to recontour land affected by rills and gullies.

Recommended practices for controlling water erosion in New Brunswick N are divided into two systems according to land gradient. On land with less than a 5 percent slope, a combination of crop rotation, winter cover crops, cross-slope farming and reduced tillage is recommended. However, narrow farm configuration, farms barely large enough to support economic potato production, and lack of a market for rotated crops are factors which reduce the desirability of crop rotation and contour farming on many Potato Belt farms.

Slopes steeper than 5 percent require structural controls as well as the above measures, particularly if moderate or severe erosion is already apparent. Structural erosion control practices were first introduced in New Brunswick in 1948 and have undergone several stages of modification until 1973, when the present system was adopted (Arsenault, 1977). Currently, variable grade parallel diversion terraces, combined with grassed or rock waterways, are used. The capital cost of the system averages approximately $1,000/ha; but is currently subsidized at an average of 60 percent by the federal government. By the end of 1983, some 2,400 ha of potato land (approximately 10 percent) were being protected by this system. While the system is successful at limiting annual soil loss to 10 tonnes/ha, it can only serve to maintain or slowly improve yields unless large quantities of organic matter are applied or returned to the soil. Other factors which limit the general acceptability of structural measures from the farmer's viewpoint are a 10 percent loss of productive land due to the structure itself; and the need to halt production for a year to permit construction.

5.6 QUEBEC

5.6.1 Extent and Severity

Water erosion problems have been recognized in Quebec since the late 60's, but have only recently received widespread attention. Soil erosion in Quebec has been exacerbated with the transition of the farming system from small, mixed enterprises to larger, more intensive, specialized production units. This transition has brought with it a marked increase of row crops (most notably grain corn and silage corn) and an attendant pattern of monocropping over large areas. The economic pressure towards larger production units, and more frequent soil tillage, and the reduction in the use of forage crops in the overall crop rotation, has accelerated soil erosion in all three Quebec regions.

Our analysis shows that the area of Quebec just west of the New Brunswick Potato Belt has a moderate risk of soil erosion, primarily because of slope conditions. Inland from Riviere-du-Loup and Rimouski, steep slopes produce similar water erosion risk, but the very small percentage of farmland there suggests there is less of a problem than indicated by the risk.

An area of high water erosion risk is noted in southern Dorchester County near the U.S. border. Because the amount of cultivated land is small, tilled fields are probably located on below-average slopes, resulting in a lower risk than indicated. Other similar soil areas are found from southern Brome County (Sutton) east through the Sherbrooke area. Some highly erodible sandy .loams in southern Drummond County also have a moderate risk.

Moderate to high water erosion risk is found on erodible soils west of Montreal in the Lachute area, and on steeper slopes near St. Jerome and further north around St. Jovite. In the intensively farmed areas close to Montreal, in the vegetable growing areas of Ile Jesus and in Deux Montagnes where silage corn is also widely grown, moderate water erosion risk is also evident.

Along the north shore of the St. Lawrence, moderate water erosion risk is apparent on the upland soils both east and west of Shawinigan (St. Adelphe and Charette areas), and north-east of Quebec City in the agricultural soils around Bale-St-Paul.

Water erosion does not appear to be much of a problem in the Lac St-Jean region. However, a significant area (10 to 15 percent) of soils in this region have been moderately or severely eroded in the past (Raymond *et al*, 1965). They are not identified in the present analysis, probably for two reasons: (i) the scale of the landscape maps used did not separate local steep slopes; and (ii) a considerable area of land has been abandoned in the last 20 years, and some of the more erodible soils may well have been those affected by this, or other land use changes (e.g. reduced area of potatoes).

One soil area northwest of Rouyn-Noranda has a high risk because dominant slopes are steep, and a similar situation exists in the Gatineau River Valley. In the latter case, the area of farmland is relatively small, and consequently, the steeper slopes are unlikely to be used for cultivated crops.

Wind erosion risk throughout the agricultural portion of Quebec is generally either 'low' or 'very low' in terms of the classes chosen for this study. Nonetheless, for comparative purposes, even low risk areas may be important as they contain erosion-prone crops that have risk values far above average.

One low, but probably significant, wind erosion risk area is located in the sandy soils south of Quebec City around St-Anselme. Other areas of low but significant wind erosion risk occur on sandy soils southeast of Shawinigan (Mont Carmel), west of Quebec City (Pont Rouge) and in several soils in the Lac St-Jean region. In all of these areas, soils are highly wind erodible sands and sandy loams, but the climatic factors associated with wind erosion (wind speed, soil moisture) tend to be very low. There does not appear to be any significant wind erosion risk in the Gaspe or in northwest Quebec.

Low, but significant, wind erosion risk areas also occur in the southwest in Huntington County and south-east of Montreal near Chambly, around St-Hyacinthe, and north of Drummondville. Climatic factors are generally low, but high soil erodibility and intensive cropping combine to give an above average wind erosion risk. Other areas of comparable risk are found near Quyon and Fort Coulonge. Intensively cultivated organic soils south of Montreal may also have a substantial wind erosion risk, but they could not be included in the computation of quantitative estimates.

Of interest, but of little significance to agriculture, is the relatively high wind erosion risk found in the Iles de la Madeleine.

5.6.2 Economic Impact

Water erosion studies on agricultural land have been conducted in a number of locations in Quebec including Lac St. Jean, Lennoxville, St-Leon and Charlevoix (Dube, 1975; Dube and Mailloux, 1969; Pesant, 1984) but unfortunately no attempts to quantify crop yield reductions or other economic impacts were made. Like the Atlantic Provinces, the economic impacts generated by Quebec NGP participants were based solely on observation, professional judgment and findings outside the province.

Tables 5.7 to 5.9 display our estimates of the annual on-farm costs of water erosion in each of the three Quebec regions. The total cost for the three regions combined is estimated to range between $14.4 and 17.1 million, with the St. Lawrence region generating just over half of the impact. The highest losses are associated with land in potatoes, vegetables and corn in the St. Lawrence Region; corn and spring grains in

TABLE 5.7. Estimated Annual Cost Of Water Erosionin The Quebec St. Lawrence Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	950	15	1900	0	33	800	0	23	522	0	0	18	540
grain, rot w/for[2]	950	10	1400	0	30	600	0	23	304	0	0	14	318
silage	960	15	200	0	33	100	0	23	60	0	0	2	63
silage, rot w/for	960	10	2000	0	30	800	0	23	422	0	0	18	441
OTHER ROW CROPS													
potatoes	3400	15	1000	0	40	2100	0	70	3,366	0	717	147	4,230
vegetables (a)[1]	2600	15	2100	0	40	0	0	110	819	0	0	0	819
vegetables (b)	2600	15	1000	0	40	2100	0	110	2,574	0	0	231	2,805
sugar beets[3]	470	15	100	0	40	0	0	110	7	0	0	0	7
SPRING GRAIN	360	13	9100	0	30	1900	0	13	631	0	0	24	655
Total Of All Crops - Low Estimate Using (a)									$6,132	$0	$717	$224	$7,073
Extra With Vegetables Assumed Randomly Dist. Within Polygons									$1,755	$0	$0	$231	$1,986
High Estimate Using (b)									$7,887	$0	$717	$455	$9,059

1. See footnote 2, table 5.1
2. From Eastern Townships/Outaouais Region
3. Sugarbeets were not assessed separately; values for vegetables were used.

TABLE 5.8. Estimated Annual Cost Of Water Erosion In The Quebec Eastern Townships/outaouais Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	950	15	3700	0	40	2200	0	23	1,363	0	0	51	1,414
grain, rot w/for	950	10	1900	0	20[3]	1200	52	23	409	62	0	28	498
silage	960	15	200	0	40	100	0	23	67	0	0	2	70
silage, rot w/for	960	10	1800	0	20[3]	1100	52	23	384	57	0	25	466
OTHER ROW CROPS													
potatoes	3400	10	0	97	25	0	387	70	0	0	0	0	0
vegetables (a)[2]	2600	15	300	0	40	0	0	110	117	0	0	0	117
vegetables (b)	2600	15	300	0	40	300	0	110	429	0	0	33	462
SPRING GRAIN	360	13	16000	0	28	8600	0	13	1,616	0	0	112	1,728
FALL GRAIN	210	13	200	0	28	0	0	13	5	0	0	0	5
Total Of All Crops - Low Estimate Using (a)									$3,961	$119	$0	$218	$4,298
Extra With Vegetables Assumed Randomly Dist Within Polygons									$312	$0	$0	$33	$345
High Estimate Using (a)									$4,273	$119	$0	$251	$4,643

1. Yield reduction factor from Quebec St. Lawrence Region
2. See footnote 2 to Table 5.1
3. See footnote 3 to Table 5.5

TABLE 5.9. Estimated Annual Cost Of Water Erosion in The Northern Quebec Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN	960	6	1100	18	15	1100	40	13	222	64	0	14	300
OTHER ROW CROPS													
potatoes[1]	3400	5	700	0	15	500	0	70	374	0	371	35	780
vegetables (a) [2]	2600	8	500	25	15	0	50	110	104	13	0	0	117
vegetables (b)	2600	8	700	25	15	500	50	110	341	43	0	55	439
SPRING GRAIN	360	3	9000	20	6	21000	40	13	551	1,020	0	273	1,844
Total Of All Crops - Low Estimate Using (a)									$1,251	$1,097	$371	$322	$3,041
Extra With Vegetables Assumed Randomly Dist Within Polygons									$237	$30	$0	$55	$322
High Estimate Using (b)									$1,488	$1,127	$371	$377	$3,363

1. Yield reduction factor from New Brunswick. Crop assumed grown in rotation with grain and forage.
2. See footnote 2, table 5.1

the Eastern Townships/Outaouais Region, and spring grains in Northern Quebec.

NGP participants in the three regions estimated that the following percentages of cultivated land would erode enough to move to a higher, more severe erosion category within 5 years:

QUEBEC REGION	% Cultivated Land Degrading From: Little Or No To Moderate	% Cultivated Land Degrading From: Moderate to Severe
St. Lawrence	3	2
Eastern Townships/Outaouais	12	5
Northern Quebec	15	5

Assuming that these rates of deterioration apply to all affected crops, it is predicted that the annual cost of erosion in Quebec will increase by as much as $3.5 million (constant dollars) in 5 years' time. Over 40 percent ($1.6 million) of this increase will occur in the St. Lawrence Region despite its predicted low rate of increase, due to the large amount of row crops grown relative to the other two regions. Even so, the predicted increase of $1.1 million in the Eastern Townships/Outaouais and $850,000 in the North will have a proportionately heavier impact on the farm incomes of these regions.

We estimate the annual on-farm cost of wind erosion to be $2.2 million in the St. Lawrence Region, second (in our study area) only to Southern Ontario (Table 5.10). The crops most affected are potatoes and vegetables, especially when grown in sandy soils and organic soils, but organic soils were not covered in this study. The potential on-farm cost of wind erosion is estimated to be $23,000 annually in the Northern Quebec Region (Table 5.11), while the damage in the Eastern Townships/Outaouais is too small to estimate.

TABLE 5.10. Estimated Annual Cost Of Wind Erosion in The Quebec St. Lawrence Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	950	15.0	100	0	33.0	0	0	23	14	0	0	0	14
grain, rot w/for	950	10.0	100	0	30.0	0	0	23	10	0	0	0	10
silage	960	15.0	0	0	33.0	0	0	23	0	0	0	0	0
silage, rot w/for	960	10.0	100	0	30.0	0	0	23	10	0	0	0	10
OTHER ROW CROPS													
potatoes	3400	15.0	1800	0	40.0	0	0	70	918	0	520	0	1,438
vegetables[1]	2600	15.0	1800	0	40.0	0	0	110	702	0	0	0	702
sugar beets	470	15.0	0	0	40.0	0	0	50	0	0	0	0	0
SPRING GRAIN	360	13.0	900	0	30.0	0	0	13	42	0	0	0	42
TOTAL									$1,695	$0	$520	$0	$2,216

[1] Yield reduction factor from Quebec St. Lawrence Region.

TABLE 5.11. Estimated Annual Cost Of Wind Erosion in The Northern Quebec Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN	960	6	100	18	15	0	40	13	6	2	0	0	8
OTHER ROW CROPS			0			0							
potatoes [1]	3400	5	0	0	15	0	0	70	0	0	0	0	0
vegetables	2600	8	0	25	15	0	50	110	0	0	0	0	0
SPRING GRAIN	360	3	500	20	6	0	40	13	5	10	0	0	15
TOTAL									$11	$12	$0	$0	$23

1. Yield reduction factor from New Brunswick. Crop assumed in rotation with grain and forage

Quebec participants identified a number of problems experienced in Quebec as a result of erosion which have economic consequences. These include:

- Additional time, cost and machinery wear and tear in land preparation;
- Soil deposition in drainage ditches and channels;
- Loss of soil amendments (fertilizer, pesticides, lime);

The most common erosion control measures recommended and used by farmers vary greatly by region and crop. The measures recommended by agronomists are not always followed by farmers for reasons of cost, lack of know-how or inconvenience. The measures cited by Quebec NGP participants are:

- Contour plowing or tillage (impractical on fields which are long and narrow; a common pattern in Quebec);
- Placement of stones in ditches to slow water flow;
- Minimum (or zero) tillage. The most common techniques are the use of cultivators instead of plows; leaving crop residues on the soil; and reduced number of trips with cultivator;
- Shallower plowing and tillage with present implements or use of a chisel plow;
- Use of green manure or livestock manure to improve soil structure and organic matter content;
- Land levelling to reduce slopes and eliminate hollows in the field;

- Planting of trees as windbreaks, especially around horticultural crops and tobacco.

5.7 ONTARIO

5.7.1 Extent and Severity

The location and extent of water erosion in the Great Lakes Basin was estimated by van Vliet *et al* (1978) in order to quantify agricultural contributions to water pollution. Subsequently, Wall and Driver (1982) made a county by county estimate of cropland erosion in order to estimate costs to farmers. On a regional basis, (the only available means of comparison) our estimate of the amount of cropland with 'severe' erosion was very close to their 'excessive' erosion area in the Southern and Western regions, but was considerably lower than theirs in Central and Eastern Ontario.

More recently, Shelton *et al* (1984) utilized the same 1:500,000 landscape maps as used here, a similar data base and similar methods, to estimate the location of erosion risk areas. Our respective results are very similar even though slightly different climate and soil variables were used. However, for consistency with the classes of erosion used and the analyses carried out for the other provinces, and to facilitate the preparation of the regional crop group data summaries required for the economic analysis, it was decided to re-compute the erosion risk values for all polygons.

The most severe water erosion risk in Ontario occurs in the erodible silt loam soils of Elgin, southern Middlesex and southwest Oxford counties. This area is intensively farmed on rolling topography with fairly steep slopes (10 to 15 percent). Two areas in the hilly morainal soils south of Cambridge to northwest of Guelph also have high erosion risk because of erodible loamy texture on rolling topography. Further north, in the escarpment lands south of Collingwood, a similar situation is found but with steeper slopes making up for slightly less agricultural intensity.

Another area of high intensity land use (corn, vegetables) on fairly steep rolling land is found in the loamy soils north of Lake Ontario between Port Hope and Trenton, and here water erosion risk is also high.

The only soil area with a high risk, but without such steep slopes, is the ridged silt loam in the Exeter to Seaforth portion of Huron County. Soil erodibility is fairly high, as is the intensity of cultivation practices.

Moderate water erosion risk is widely distributed through the western portion of southern Ontario, primarily among the erodible silt loam and loam soils. They are found north of Rondeau Harbour in the Ridgetown area, in northwest Middlesex County in a band running north, parallel to the Lake Huron shore as far as Lucknow, and in a large part of southern Bruce, central Grey and Dufferin Counties. In the latter case, the escarpment slopes and potato production are important contributing factors. Another area of moderate erosion risk occurs south and west of Hamilton, and on top of the Niagara escarpment from Hamilton to St. Catharines, where grapes are widely grown. Rolling sandy loam soils in central Simcoe County, from York County north of Toronto through Durham County to Rice Lake, and in Central Prince Edward County, also have moderate water erosion risk. Crops grown here are mainly corn and vegetables, with some tobacco in Durham County.

Most of the rest of Ontario has low or very low water erosion risk. In eastern Ontario this is mainly because of flat slopes, and low agricultural intensity on the more steeply sloping soils. Northern Ontario does not generally have sufficient agricultural intensity, especially row crops, to realize any real water erosion potential. Interestingly, the most intensively cropped area of the province, Essex and Kent Counties, has relatively low water erosion risk, due primarily to the relatively flat landscapes. Since such a large percentage of the southern Ontario landscape is farmed, however, the overall effect of even a relatively low rate of erosion per hectare is potentially significant for water quality in streams and lakes.

The only area in eastern Canada where moderate wind erosion risk rates occur is in southwestern Ontario, where intensive cultivation of row crops such as corn, soybeans and vegetables leaves about 40,000 ha of highly erodible sandy soils unprotected from the wind during the spring and fall. Wind erosion climate factors (wind speed, moisture) are relatively high. Two soils areas in Essex County (one south of Windsor and the other near Leamington), an area on the Kent-Middlesex border and an area in western Middlesex County near Strathroy are affected by 'moderate' wind.

These areas are the same as some of the extensive areas reported by Fitzsimons and Nickling (1982). They represent about 50 percent of the area reported by Wall and Driver (1982) as being 'affected' by wind erosion. In each of the other regions, except Eastern Ontario, our areas of susceptible crops with moderate risk were much smaller than those reported by Wall and Driver (1982). This suggests that the class limits we used for wind erosion were not well matched to observed wind erosion levels, and tended to underestimate the extent of the problem.

Areas of low, but significant, wind erosion risk occur throughout the sandy soils of Essex County, through Elgin and Norfolk Counties to the Paris area, in western Simcoe County, and in the sandy soils of the Port Hope area and north of Brighton (north of Lake Ontario). Tobacco and potatoes are grown on many of these soils. A small number of sandy soils in eastern Ontario between Ottawa and Hawkesbury also have a low, but significant risk of wind erosion. Intensively farmed organic soils, both in the Southern Ontario region and north of Toronto (Holland Marsh) are also susceptible to wind erosion, but were not included in the estimation procedure used in this study.
It is interesting to note that in the Kent and Essex region, where climate and cropping is conducive to wind erosion, even some clay soils have a significant risk. In all other areas, clay soils have only very low wind erosion risk.

5.7.2 Economic Impact

Ontario is the province most affected by the erosion of agricultural land in terms of total soil loss and the size of on-farm economic impacts. Ontario has undergone a marked increase in intensive row crop production over the past 25 years. Increases in corn and soybeans at the expense of cereal grains and hay have been identified as a major cause of increased erosion. The development of shorter season corn hybrids and soybean varieties has resulted in this change. As a consequence, intensive corn production has spread northward and eastward into parts of Ontario (and Quebec) which were previously marginal for the crop, bringing with it an increase in soil erosion.

The relationship between agricultural land use and water erosion is not as well documented in Ontario as it is in many American states, but is better researched here than in any other province covered in our study. Published soil loss rates in the province go back at least to 1961, with a 12 year study comparing continuous corn, corn in rotation, oats and meadow (Ripley *et al.*, 1961). Recent studies such as those reported by Battison and Miller (1983) and the Land Evaluation Group (1983) at the University of Guelph have examined soil loss and crop yield reductions in Western Ontario. Corn yield reductions were found to average approximately 30 percent on eroded areas of Waterloo County.

Of particular interest was a recent study sponsored by the Ontario Ministry of Agriculture and Food which estimated the cost of erosion (water and wind) to agriculture in Ontario (Wall and Driver, 1982). The authors estimated that the annual cost of water erosion in Ontario, including yield losses on corn and bean crops, nutrient loss and pesticide loss, ranged from $67 to $122 million.

The yield losses documented in the most recent Ontario studies had a great deal of influence on the inputs generated by NGP participants in the meetings at Guelph and Ottawa. Estimates of the annual on-farm cost of water erosion in Ontario are displayed in Tables 5.12 to 5.16 for each of five Ontario regions. The total annual cost in the province is expected to range from $112 to 157 million; mostly from Southern and Western Ontario. These estimates are more than twice those we obtained for Atlantic Canada, Quebec and British Columbia combined.

The wide range in the total estimate is a function of the large hectarage of tobacco and vegetables in Southern Ontario locations susceptible to erosion. Depending on the assumption made with respect to the relative slope on which these crops are grown, the economic impact estimate in the one region alone will vary by $38 million. This points to the need for more erosion-related research on high-value crops, which are often overlooked because of the small amount planted.

Further examination of the tables shows that corn (particularly grain corn) is a significant contributor to economic losses in all regions except Northern Ontario, while soybeans and tobacco are significant only in the Southern and Western regions. Erosion on potato land accounts for more than $2.6 million of the annual loss in Central and Western Ontario, but for very little erosion damage elsewhere in the province.

Our cost estimates for water erosion in Ontario are higher than those of Wall and Driver. The principal reason for this apparent discrepancy is our inclusion of more crops in the calculation of yield loss estimates. While both studies cover the same row crops, Wall and Driver do not estimate the yield reduction cost of vegetables, potatoes, tobacco or small grains. The yield reduction factors for these crops generated by NGP participants are admittedly estimates, but are consistent with (or more conservative than) the factors suggested in the other provinces for the same crops.

TABLE 5.12. Estimated Annual Cost Of Water Erosion in The Eastern Ontario Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	800	5[4]	5700	37	30[4]	0	93	23	228	211	0	0	439
grain, rot w/for	800	12	9300	0	32	0	0	23	893	0	0	0	893
silage	500	5[4]	500	37	30[4]	0	93	23	15	19	0	0	34
silage, rot w/for	600	12	10000	0	32	0	0	23	720	0	0	0	720
BEANS													
soybeans	630	10	300	0	25[4]	0	56	16	19	0	0	0	19
soybns, rot w/fo	630	7.5	300	0	30	0	0	16	14	0	0	0	14
OTHER ROW CROPS													
potatoes[1]	2100	10	100	0	20	0	0	50	21	0	0	0	40
vegetables[2] (a)[3]	4700	15	0	0	15	0	0	0	0	0	0	0	0
vegetables (b)	4700	15	300	0	15	0	0	50	212	0	0	0	212
SPRING GRAIN	310	5	4200	11	7	0	18	13	65	46	0	0	111
FALL GRAIN[2]	440	10	100	0	12	0	28	13	4	0	0	0	4
Total Of All Crops - Low Estimate Using (a)									$1,979	$276	$19	$0	$2,274
Extra With Vegetables Assumed Randomly Dist Within Polygons									$212	$0	$0	$0	$212
High Estimate Using (b)									$2,191	$276	$19	$0	$2,485

Yield reduction factors from:

1. P.E.I. Crop assumed in rotation with grain.
2. Southern Ontario
3. See footnote 2 to table 5.1
4. See footnote 3 to table 5.5

TABLE 5.13. Estimated Annual Cost Of Water Erosion In The Central Ontario Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	800	5[4]	6100	37	30[4]	4200	93	23	1,252	616	0	97	1,965
grain, rot w/for	800	12	6100	0	32	4200	0	23	1,661	0	0	97	1,757
silage	600	5[4]	400	37	30[4]	300	93	23	66	43	0	7	116
silage, rot w/for	600	12	3500	0	32	2400	0	23	713	0	0	55	768
BEANS													
soybeans	630	10	500	0	25	200[4]	56	16	63	11	0	3	77
soybns, rot w/for	630	7.5	300	0	30	200	0	16	52	0	0	3	55
white[1]	710	30	200	0	30	100	0	19	64	0	0	2	66
OTHER ROW CROPS													
potatoes[2]	2100	10	1600	0	20	800	0	50	672	0	437	40	1,149
tobacco (a)[3]	8700	15	200	0	15	0	0	110	261	0	0	0	261
tobacco (b)	8700	15	300	0	15	200	0	110	653	0	0	22	675
vegetables (a)	4700	15	1400	0	15	0	0	50	987	0	0	0	987
vegetables (b)	4700	15	2900	0	15	1400	0	50	3,032	0	0	70	3,102
SPRING GRAIN	310	5	7000	11	7	3400	18	13	182	138	0	43	363
FALL GRAIN[1]	440	10	1600	0	25	1800	0	13	268	0	0	23	291
Total Of All Crops - Low Estimate Using (a)									$6,241	$808	$437	$369	$7,855
Extra With Vegetables Assumed Randomly Dist Within Polygons									$2,436	$0	$0	$92	$2,528
High Estimate Using (b)									$8,677	$808	$437	$461	$10,383

Yield reduction factors from:

1. Southern Ontario
2. P.E.I. Crop assumed in rotation with grain.
3. See footnote 2 to Table 5.1
4. See footnote 3 to Table 5.5

TABLE 5.14. Estimated Annual Cost Of Water Erosion In Northern Ontario Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN [1]	600	12	300	0	32	0	0	23	22	0	0	0	22
OTHER ROW CROPS													
potatoes[2]	2100	10	200	0	20	0	0	50	42	0	38	0	80
vegetables[3] (a)[4]	4700	15	0	0	15	0	0	50	0	0	0	0	0
vegetables (b)	4700	15	400	0	15	0	0	50	282	0	0	0	282
SPRING GRAIN [1]	310	20	700	0	30	0	0	13	43	0	0	0	43
Total Of All Crops - Low Estimate Using (a)									$107	$0	$38	$0	$145
Extra With High Value Crops Assumed Randomly Dist Within Polygons									$282	$0	$0	$0	$282
High Estimate Using (b)									$389	$0	$38	$0	$427

Yield reduction factors from:

1. Eastern Ontario Region
2. P.E.I. Crop assumed rotated with grain.
3. Southern Ontario Region
4. See footnote 2 to table 5.1

TABLE 5.15. Estimated Annual Cost Of Water Erosion In The Western Ontario Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	800	6[3]	83000	40	20[3]	24000	40	23	7,824	4,280	0	552	12,656
grain, rot w/for	800	10	43000	0	25	12000	0	23	5,840	0	0	276	6,116
silage	600	6[3]	7000	40	20[3]	2000	40	23	492	360	0	46	898
silage, rot w/for	600	10	38000	0	25	11000	0	23	3,930	0	0	253	4,183
BEANS													
soybeans	630	20	8900	0	50	13600	0	16	5,405	0	0	218	5,623
soybns rot w/for	630	17.5	2500	0	45	3800	0	16	1,353	0	0	61	1,414
white	710	30	5600	0	30	8600	0	19	3,025	0	0	159	3,184
OTHER ROW CROPS													
potatoes[1]	2100	10	1500	0	20	1400	0	50	903	0	519	70	1,492
tobacco (a)[2]	8700	15	200	0	15	0	0	110	261	0	0	0	261
tobacco (b)	8700	15	200	0	15	200	0	110	522	0	0	22	544
vegetables (a)	4700	15	5400	0	15	0	0	50	3,807	0	0	0	3,807
vegetables (b)	4700	15	5700	0	15	5400	0	50	7,826	0	0	270	8,096
SPRING GRAIN	310	10	100000	0	15	26000	32	13	4,309	832	0	325	5,466
FALL GRAIN	440	10	17000	0	12.5	8200	28	13	1,199	230	0	103	1,531
Total Of All Crops - Low Estimate Using (a)									$38,348	$5,702	$519	$2,062	$46,630
Extra With High Value Crops Assumed Randomly Dist Within Polygons									$4,280	$0	$0	$292	$4,572
High Estimate Using (b)									$42,627	$5,702	$519	$2,354	$51,202

1. Yield reduction factor from P.E.I. Crop assumed in rotation with grain
2. See footnote 2, table 5.1
3. See footnote 3 to table 5.5

TABLE 5.16. Estimated Annual Cost Of Water Erosion In The Southern Ontario Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	800	6[2]	43000	40	20[2]	78000	40	23	14,544	4,840	0	1,794	21,178
grain, rot w/for	800	10	11000	0	25	21000	0	23	5,080	0	0	483	5,563
silage	600	6[2]	2100	40	20[2]	3900	40	23	544	240	0	90	873
silage, rot w/for	600	10	3900	0	25	7200	0	23	1,314	0	0	166	1,480
BEANS													
soybeans	630	20	21000	0	50	23000	0	16	9,891	0	0	368	10,259
soy, rot w/for	630	20	1800	0	50	2000	0	16	857	0	0	32	889
white	710	15	1200	60	30	1300	0	19	405	72	0	24	501
OTHER ROW CROPS													
tobacco (a)[1]	8700	10	6500	0	20	0	0	110	5,655	0	0	0	5,655
tobacco (b)	8700	10	20000	0	20	6500	0	110	28,710	0	0	715	29,425
vegetables (a)	4700	15	6500	0	15	0	0	50	4,583	0	0	0	4,583
vegetables (b)	4700	15	20000	0	15	6500	0	50	18,683	0	0	325	19,008
SPRING GRAIN	310	10	24000	0	15	14000	32	13	1,395	448	0	175	2,018
FALL GRAIN	440	10	19000	0	12.5	8500	28	13	1,304	238	0	106	1,648
Total Of All Crops - Low Estimate Using (a)									$45,570	$5,838	$0	$3,238	$54,646
Extra With High Value Crops Assumed Randomly Dist Within Polygons									$37,155	$0	$0	$1,040	$38,195
High Estimate Using (b)									$82,725	$5,838	$0	$4,278	$92,841

1. See footnote 2 in table 5.1
2. See footnote 3 in table 5.5

The yield losses for these crops alone account for between $26 and 70 million of our estimate for Ontario. This amount, if removed from our calculations, would make our estimate only slightly higher than that of Wall and Driver.

There are many other differences between the two methods of economic impact estimation, including the means of determining affected land areas, the method of valuing fertilizer loss, and the inclusion/exclusion of marketable loss. These differences tend to offset one another to produce comparable estimates when yield losses from the same crops are considered.

Estimates of the future cost of water erosion were generated from the following rates of change over a five year period (generated by study participants):

ONTARIO REGION	% LAND DEGRADING FROM: Little Or No To Moderate	Moderate To Severe
Southern, Western	1	2
Eastern, Central	10	10
Northern	3	0

If these rates of change are applied to all crops, the annual cost of water erosion in the province would increase by $8 to 9 million (constant dollars) in 5 years' time. Despite the higher rates of change applied to the Eastern and Central Regions, the absolute value of the change would be fairly evenly distributed over the four southernmost regions, with Northern Ontario changing very little.

As shown in Tables 5.17 to 5.19, wind erosion is a major problem only in Southern Ontario (wind erosion impact in the Central and Northern Regions is essentially nil).

TABLE 5.17. Estimated Annual Cost Of Wind Erosion in The Eastern Ontario Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	800	5[3]	800	37	30[3]	0	93	23	32	30	0	0	62
grain, rot w/for	800	12	1200	0	32	0	0	23	115	0	0	0	115
silage	600	5[3]	100	37	30[3]	0	93	23	3	4	0	0	7
silage, rot w/for	600	12	1300	0	32	0	0	23	94	0	0	0	94
BEANS													
soybeans	630	10	0	0	25[3]	0	56	16	0	0	0	0	0
soybns, rot w/fo	630	7.5	0	0	30	0	0	16	0	0	0	0	0
OTHER ROW CROPS													
potatoes[1]	2100	10	0	0	20	0	0	50	0	0	0	0	0
vegetables[2]	4700	15	100	0	15	0	0	50	71	0	0	0	71
SPRING GRAIN	310	5	1800	11	7	0	18	13	0	0	0	0	0
FALL GRAIN[2]	440	10	0	0	12	0	28	13	0	0	0	0	0
TOTAL OF ALL CROPS									$314	$33	$0	$0	$348

Yield reduction factors from:

1. P.E.I. Crop assumed in rotation with grain
2. Southern Ontario
3. See footnote 3, in table 5.5

TABLE 5.18. Estimated Annual Cost Of Wind Erosion In The Western Ontario Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	800	6[2]	100	40	20[2]	0	40	23	5	4	0	0	9
grain, rot w/for	800	10	100	0	25	0	0	23	8	0	0	0	8
silage	600	6[2]	0	40	20[2]	0	40	23	0	0	0	0	0
silage, rot w/for	600	10	0	0	25	0	0	23	0	0	0	0	0
BEANS													
soybeans	630	20	0	0	50	0	0	16	0	0	0	0	0
soybns rot w/for	630	17.5	0	0	45	0	0	16	0	0	0	0	0
white	710	30	0	0	30	0	0	19	0	0	0	0	0
OTHER ROW CROPS													
potatoes[1]	2100	10	0	0	20	0	0	50	0	0	0	0	0
tobacco	8700	15	0	0	15	0	0	110	0	0	0	0	0
vegetables	4700	15	0	0	15	0	0	50	0	0	0	0	0
SPRING GRAIN	310	10	0	0	15	0	32	13	0	0	0	0	0
FALL GRAIN	440	10	0	0	12.5	0	28	13	0	0	0	0	0
TOTAL OF ALL CROPS									$13	$4	$0	$0	$17

1. Yield reduction factor from P.E.I. Crop assumed in rotation with grain
2. See footnote 3, in table 5.5

TABLE 5.19. Estimated Annual Cost Of Wind Erosion In The Southern Ontario Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN													
grain	800	6[1]	20000	40	20[1]	0	40	23	960	800	0	0	1,760
grain, rot w/for	800	10	5300	0	25	0	0	23	424	0	0	0	424
silage	600	6[1]	1000	40	20[1]	0	40	23	36	40	0	0	76
silage, rot w/for	600	10	1800	0	25	0	0	23	108	0	0	0	108
BEANS													
soybeans	630	20	5300	0	50	0	0	16	668	0	0	0	668
soy, rot w/for	630	20	500	0	50	0	0	16	63	0	0	0	63
white	710	15	300	60	30	0	0	19	32	18	0	0	50
OTHER ROW CROPS													
tobacco	8700	15	1400	0	15	900	0	110	3,002	0	0	99	3,101
vegetables	4700	15	1400	0	15	900	0	50	1,622	0	0	45	1,667
SPRING GRAIN	310	10	2200	0	15	0	32	13	68	0	0	0	68
FALL GRAIN	440	10	0	0	12.5	0	28	13	0	0	0	0	0
TOTAL OF ALL CROPS									$6,982	$858	$0	$144	$7,984

1. See footnote 3 in table 5.5

The major crops affected in Southern Ontario are tobacco, grain corn and vegetables. These crops tend to be grown on sands and sandy loams, with little or no protection from wind as a result of the dearth of woodlots and shelterbelts. Our low estimates of wind erosion risk in Central Ontario (compared with Wall and Driver's report, for example) reflect primarily the application of the Wind Erosion Equation and the use of identical class limits for both wind and water erosion. It suggests that the procedure we used may tend to underestimate the occurrence of wind erosion in Ontario, and so this probably applies to the other regions as well.

NGP participants in Ontario identified many of the same problems associated with erosion as participants in other provinces, including increased field time, machinery and fuel costs, requirements for extra herbicides and trace elements, loss of productive land and the malfunction of drainage ditches. One Western Ontario participant noted that the movement of herbicides on eroded soils, when combined with heavy rainfall, can result in splash injury to crops such as soybeans, ultimately causing a loss of yield. In Eastern Ontario, the increased difficulty of working eroded soils was estimated to add 15 to 30 percent to tillage costs. In the area around Alfred (east of Ottawa), it was noted that drainage ditches often require rebuilding every 3 to 4 years on eroded land, as opposed to every 10 years where the land was not eroded. It is difficult to generalize about the costs of these problems to farmers; however they are clearly significant when moderate or severe erosion is present.

The most common methods recommended and used in Ontario to control erosion are:

- Crop rotation, including a forage;
- Reduced tillage and residue management practices. These include conservation tillage, zero till, ridge till and a reduction in the number or depth of tillage operations;

- Use of a winter cover crop (aerial seeding or underseeding);
- Green manure or animal manure to improve organic matter content;
- Structural controls such as grass waterways, rock chutes and terracing;
- Surface or tile drainage;
- Wind breaks.

The concepts of conservation and zero tillage have received more attention in Ontario than in any other province, and are being promoted by many farmer associations. Experiments on private land with government assistance are being conducted in Western, and to a lesser extent, Eastern Ontario in order to quantify the changes in crop yields, fertilizer and pesticide requirements and various soil characteristics resulting from alternative tillage practices. The results to date are variable, but they suggest that reduced tillage systems result in little or no change in yield and save on energy and labour costs even when additional equipment needs to be purchased. A good summary on the costs and benefits of the alternative tillage practices tried in Ontario has been prepared by Bos (1983).

5.8 BRITISH COLUMBIA (Excluding the Peace River Region)

5.8.1 Extent and Severity

Over 90 percent of the farm land in all British Columbia regions has low or very low water erosion risk. This is mainly because of the large area of crops requiring low intensity tillage (tree fruits, grapes, hay, pasture and range) grown on slightly erodible soils in level to gently sloping landscape positions.

In the South Coastal Region, approximately 6 percent of the land area has a high erosion risk. These areas are primarily characterized by intensive cropping for corn, vegetables, small fruits, potatoes, beans and small grains on highly erodible silt loam, loam and very fine sandy loam soils on rolling and undulating landscapes. High erosion risk is also found in areas with little cultivated land on the fringe of the present area of cropland, especially in the eastern portion of the Lower Fraser Valley towards the town of Hope. If cultivation of erosion-prone crops becomes more widespread, serious problems will likely occur in these high risk areas.

In the southern interior valleys, less than 1 percent of the farmland has a high water erosion risk. This small area is used mainly for corn, vegetables, potatoes, small fruits and small grains. In particular, the Elk River Valley in the eastern Kootenays, and the Fraser River Valley between Soda Creek and Chimney Creek, have a high risk of erosion where relatively steep land is farmed.

Slightly erodible sandy and clay soils in gently sloping landscape positions used for corn, vegetables, potatoes and small grain represent the small area having moderate risk of water erosion. These areas are found throughout the province, but only occupy about 2 percent of the farm land area. They are the only soils with a significant water erosion risk in the Omineca region, where they occur in the Nechako River Valley east of Ft. Fraser.

There appears to be only very low risk of wind erosion in Southern British Columbia. Climatic factors which determine risk are highly variable across the province, however. The mapping scale used in this study may have resulted in some small areas being misinterpreted. For example, the Sumas Prairie of the Lower Fraser Valley has been known to experience some wind erosion periodically, but this area does not emerge as one of high risk in this analysis.

5.8.2 Economic Impact

The erosion of agricultural land in British Columbia has traditionally been considered a problem in the Peace River Region, and has received relatively less attention elsewhere until recently. Field studies of erosion on agricultural land have been primarily restricted to the Peace Region, and no studies have been conducted which relate erosion to crop yield reduction or other factors influencing economic impacts. Our analysis, which relies on the British Columbia NGP meetings and questionnaires, is based solely on observation, professional judgment and information from outside the province. Because another study has examined the economic impacts of soil degradation in the Peace River District (Anderson & Knapik, 1984), we restricted our analysis to the rest of the province.

Because many of the crops grown in southern British Columbia have not been studied in terms of the effect of erosion on yield, it was necessary to apply economic impact factors to more general crop categories than those used in other provinces. For this reason, only three crop groups are considered in the economic analysis: corn (mostly silage), fruits and vegetables (comprising tree fruits, grapes, small fruits and other row crops), and grains and oilseeds.

Study participants identified the Lower Fraser Valley area within the South Coastal Region and, to a lesser extent, the Okanagan Valley area within the Southern Interior Region, as being the main areas of erosion concern in that portion of British Columbia considered here. Agriculture in both these areas is characterized by intensive cultivation of relatively high value crops. Fertilizer application rates are typically very high. NGP participants indicated, therefore, that increased inputs of fertilizer would not ameliorate the effects of soil erosion. The effects of erosion on soil water retention and soil structure were considered much more serious than possible impacts on soil nutrients, given the high, sometimes excessive, rates of fertilization that are presently employed. For this reason, the use of fertilizer to offset potential crop yield losses due to erosion was not considered in the analysis of economic impacts.

The results of our economic analysis for water erosion are displayed in Tables 5.20 to 5.22. We estimate that the annual on-farm cost of water erosion in the South Coastal Region ranges from $7.5 to 12.5 million, ranking it fourth out of the 16 regions studied in terms of economic impact. As with Southern Ontario, the large range within the estimate reflects our uncertainty as to the distribution of fruit and vegetable crops on slopes or relatively flat land within each soil polygon with moderate or high erosion potential.

The annual cost of water erosion in the Southern Interior Region is estimated at $1.3 to 1.9 million. The $274,000 estimate for the Omineca Region confirms that erosion is not presently a problem there.

Workshop participants stressed that although the present extent and rate of soil erosion in the Southern Interior and Omineca Regions is not high, the risk of substantially greater erosion exists, particularly in the Okanagan Valley. Existing management practices and the predominance of forage production are apparently the main reasons why erosion is not a more serious problem. Participants warned that future conversion of forage lands to row cropping could result in significant increases in soil erosion.

If present trends continue, NGP participants predicted that a moderate rate of deterioration would only occur in the South Coastal Region. It was felt that within 5 years, 2 to 3 percent of lands with little or no erosion would become moderately eroded and an equivalent amount of moderately eroded land would become severely eroded.

TABLE 5.20. Estimated Annual Cost Of Water Erosion In British Columbia South Coastal Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN SILAGE	1900	12.5	1100	0	37.5	3900	0	23	3,040	0	0	90	3,130
FRUIT & VEGETABLES (a)[1]	8200	17.5	2900	0	30.0	0	0	50	4,162	0	0	0	4,162
FRUIT & VEGETABLES (b)	8200	17.5	1300	0	30.0	2900	0	50	9,000	0	0	145	9,145
GRAINS & OILSEEDS	750	5.0	1200	0	15.0	1100	0	13	169	0	0	14	183
Total Of All Crops - Low Estimate Using (a)									$7,370	$0	$0	$103	$7,474
Extra With High Value Crops Assumed Randomly Dist Within Polygons									$4,838	$0	$0	$145	$4,983
High Estimate Using (b)									$12,208	$0	$0	$248	$12,457

1. See footnote 2, table 5.1

TABLE 5.21. Estimated Annual Cost Of Water Erosion In British Columbia Southern Interior Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN SILAGE	1900	12.5	200	0	37.5	500	0	23	404	0	0	12	415
FRUIT & VEGETABLES (a)[1]	8200	17.5	300	0	30.0	0	0	50	431	0	0	0	431
FRUIT & VEGETABLES (b)	8200	17.5	200	0	30.0	300	0	50	1,025	0	0	15	1,040
GRAINS & OILSEEDS	750	5.0	2700	0	15.0	2500	0	13	383	0	0	33	416
Total Of All Crops - Low Estimate Using (a)									$1,217	$0	$0	$45	$1,262
Extra With High Value Crops Assumed Randomly Dist Within Polygons									$594	$0	$0	$15	$609
High Estimate Using (b)									$1,811	$0	$0	$60	$1,871

1. See footnote 2, table 5.1

TABLE 5.22. Estimated Annual Cost Of Water Erosion In British Columbia Omineca Region.

		MODERATE EROSION			SEVERE EROSION				TOTAL COSTS				
CROP/CROP GROUP	VALUE ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	YIELD LOSS (%)	LAND (HA)	ADDED FERT ($/HA)	ADDED TILLAGE ($/HA)	YIELD COST $000	FERT COST $000	QUAL LOSS $000	TILLAGE COST $000	TOTAL COST $000
CORN SILAGE	1900	12.5	200	0	37.5	0	0	23	0	0	0	0	0
GRAINS & OILSEEDS	750	5.0	1300	0	15.0	1800	0	13	251	0	0	23	274
TOTAL OF ALL CROPS									$251	$0	$0	$23	$274

If this prediction is accurate, the annual cost of water erosion would increase by between $27,000 and $314,000 (constant dollars) in 5 years' time, depending on whether high value crops are assumed to be grown on flat or average slopes.

Soils and crops most affected by wind erosion in the South Coastal Region include row crops on organic soils, corn silage on a variety of soils, annual crops grown on the lacustrine soils in the Sumas Prairie area, some annual crops grown on a variety of soils in the Agassiz area, as well as any annual crops grown on other fine-textured soils. In the Southern Interior, wind erosion has been observed on very light sandy soils planted to grapes and annual crops and on the light silt loams in annual crops or summerfallow along the Fraser River benches.

Wind erosion was considered a relatively minor problem in both the Southern Interior and Omineca Regions. Even within the South Coastal Region, the amount of cropland calculated to be a moderate or severe wind erosion risk was too small to estimate an economic impact. This discrepancy is explained by the localized nature of the problem, and by the possible underestimation inherent in the prediction procedure used.

Additional problems experienced by farmers in the South Coastal and Southern Interior Regions due to erosion were noted by study participants to include:

- The need for increased ditch maintenance and repair of drainage outlets, particularly in areas of fine soil texture and steeper slopes;

- The requirement to fill in gullies, particularly in areas of fine soil texture and steeper slopes; or, conversely, the increased machinery access problems resulting from unfilled gullies;

- Problems associated with crop quality and maturity dates (the redistribution of productivity within a field resulting in variable crop quality and maturity dates);

- Irrigation storage failures.

Most crops found on eroded or eroding lands in British Columbia are grown in monoculture. No common crop rotations are extensively used on lands susceptible to erosion in the province. The only crop rotation identified by the study that sometimes occurs on moderately eroded land is a corn silage-grass hay rotation observed in the parts of the South Coastal Region and, to lesser extent, in portions of the Southern Interior. It was felt that corn silage yields would improve by about 10 percent if grown in this rotation as opposed to being grown in monoculture.

General measures which are recommended to control erosion in the South Coastal and Southern Interior Regions include:

- Manuring;

- Seeding of a winter cover crop (e.g. fall rye) on lands used for annual crops; plowing-under of this crop in the spring (green manuring);

- Reduced tillage practices;

- Maintenance of proper stocking rates on forage lands used for pasture, as well as on rangelands;

- Contour plowing;

- Strip cropping;

- Grassed waterways.

Most of these measures are not presently practiced on erodible soils. Real or perceived disadvantages largely center on the additional costs involved. In addition, cover cropping was felt to restrict the range of annual crops that could be grown because the summer crop must be harvested in time to plant the cover crop. Manuring costs can reach $310/ha, depending upon the equipment employed, the source of the manure, and whether custom operators are used. The costs of a winter cover crop are estimated to be as much as $170/ha. No cost estimates were provided for any of the other recommended practices.

Study participants felt that if the measures recommended above were employed, they would prevent further soil degradation and yield reductions. It was felt, however, that these practices would not result in yield improvements even when used over a period of several years.

In addition to assessing the effects of erosion on several categories of cultivated crops, the British Columbia NGP participants also attempted to consider the effects of erosion on rangeland and native pasture. This proved to be difficult to address quantitatively, due to a lack of research data and the resulting inability of participants to estimate yield loss coefficients. It has been possible, however, to define the costs of required amelioration, regardless of the present degree of degradation.

The primary concern related to the erosion of rangelands in British Columbia is the historical erosion associated with overgrazing in the late nineteenth and early twentieth centuries, particularly on the lower elevation grassland ranges of the Southern Interior Region. Overgrazing, along with natural conditions which increase erosion risk (slope, aspect, wind, precipitation) has led to soil erosion. The erosion in itself, however, has not contributed significantly to lost production potential. Existing productivity has been largely impaired as result of changes in vegetative cover caused by overgrazing. Rehabilitation of these areas is a long-term process if left to nature, requiring up to 50 years.

Improved technology and grazing management practices can accelerate the grazing rehabilitation process. Grazing management practices have been steadily improving since 1948. Since 1970, the seeding of tame species (mainly crested wheatgrass) on these degraded ranges has been steadily increasing. This highly successful one-time renovation practice currently costs about $160/ha. As long as improved management continues, there should be a steady continued improvement of grassland ranges and concomitantly, an assumed reduction in erosion risk.

6.0 ACIDIFICATION

6.1 OVERVIEW OF THE PROBLEM

Acidification of soil is a naturally occurring process which has been augmented over the years by man's activities. At the national level, the chief factors which increase soil acidification are the use of nitrogen fertilizers and acid rain caused by emissions from sources such as fossil fuel plants or internal combustion engines. Our impact estimates are based on increases in soil acidity due to these impacts. Natural acidity, a soil limitation, is not considered. In addition, soils which are well buffered and considered not to be sensitive to acidification were excluded from the economic analysis, as it may be many years before pH values fall to the point where crop yields are affected.

Accelerated soil acidification decreases the availability of macronutrients to crops and may increase the solubility of micro-elements to toxic levels (Coote *et al.*, 1981). Either of these effects can inhibit crop growth, but can be neutralized by the addition of lime to the soil. Our economic assessment is based on the cost of adding lime to neutralize annual acidity additions to sensitive and moderately sensitive agricultural soils. The location of areas with an acidity risk on sensitive and moderately sensitive soils is shown in Figure 6.1. An acidity risk is defined here as a combination of fertilizer and precipitation acidity exceeding 150 kg/ha/yr in $CaCO_3$ equivalent.

6.2 ATLANTIC CANADA

6.2.1 Extent and Severity

Most of the mineral soils in Newfoundland are very sensitive to acidification. Acid rain levels are among the lowest in eastern Canada at 20 to 25 kg/ha/yr lime equivalent, but on cultivated fields fertilizer rates could generate acidity at up to seven times this

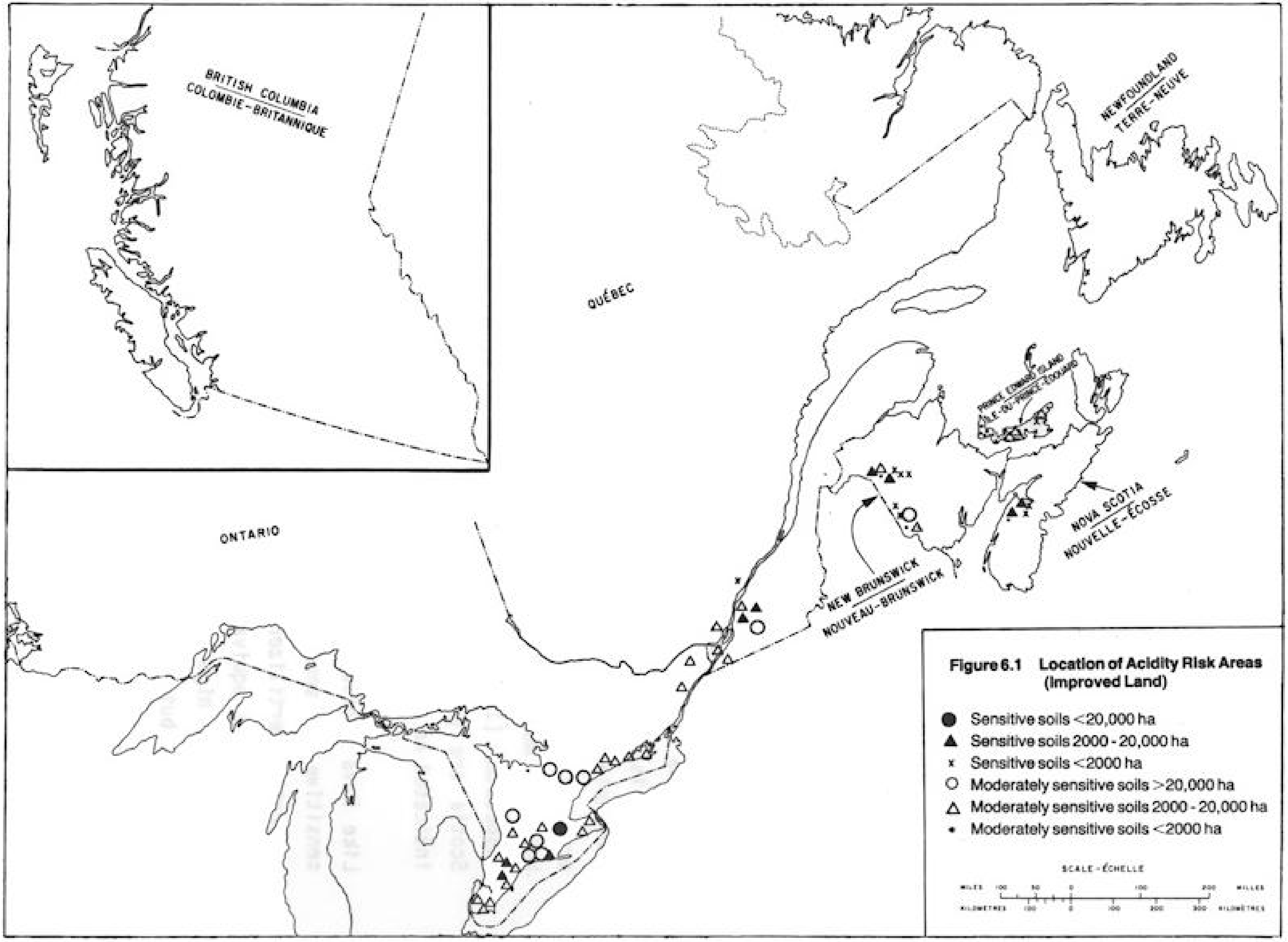

Figure 6.1 Location of Acidity Risk Areas (Improved Land)

rate, as applications of nitrogen (N) fertilizer in this region appear to be high. In only four locations (one in the Robinson's area in the southwest and the others in the Lethbridge - Musgravetown area) could natural soil buffering be expected to resist the development of fertilizer related acidification. Thus, this problem is significant in Newfoundland.

Most Nova Scotia soils are also sensitive or moderately sensitive to acidification. Acid rain levels appear to be moderate, being mostly between 30 and 35 kg/ha/yr lime equivalent. Nitrogen fertilizer use per hectare of crop land in Nova Scotia is high compared with the other provinces in eastern Canada except Newfoundland. Nevertheless, average contributions of fertilizer to cropland acidity are only about twice the acid rain inputs. In the intensively cropped areas of the Annapolis Valley region the fertilizer contributions are twice the provincial average, making fertilizer induced acidity a significant economic burden, as lime is widely used in this area to prevent soils becoming more acidic. In agreement with the Jacques, Whitford and Associates (1985) report, this study also found that soils in Nova Scotia are probably more sensitive to acidification than originally indicated on the map prepared by Wang and Coote (1981).

Like Nova Scotia, most soils in Prince Edward Island are moderately sensitive or sensitive to acidification and acid rain levels are moderate. Fertilizer generated acidity is high, averaging over 100 kg/ha/yr lime equivalent. No areas in Prince Edward Island appear to be quite as high as the most affected potato growing area in New Brunswick, but many areas of Prince County are well above the provincial average. Acidification must therefore be considered a significant problem.

With the exception of two small soil areas, all of the agricultural soils of New Brunswick are sensitive or moderately sensitive to acidification. The two exceptions are a loamy soil area just to the south of Gagetown within the Military Reserve, and a loamy bottomland near the mouth of the Kennebecasis River at Hampton. As in Nova Scotia, Wang and Coote (1981) found a much larger area of non-sensitive soils than found in this analysis. This anomaly is particularly evident southern New Brunswick. We feel that our more detailed data base which included soil chemical data stored in the CanSIS computer files for representative soil sites, provided somewhat more precise estimates than those made earlier using more generalized data.

Average fertilizer-induced acidity outside the Potato Belt is about 50 kg/ha/yr lime equivalent, which makes this source only slightly higher than the 35 kg/ha/yr associated with acid rain. Some intensively cultivated land, such as the sensitive sandy soils north of Shediac and near Cap Pele on the Northumberland Strait, have fertilizer acidity inputs far above average, and 2 to 3 times the acid rain source. Due to the high use of N fertilizer for the important crops of the Potato Belt Region, average fertilizer acidity is high (over 100 kg/ha/yr lime equivalent) in this region, and is nearly three times the acid rain input. One moderately sensitive soil area just north of Grand Falls has an estimated fertilizer acidity input exceeding 150 kg/ha/yr lime equivalent, the second highest value anywhere in eastern/central Canada (after a non-sensitive soil area in Southern Ontario).

6.2.2 Economic Impact

Calculations of the annual costs of neutralizing acidity in Atlantic Canada are displayed in Table 6.1. These costs, based on the average farm-gate cost of lime in each region, are approximately $1.6 million for all of Atlantic Canada. Over half this impact occurs in Prince Edward Island due to the large amount of improved land in this province relative to the other Atlantic provinces, and the high cost of transporting lime from the mainland.

TABLE 6.1. Annual Economic Impact Of Acidity On Agriculture In The Atlantic Provinces.

REGION	Sens. & Mod. Sensitive Improved Land[1] (000 ha)	Lime Required To Neutralize Annual Increases In Acidity (kg/ha)[1]			Cost Of Lime[2] ($/Tonne)	Annual Neutralization Cost ($000)
		Acid Precip.	Fert.	Total		
Newfoundland	9	23	101	124	84	94
Nova Scotia	171	32	75	107	13.5	247
P.E.I.	199	30	101	131	32	834
N.B. Potato Belt	81	39	108	147	20	238
N.B. Other	106	36	49	85	20	180
TOTAL	566					$1,593

Source:

[1] Physical study data runs.

[2] Unsubsidized cost of lime delivered to the farm as reported by study participants in each region.

Comparable estimates of the cost of neutralizing acidity are available only for Nova Scotia. Using a similar methodology Jacques, Whitford and Associates (1985) calculated a cost range of $120,000 to $250,000 per year, compared with our estimate of $247,000.

In Newfoundland, the acidity problem is compounded by the fact that proper liming has never been done on most agricultural lands. First time application rates of approximately 15 tonnes/ha (6.8 tons/acre) are often recommended, with 6.7 tonnes/ha (3 tons/acre) applied over a 10 year period to maintain pH. While the annual use of lime in the province appears to be equivalent to the maintenance rate, first time applications have been only a fraction of those that are required. The factors deterring more widespread use of lime in the province are cost ($30/tonne to the farmer) and the scarcity of bulk lime spreaders.

In Prince Edward Island acidity is not perceived to be a problem in the farming community. NGP participants estimated that 30 percent of the agricultural land in the province which has an acidity problem is not being treated at all. Of the remainder, half is receiving lime below the recommended rate (approximately 4.4 tonnes/ha every 3 to 5 years). Factors deterring Prince Edward Island farmers from applying higher levels of lime are cost, concern about rotation with potatoes (requires a lower pH than grain or forage), and lack of perception of the problem.

Acidity concerns in New Brunswick vary by crop and location. NGP participants suggested that only 5 to 10 percent of the land requiring lime is not receiving any. Most farmers in the Potato Belt, who use lime, apply it at or near recommended levels. In the rest of the province under-application is much more prevalent. Many farmers growing potatoes in rotation with grain, however, tend to apply lime at rates well below those recommended for grain due to concern for potato scab.

6.3 CENTRAL CANADA

6.3.1 Extent and Severity

As a general pattern, soil sensitivity to acidification decreases from east to west across Quebec. All soils in the Gaspe appear to be sensitive (coarse textured) or moderately sensitive (fine textured). In the eastern townships and the regions north of the St. Lawrence and Ottawa Rivers (including Lac St-Jean) clay soils are generally non-sensitive and loams and sandy soils either non-sensitive, moderately sensitive or sensitive depending on pH, and exchangeable bases. In the predominantly clay soil area south and east of Montreal, and in the silty clay soil area of northwestern Quebec, soils sensitive to acidification are few, and are limited to those derived from very coarse textured materials.

Acid rain levels are highest in the Montreal to Quebec City region with values of approximately 55 kg/ha/yr lime equivalent. In Gaspe and the northwest they fall to about 30 and 25 kg/ha/yr respectively. Acidity inputs due to fertilizer follow a somewhat similar pattern, being highest in the intensive, but predominantly non-sensitive clay soils of the Montreal Plain. The most seriously affected areas are those sensitive sandy soils in the Montreal to Quebec region used intensively for high N-consuming row crops, and which receive large acid inputs from the atmosphere. The effects of fertilizer inputs are approximately twice the effects of acid rain inputs, this ratio being slightly higher on cultivated soils in the northwest region.

Very few soils in the agricultural part of Ontario are 'sensitive' to acidification - Western and Southern Ontario have none. In the most intensively farmed areas, moderate sensitivity to acidification occurs in some sandy and loamy soils, amounting to about 20 percent of the south and 30 percent of the western region's improved land area. This part of the province has the highest acid rain levels, averaging near 50 kg/ha/yr lime equivalent. Average fertilizer-induced acidity input is approximately twice that induced by acid rain. Because such a large portion of the landscape is treated with fertilizer, the overall effect is large in terms of input to soil acidity.

In Central and Eastern Ontario, the sensitive soils are found mostly among the sands on the fringe of the Canadian Shield. There are also some sensitive soils south of the Ottawa River between Petawawa and Ottawa, and in a strip south and east of Ottawa to Hawkesbury. Moderately sensitive areas are scattered throughout the sandy and loamy soils. Included are several areas near Lake Ontario and in northern Prince Edward County. Acid rain levels are as high as in southwestern Ontario, but the effect of fertilizer inputs is slightly lower at about 80 kg/ha/yr lime equivalent.

Northern Ontario has a few soils in the agricultural areas that are sensitive, and these are invariably sandy. Acid rain levels range from as low as 10 kg/ha/yr lime equivalent in the Rainy River area to 40 around North Bay. Fertilizer inputs on cultivated soils are similar to Eastern Ontario.

6.3.2 Economic Impact

A breakdown of the annual costs of neutralizing acidity in the Quebec and Ontario study regions is provided in Table 6.2. The total economic impact in Ontario is estimated to be $3.7 million, the highest of any province covered in the study. Quebec, at $2.7 million, incurs the second highest cost of the provinces studied. The highest acid neutralization costs occur in Southern and Western Ontario due to the combination of high acidity inputs and large cultivated land base.

While lime use appears to be effectively neutralizing acidity inputs in Quebec (Coote *et al.*, 1981), NGP participants reported a large variation in usage patterns between and within regions.

TABLE 6.2. Annual Economic Impact Of Acidity on Quebec And Ontario Agriculture.

REGION	Sens. & Mod. Sensitive Improved Land[1] (000 ha)	Lime Required To Neutralize Annual Increases In Acidity (kg/ha) [1]			Cost Of Lime[2] ($/Tonne)	Annual Neutralization Cost ($000)
		Acid Precip.	Fert.	Total		
QUEBEC						
St. Lawrence	387	53	78	131	21.50	1,090
Eastern Twps/ Outaouais	292	52	70	122	20.0	712
Northern	374	36	63	99	23.50	870
Quebec Total	1,053					$2,672
ONTARIO						
Eastern	125	50	88	138	22	380
Central	53	49	95	144	22	168
Western	476	46	94	140	22	1,466
Southern	360	50	110	160	22	1,267
Northern	83	25	84	109	50	452
Ontario Total	1,092					$3,733

Source:

[1] Physical study data runs.

[2] Unsubsidized cost of lime delivered to the farm as reported by study participants in each region.

In the St. Lawrence Region, NGP participants reported that lime is not used on approximately 50 percent of the cropland which requires liming. Comparable figures for the Eastern Townships/Outaouais and Northern. Quebec are 20 and 70 percent respectively. Even where used, application rates are often below recommended levels in the two southernmost regions. Factors apparently inhibiting farmers from using lime are the removal of government subsidies for lime transportation; the short field time when lime should be applied; and the lack of transport facilities at peak demand periods. A typical application rate is 6 tonnes/ha.

Ontario lime application rates are equally variable. The reported rate of non-usage of lime when it is needed (i.e. on sensitive and moderately sensitive soils) is a moderate 25 percent in the Southern, Western and Northern Regions, but very high (65 to 70 percent) in the Eastern and Central Regions. One reason given for the magnitude of the latter figure is the lack of recognition of low pH as a problem in the Eastern/Central farming communities mainly due to the low proportion of acid sensitive soils in these areas. When lime is used, typical application rates are 4.5 to 6.7 tonnes/ha (2 to 3 tons/acre) in Eastern/Central Ontario and 9 to 11.2 tonnes/ha (4 to 5 tons/acre) in Southern/Western Ontario.

Factors which prevent more widespread use of lime in Ontario are cost, lack of awareness and land tenure. Cost is particularly a problem in Northwestern Ontario where prices reach $80/tonne when it is available. Land tenure is an issue in Southwest Ontario, where one-year tenants are unlikely to spend money for long term land improvement such as the liming of acid-sensitive soils.

6.4 EFFECTS OF ACIDIFICATION ON BRITISH COLUMBIA

6.4.1 Extent and Severity

Most of the coarse textured soils of the Fraser Valley, eastern Vancouver Island and the Gulf Islands are sensitive to acidification. Only the clay soils and some of the loam soils in these areas are non-sensitive, and soils in this category amount to just 12 percent of the farmland area. Average acid rain input is only 18 kg/ha/yr lime equivalent, which is exceeded more than fourfold by the average fertilizer acidity input.

In the interior valleys of southern British Columbia there are large areas of coarse textured fluvial-glacial soils in outwash terraces associated with major river valleys. These areas represent approximately 90 percent of the farmland area that is moderately sensitive or sensitive to acidification. In the Omineca Region, however, over 95 percent of the soils are sensitive or moderately sensitive. In the Omineca and Southern Interior Regions, acid rain inputs are very low (less than 8 kg/ha/yr lime equivalent on average), as are fertilizer inputs (less than 25 kg/ha/yr on average). There are areas in the Okanagan Valley, however, where the fertilizer input is as high as 125 kg/ha/yr lime equivalent, on some soils which are moderately sensitive to acidification. High nitrogen fertilizer use on fruit trees and vegetables account for the magnitude of these values. Because of the low precipitation acidity input, none of these areas met the criterion for inclusion on the map of Figure 6.1.

6.4.2 Economic Impact

Estimates of the annual cost of neutralizing of acidification in British Columbia are provided in Table 6.3. The $1.2 million estimate is nearly as high as. the total for all Atlantic Canada, despite much lower rates of acidification in British Columbia The high cost of lime in the province contributes to our high estimates.

Within the South Coastal Region in general and the Fraser Valley in particular, acid soils occur naturally and are a major agricultural problem. Agricultural practices serve to exacerbate this problem.

TABLE 6.3. Annual Economic Impact Of Acidity On Agriculture In British Columbia (Excluding the Peace River Region).

REGION	Sens. & Mod. Sensitive Improved Land[1] (000 ha)	Lime Required To Neutralize Annual Increases In Acidity (kg/ha)[1]			Cost Of Lime[2] ($/Tonne)	Annual Neutralization Cost ($000)
		Acid Precip.	Fert.	Total		
South Coast	127	18	60	78	50	495
Southern Interior	251	6	21	27	50	339
Omineca	171	8	25	33	60	339
TOTAL	549					$1,173

Source:

[1] Physical study data runs.

[2] Unsubsidized cost of lime delivered to the farm as reported by study participants in each region.

Acidification is considered to have already resulted in decreased yields for most crops in the region. This process is considered by NGP participants to be accelerating. Most cultivated lands have been limed at some time, although lime application is considered to be below recommended levels on 40 to 60 percent of cultivated lands within the region. Low levels of management (chiefly by hobby farmers and part-time farmers), lack of knowledge, problems with incorporating lime on forage/pasture stands, and the farmer's perception of the benefits and costs of liming were cited as the main reasons for this situation. The average annual costs of liming were estimated by study participants to be around $55/ha (4.5 tonnes/ha at $50/tonne every 4 years).

In the Southern Interior, acidification is considered to be a problem on the older, intensively managed stands of tree fruits. Grapes being a more recently introduced crop in the region, have generally not developed the same acidification problems as have been observed in the tree fruit soils, and yields have not yet begun to decline despite increasing acidification. Tree fruit production has already been affected (King, 1972), and NGP participants indicated that acidification of these lands is still increasing. Liming is generally used where required (perhaps 10 percent of lands requiring lime do not receive it), with application rates at or above recommended levels on at least 80 percent of the land. The annual cost of lime application was estimated to vary between $185 and $320/ha.

In the Omineca Region, naturally occurring acid soils are a problem which current farming practices are compounding. Yields of grains and forage crops have already been affected by acidification, and the problem is increasing. Little or no lime is used in the region because of its high cost. Liming costs are estimated to vary between $60 and $300/ha every 3 to 5 years, or $12 to $100/ha annually.

7.0 SOIL COMPACTION AND STRUCTURE DETERIORATION

7.1 OVERVIEW OF THE PROBLEM

Soil compaction is a problem associated with the passage of heavy machinery over agricultural soils, particularly those which are poorly drained, and/or low in organic matter content (often as a result of intensive cultivation). Three kinds of soil compaction effects have been noted by De Vries (1983):

1) Effect on soil hydrologic behaviour; e.g. the partition of rainfall between infiltration and ponding or overland flow;

2) Effect on plant growth, through interference with seedling emergence and root penetration. (The latter affects water and nutrient uptake);

3) Effect on cloddiness of the Ap horizon, which can affect seed establishment and harvesting efficiency.

Soil compaction is reflected by an increase in soil bulk density and a reduction in aeration and hydraulic conductivity, which may make soil more difficult to cultivate as well as adversely affect plant growth. Declining organic matter levels contribute to the problem, but tillage and harvesting on wet soils makes the effect more severe (Coote, *et al.*, 1981). Since compaction can result in poor soil drainage, initial problems are often aggravated unless corrective measures are taken to break the cycle.

Soil compaction and structure deterioration are closely linked because the loss of organic matter is an important bonding agent in the maintenance of soil structure. The collapse of soil structure is both a property and a cause of soil compaction.

Although several Canadian studies have examined the properties of soil compaction and/or their relationship to the use of heavy machinery, only a few (conducted mainly in Quebec and Ontario) have studied the effects of compaction on crop yields. A series of experiments conducted in the Montreal area demonstrated that corn yield reductions of up to 50 percent could occur in heavily compacted soil (Raghavan *et al.*, 1979). Later experiments in the same area demonstrated that yield reductions are less severe in loam than in clay fields (34 to 40 percent in clay vs. 6 to 14 percent in loam under the same treatment), and that rainfall conditions affect the severity of this effect (Gameda *et al.*, 1983). Significant reductions in corn yield were also observed on compacted Brookston clay soil in southwestern Ontario as a result of reduced intake of nitrogen and potassium (K). Fertilizer use was found to compensate for inefficient N uptake, but not for K (Bolton *et al.*, 1979).

In general, our understanding of soil compaction and its effects on crop production is deficient relative to our understanding of the erosion process. Fewer studies have been done on the former (in the United States as well as Canada), and there exists no standardized methods for assessing the compaction problem. Furthermore, the only estimates of the economic cost of soil compaction in the study area are contained in a recent and still unpublished series of papers on soil degradation prepared for the Science Council of Canada. The methodology used in our study for estimating the cost of soil compaction has not been used before and consequently our confidence in accuracy of the costs presented here is limited.

The location of areas with high compaction risk is shown in Figure 7.1.

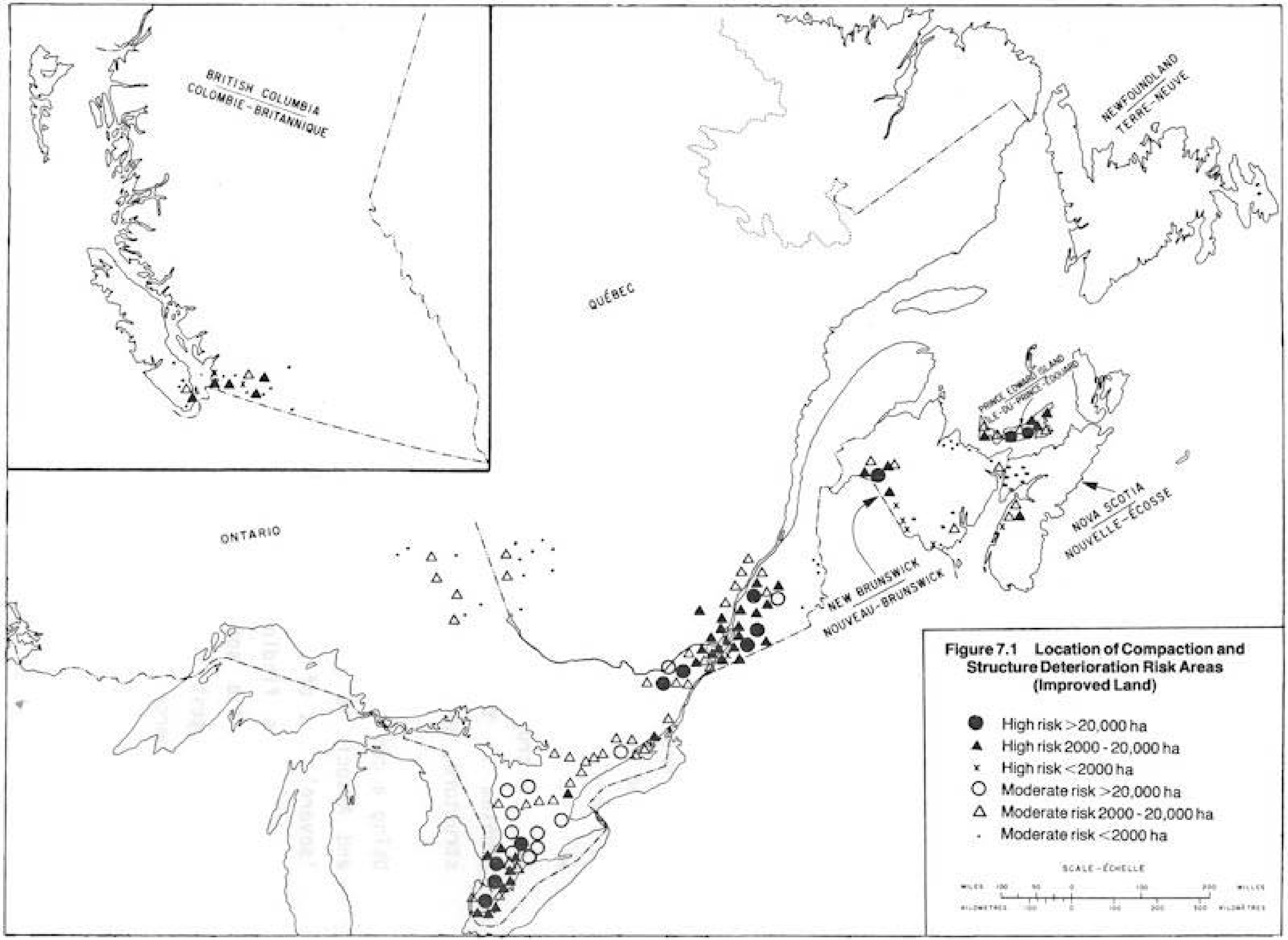

Figure 7.1 Location of Compaction and Structure Deterioration Risk Areas (Improved Land)

7.2 ATLANTIC CANADA

7.2.1 Extent and Severity

The potential for soil compaction and structure deterioration in Newfoundland is low or moderately low for most agricultural soils. Two poorly drained loamy areas, and one imperfectly drained clay loam area have a moderate risk of soil compaction and structure deterioration, but neither of these areas is used extensively for agriculture. Four sandy soil areas with moderately high tillage compaction potential are not currently considered to pose a significant problem due to good drainage characteristics and very little percentage cleared and cultivated.

Compaction as a result of farming practices is less of a problem than natural soil compaction in Nova Scotia. The chief area of concern is in the intensively farmed Annapolis-Cornwallis Valley where sandy soils low in organic matter have a moderate compaction risk and the fine textured soils have a high risk. Heavy textured soils in other regions of the province, both poorly and imperfectly drained, have a moderate risk of compaction and structure loss. They are not used extensively for row-crops, so this risk does not currently present a serious problem in these soils. Many Nova Scotia soils have poor natural structure, and tend to have poor tilth when intensively cultivated.

Using a completely different approach, the report by Jacques, Whitford and Associates (1985) concluded that there were no soils having a 'severe' risk of compaction in Nova Scotia. The results of our study confirm this finding. However, the former study grouped nearly 80 percent of the soils into a 'moderate' risk category. Our study results suggest that the distribution of crops was such that most soils (85 percent) were effectively at low risk.

Many soils in Prince Edward Island have a moderate or high compaction risk from soil management practices, associated mainly with potatoes. Thus Prince County contains the area most affected. Over 80 percent of the improved land of the province has at least moderate compaction risk from tillage and soil management, even though there is no significant area of clay soils. Most of the affected soils also have naturally compact subsoils. This phenomenon may be, therefore, the most severe soil quality problem facing Prince Edward Island farmers, and is one which is widely distributed throughout the province.

Over 55 percent of the improved land in the New Brunswick Potato Belt Region has a high risk of compaction; Almost all the cultivated area south of St. Leonard (just north of Grand Falls), is affected except the well drained sandy and loamy soils around Perth-Andover. The severe effects of tillage and harvesting associated with potato and vegetable production cause this management-induced soil compaction risk, and this is aggravated by low organic matter levels. The problem is further compounded on some heavy textured soils by poor drainage.

Compaction from tillage and soil management is less widespread in Southern and Eastern New Brunswick . An area of fine textured soils east of Fredericton, another just east of Chatham, and a third to the east of Sackville, seem to have the greatest risk of compaction from tillage. Other soils with some potential risk are, for the most part, not cultivated. Even in the three areas mentioned, tillage and traffic factors are currently only moderate, but if agriculture were to become more intensive, a significant problem could develop.

7.2.2 Economic Impact

Tables 7.1 to 7.3 display the data and calculations used to estimate the economic impact of compaction for 3 of the 5 Atlantic Canada regions. Newfoundland and New Brunswick outside the Potato Belt contain no land areas with 'high' or 'very high' compaction potential. Under our conservative set of assumptions, only on land with 'severe' compaction potential was a yield penalty assumed to occur; therefore, no impact was calculated in these two regions.

TABLE 7.1. Estimated Annual Cost Of Soil Compaction In Nova Scotia.

CROP/GROUP	Value ($/ha)	Sandy Soils		Loamy Soils		Clayey Soils		Total Cost ($000)
		Yield Loss (%)	Land (ha)	Yield Loss (%)	Land (ha)	Yield Loss (%)	Land (ha)	
CORN [1]								
grain	1000	2.5	100	10	0	20	0	3
silage	840	2.5	200	10	0	20	100	21
OTHER ROW CROPS								
potatoes[2]	3300	5	500	15	400	0[5]	0	281
tobacco[3]	9100	2.5	100	10	100	0[5]	0	114
vegetables[4]	3600	10	500	30	400	40	100	756
SPRING GRAIN[2]	390	5	600	15	200	30	0	23
FALL GRAIN[2]	480	5	500	15	100	30	0	19
TOTAL OF ALL CROPS								$1,216

Yield reduction factors from:

[1] Southern Ontario; corn assumed rotated with forage

[2] P.E.I

[3] Southern Ontario

[4] New Brunswick

[5] Not grown on clay soil.

TABLE 7.2. Estimated Annual Cost Of Soil Compaction In Prince Edward Island.

CROP/GROUP	Value ($/ha)	Sandy Soils		Loamy Soils		Clayey Soils		Total Cost ($000)
		Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	
CORN[1]	730	2.5	0	10	500	20.0	0	37
BEANS[1]	630	2.5	0	10	100	25.0	0	6
OTHER ROW CROPS								
pot-gr-for	3100	5	200	15	11000	0[3]	0	5,146
pot, other	3100	10	0	20	800	0[3]	0	496
tobacco[1]	7200	2.5	0	10	1300	0[3]	0	936
vegetables[2]	5000	10	0	30	1000	40	0	1,500
SPRING GRAIN	310	5	500	15	17000	30	0	798
FALL GRAIN	480	5	0	15	100	30	0	7
TOTAL OF ALL CROPS								$8,926

Yield reduction factors from:

[1] Southern Ontario; corn assumed rotated with forage

[2] New Brunswick

[3] Not grown on clay soil

TABLE 7.3. Estimated Annual Cost Of Soil Compaction In The New Brunswick Potato Belt.

		Sandy Soils		Loamy Soils		Clayey Soils		
CROP/GROUP	Value ($/ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (ha)	Yield Loss (%)	Land (ha)	Total Cost ($000)
CORN[1]	730	2.5	0	10	300	20	0	22
BEANS[1]	630	2.5	100	10	300	25	0	20
OTHER ROW CROPS								
pot, contin	2500	10	700	20	1300	0[2]	0	825
pot-other	2500	5[3]	3800	10[3]	7600	0[2]	0	2,375
vegetables	5600	10	550	30	1100	40	1100	4,620
SPRING GRAIN	290	5[4]	1800	15[4]	7900	20[5]	1000	428
FALL GRAIN	290	5[4]	0	15[4]	0	20[5]	100	6
TOTAL OF ALL CROPS								$8,296

[1] Yield reduction factors from Southern Ontario

[2] Not grown on clay soil

[3] Assumed to be half the value of that for continuous cropping due to the benefits of rotation

[4] From PEI estimates

[5] From Southern and Western Ontario estimates

The annual economic impact of compaction in Atlantic Canada is estimated at $18.4 million, 48 percent from Prince Edward Island and 45 percent from the New Brunswick Potato Belt. The crops which are most affected are potatoes, vegetables and tobacco.

Compaction in New Brunswick and Prince Edward Island is a problem recognized by farmers and agricultural specialists, and a number of techniques have been employed to ameliorate the problem with mixed success. In New Brunswick , some farmers use a combined tillage implement (disker, coulter and chisel plow) to reduce the number of passes over a field. Crop rotation and green manure are used for preventative and restorative purposes. Green manuring was noted to be rare in New Brunswick and of benefit only in the long term on already compacted soils. More immediate solutions attempted include subsoiling ($95/ha) and deep ripping (up to $250/ha), with mixed results. Other techniques include the installation of tile drainage (up to $1,500/ha) and the use of flotation tires on lime spreaders.

In Prince Edward Island , tobacco farmers have spent as much as $250/ha to obtain and spread animal manure, part of the benefit of which is to improve soil structure. Manure is considered to be an effective solution over time. Other amelioration measures noted by Prince Edward Island NGP participants were crop rotation, not cultivating wet soils and chisel plowing.

7.3 CENTRAL CANADA

7.3.1 Extent and Severity

The main area in Quebec with a high risk of soil compaction from tillage practices is located south and east of Montreal, where poorly drained clay and loam soils are very intensively cultivated for row crops. Other similar areas occur south of the St. Lawrence River around Nicolet and Drummondville. Intensive vegetable production on the imperfectly drained Ile Jesus soils also results in a high compaction risk. High risk is also associated with the poorly drained clay soils around l'Assomption and west of

Joliette on the north side of the St. Lawrence. About 33 percent of the St. Lawrence Region has a high risk of compaction. Another 25 percent has a moderate risk, including poorly drained sandy soils and imperfectly drained loamy soils with moderate to high tillage/traffic impacts. These soils are fairly evenly scattered through the Montreal Plain.

Other soils with moderate compaction risk include poorly drained clays and loams low in organic matter that are subjected to moderate tillage traffic. They are found near the United States border southeast of Quebec City in Dorchester County, and north and east of Sherbrooke. Further east these moderate risk areas are evident between Montmagny and Riviere-du-Loup, but the current intensity of tillage is very low.

North of the St. Lawrence, moderate compaction risk is found in clays, and some sandy soils, west of Quebec to the Shawinigan area, and in poorly drained clays along the Ottawa River Valley from Montebello to Luskville (west of Hull). Northwestern Quebec has many areas of poorly drained clay and silty clay soils with a moderate compaction risk. These soils could become more seriously affected if cropping intensity should increase. The risk of soil compaction appears to be relatively low in the Lac St-Jean area.

In the Southern Region of Ontario, a very high risk of compaction occurs on the clay and clay loam soils of Essex, Kent and Lambton Counties. A high percentage of these soils are used for row crops such as corn, soybeans and vegetables. This area, a small area south of Montreal, and another small area in the Potato Belt of New Brunswick have the highest compaction risk in Eastern and Central Canada. In this part of the province many loamy soils have a high compaction risk, and moderate risk is found on many sandy soils. Over 90 percent of the improved land of the Southern Ontario region appears to have at least a moderate risk of compaction.

Areas of moderate compaction risk are found throughout the Western and Central Ontario Regions. Exceptions include the northern parts of Bruce, Grey and Simcoe Counties, and some low risk sandy soils north and east of Toronto and in southern Waterloo and northern Brant Counties. Small areas of clay and loam soils in this region have high risk; these are found in Simcoe, Halton and Norfolk Counties. A significant area of high risk soil occurs in the poorly drained Napanee clay plain, and on Amhurst Island, west of Kingston.

In Eastern Ontario, compaction due to poor soil management is a high probability in the clay soils south and west of Ottawa, where intensive tillage (mostly corn) is practiced. Another extensive area with poorly drained clay soils stretches north and south of Winchester and east from this area in a strip across to the Quebec border. This area also has a high compaction risk, but is less intensively farmed at present than the area nearer Ottawa. Moderate compaction risk is found in the northern part of Eastern Ontario, from Pembroke to Alfred, and east of Cornwall to the Quebec border, on all soils where drainage is poor or imperfect.

In Northern Ontario there are some areas of poorly drained silty clays and loams with moderate compaction risk, but the present intensity of tillage is low; consequently, few problems are anticipated. They are found south of Cochrane, east of Timmins and through the northern clay belt (Kapuskasing to Hearst). Another area of poorly drained silty clay in the Rainy River basin from Rainy River to Ft. Francis has moderate risk. A portion of this area is currently used for beef, hay and small grains production, but should the intensity or area of farming increase substantially, the problem could become serious.

7.3.2 Economic, Impact

Of the 8 regions in Quebec and Ontario, 5 were found to have soil and crop combinations with high or very high compaction potential. Tables 7.4 to 7.8 display the likely on-farm economic impact of compaction in these 5 regions.

TABLE 7.4. Estimated Annual Cost Of Soil Compaction In The Quebec St. Lawrence Region.

		Sandy Soils		Loamy Soils		Clayey Soils		
CROP/GROUP	Value ($/ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	Total Cost ($000)
CORN								
grain, contin	950	0.0	2700	15.0	2400	35.0	19000	6,660
grain, rot	950	0.0	1900	7.5[2]	1600	17.5[2]	13000	2,275
silage, contin	960	0.0	300	15.0	200	35.0	2000	701
silage, rot	960	0.0	2800	7.5[2]	2400	17.5[2]	20000	3,533
BEANS	670	0.0	0	12.5[2]	200	30.0[2]	800	178
PTV								
potatoes	3400	0.0,	3000	15.0	4000	0.0[1]	0	2,040
vegetables	2600	10.0[3]	3000[3]	30.0	4000	50.0	3700	8,710
sugar beets [4]	470	10.0	100	30.0	0	50.0	2200	522
SPRING GRAIN	360	0.0	9000	10.0	8000	35.0	44000	5,832
FALL GRAIN	210	0.0	1000	10.0	0	35.0	100	7
TOTAL OF ALL CROPS								$30,457

1. Not grown on clay soil
2. See footnote 3 for N.B. Potato Belt (Table 7.3)
3. From N.B. estimates
4. Values for sugarbeets not assessed separately, values for vegetables are used

TABLE 7.5. Estimated Annual Cost Of Soil Compaction In The Eastern Ontario Region.

CROP/GROUP	Value ($/ha)	Sandy Soils Yield Loss (%)	Sandy Soils Land (Ha)	Loamy Soils Yield Loss (%)	Loamy Soils Land (Ha)	Clayey Soils Yield Loss (%)	Clayey Soils Land (Ha)	Total Cost ($000)
CORN								
grain	800	2.5	0	10	0	25	1400	280
grain, rot w/for	800	1.3[4]	0	5[4]	0	12.5[4]	2300	230
silage	600	2.5	0	10	0	25	100	15
silage, rot w/for	600	1.3[4]	0	5[4]	0	12.5[4]	400	180
BEANS								
soybeans	630	10	0	17.5	0	25	0	0
soybns, rot w/for	630	5[4]	0	8.8[4]	0	12.5[4]	100	8
OTHER ROW CROPS								
potatoes[1]	2100	10	0	20	0	0[3]	0	0
vegetables[2]	4700	2.5	0	10	0	20	0	0
SPRING GRAIN	310	0	0	5	0	10	2700	84
FALL GRAIN	440	0	0	5	0	10	0	0
TOTAL OF ALL CROPS								$797

Yield reduction factors from:

[1] New Brunswick

[2] Southern Ontario

[3] Not grown on clay soil

[4] See footnote 3, Table 7.3

TABLE 7.6. Estimated Annual Cost Of Soil Compaction In The Central Ontario Region.

CROP/GROUP	Value ($/ha)	Sandy Soils		Loamy Soils		Clayey Soils		Total Cost ($000)
		Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	
CORN								
grain	800	2.5	500	10	0	25	0	10
grain, rot w/for	800	1.3[4]	500	5[4]	0	12.5[4]	0	5
silage	600	2.5	0	10	0	25	0	0
silage, rot w/for	600	1.3[4]	300	5[4]	0	12.5[4]	0	2
BEANS								
soybeans	630	10	300	17.5	0	25	0	19
soybns rot w/for	630	5[4]	200	8.8[4]	0	12.5[4]	0	6
white beans	710	5	100	15	0	25	0	4
OTHER ROW CROPS								
potatoes[1]	2100	10	100	20	0	0[3]	3	21
tobacco[2]	8700	2.5	0	10	0	0[3]	0	0
vegetables[2]	4700	2.5	100	10	0	20	0	12
SPRING GRAIN	310	0	1200	5	0	10	0	0
FALL GRAIN	440	0	800	5	0	10	0	0
TOTAL OF ALL CROPS								$ 79

Yield reduction factors from:

[1] New Brunswick

[2] Southern Ontario

[3] Not grown on clay soil

[4] See footnote 3, Table 7.3

TABLE 7.7. Estimated Annual Cost Of Soil Compaction In The Western Ontario Region.

	Sandy Soils			Loamy Soils		Clayey Soils		
CROP/GROUP	Value ($/ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	Total Cost ($000)
CORN								
grain	800	2.5	1000	10	8800	20	400	788
grain, rot w/for	800	1.3[3]	500	5[3]	4500	10[3]	200	201
silage	600	2.5	100	10	700	20	0	44
silage, rot w/for	600	1.3[3]	500	5[3]	4000	10[3]	200	136
BEANS								
soybeans	630	2.5	600	10	3800	25	100	265
soybns, rot w/for	630	1.3[3]	200	5[3]	1100	12.5[3]	0	36
white beans	710	5	400	15	2400	25	0	270
OTHER ROW CROPS								
potatoes[1]	2100	10	700	20	300	0[2]	0	273
tobacco	8700	2.5	100	10	0	0[2]	0	22
vegetables	4700	2.5	2800	10	1000	20	0	799
SPRING GRAIN	310	2.5	1300	10	5600	20	2100	314
FALL GRAIN	440	2.5	1700	10	3600	20	300	204
TOTAL OF ALL CROPS								$3,350

[1] Yield reduction factor from New Brunswick
[2] Not grown on clay soil
[3] See footnote 3, Table 7.3

TABLE 7.8. Estimated Annual Cost Of Soil Compaction In The Southern Ontario Region.

		Sandy Soils		Loamy Soils		Clayey Soils		
CROP/GROUP	Value ($/ha)	Yield Loss[1] (%)	Land (Ha)	Yield Loss[1] (%)	Land (Ha)	Yield Loss[1] (%)	Land (Ha)	Total Cost ($000)
CORN								
grain	800	2.5	59000	10	21000	20	63000	12,940
grain, rot w/for	800	1.3[2]	16000	5[2]	5000	10[2]	17000	1,720
silage	600	2.5	2900	10	1000	20	3100	476
silage, rot w/for	600	1.3[2]	5400	5[2]	1900	10[2]	5800	446
BEANS								
soybeans	630	2.5	26200	10	7600	25	125000	20,580
soybns, rot w/for	630	1.3[2]	2280	5[2]	660	12.5[2]	11000	905
white beans	710	5	1800	15	520	25	9000	1,717
PTV								
tobacco	8700	2.5	8800	10	4100	0[1]	0	5,481
vegetables	4700	2.5	9200	10	4300	20	14000	16,262
SPRING GRAIN	310	2.5	5200	10	4300	20	16000	1,166
FALL GRAIN	440	2.5	17000	10	7200	20	52000	5,080
TOTAL OF ALL CROPS								$66,773

[1] Not grown on clay soil.

[2] See footnote 3, Table 7.3

The annual on-farm cost of compaction is conservatively estimated at $71 million in Ontario and $30 million in Quebec. The Southern Ontario Region, with an estimated $67 million in yield loss due to compaction, is the most severely affected of the 16 regions studied. The estimated $30 million annual compaction damage in the Quebec St. Lawrence Region is higher than the combined cost of water erosion, wind erosion and acidity in the entire province. However it must be noted that the yield reduction factors for compaction estimated by NGP participants for Quebec St. Lawrence were higher then those estimated in other regions.

The combined yield reductions from corn (grain and silage), vegetables and beans (mainly soya) account for over 80 percent of the calculated loss. Losses from compaction on land in soybeans in Southern Ontario alone account for $21.5 million of the annual loss. Corn in both provinces accounts for $31.6 million of the annual loss and $13.2 million (43 percent) of the Quebec total. These losses may be a harbinger of more serious problems to come, given the rate at which corn as a cash crop is spreading eastward from Southern Ontario.

The most commonly employed means of eliminating compaction in Quebec are subsoiling ($125 to 185/ha) and the use of alternative tillage implements such as the chisel plow and the duck's foot cultivator. Subsoiling is reported to be moderately effective at breaking up compacted soil, but its high cost and temporary benefits (generally only one year) limit its use. Chisel plowing and other forms of tillage are often ineffective when soil structure has severely deteriorated. Ultimately, some form of reduced tillage, combined with the reintroduction of forage into crop rotations, may be the best means of long term control of compaction in Quebec.

Ontario participants identified four types of potential solutions to the compaction problem: crop rotation, tile drainage, subsoiling and alternate tillage practices. Moderate to very good success has been achieved by introducing alfalfa, red clover, and in some cases, winter cereals (or canola in the north) into rotations. Tile drainage (average cost: $900-1,000/ha) is effective as a preventative, but not a corrective measure. Subsoiling is reportedly less expensive in Ontario ($25 to 125/ha) than Quebec, and can be effective if properly done.

Recommended changes in tillage practices include making fewer passes in the field, changing to a lighter implement for secondary tillage and adopting the type of conservation tillage/residue management practices which are used to control erosion. Controlled-traffic systems such as ridge tillage are being experimented with in Southern Ontario, and seem to work well for erosion and compaction control. This system, applicable to fine textured soils, requires a high degree of management skill but has been reported to save $25 to 125/ha in annual operating costs (Bos, 1983).

7.4 BRITISH COLUMBIA

7.4.1 Extent and Severity

High risk of soil compaction affects almost all poorly drained clay and clay loam soils in the Lower Fraser Valley, as well as some loamy soils where the tillage impact is severe. Silage corn and vegetables are the main crops where tillage practices which contribute to these high values are employed. The areas affected include Richmond, Delta, Langley and Matsqui. Twenty-three percent of the farmland in the South Coastal Region is in the high or very high risk category. There are no high risk areas in the other regions of southern British Columbia. Some soils contain shallow natural duric horizons, but none of these soils coincide with the high compaction risk associated with tillage practices.

Twenty-four percent of the farmland in the South Coastal Region has a moderate compaction risk primarily in the Lower Fraser Valley where poorly and imperfectly drained loamy, and sometimes sandy, soils are intensively cultivated. Only three areas of clay soils in the Southern Interior Region, and two in the Omineca Region, have moderate compaction risk. All other soils are of low or very low risk, primarily because of the scarcity of clay soils, the rare incidence of poor drainage in these regions, and the low average intensity of tillage practices on the heavier textured soils.

7.4.2 Economic Impact

As indicated above, only the South Coastal Region contains agricultural areas with high potential for compaction at the scale mapped. Our calculations conservatively estimate the annual on-farm cost of compaction in the region to be $6 million, mostly due to yield reductions of fruit and vegetable crops (Table 7.9). Part of the reason for the conservative nature of this estimate is that, as in other regions, we assume that economic impacts occur on only the severe compaction risk areas. In addition, the yield reduction factors estimated by NGP participants in Southern British Columbia were relatively low compared with all other regions (see summary Table 2.2).

Study participants indicated that several ameliorating or preventive measures have been tried to control compaction, particularly in the South-Coastal Region. These measures include:

- Reduced tillage: costs unknown;
- Subsoiling: $25 to 65/ha annually;
- Flotation tires: minor additional equipment costs;
- Cover crops: up to $175/ha annually;
- Additional drainage: additional $500-1,000/ha capital cost.

There was no consensus amongst NGP participants on the effectiveness of drainage (closer spacing, gravelled tile beds) to solve existing soil compaction problems.

TABLE 7.9. Estimated Annual Cost Of Soil Compaction In The B.C. South Coastal Region.

		Sandy Soils		Loamy Soils		Clayey Soils		
CROP/GROUP	Value ($/ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	Yield Loss (%)	Land (Ha)	Total Cost ($000)
CORN SILAGE	1900	0	300	7.5	1100	12.5	500	276
FRUIT & VEG	8200	0	400	7.5	900	12.5	4800	5,474
GRAIN & OILSEEDS	750	0	0	7.5	300	12.5	2500	251
TOTAL OF ALL CROPS								$6,000

8.0 NATURALLY-OCCURRING SUBSURFACE COMPACT LAYERS

8.1 OVERVIEW OF THE PROBLEM

Naturally-occurring subsurface compact layers inhibit crop production for many of the same reasons as their agriculturally-induced equivalent. Strictly speaking, the phenomenon is a soil limitation and not a form of soil degradation. We examined this problem however, with the intention of identifying what little is known about its severity and economic effects in the various regions. Although no reliable area or yield reduction estimates were generated, information on the location of naturally-occurring compact layers and measures used to combat the problem was obtained. Our findings are summarized below.

8.2 ATLANTIC CANADA

Subsurface compaction does not appear to be a widespread problem in Newfoundland. Ortstein layers occur in some soils in the eastern part of the province, but except for the Terra Nova area these soils are not agricultural. An area containing fragipan subsoils has been identified on the west coast in the Robinson's area north of the Codroy Valley, but, again, agricultural use is very low.

Soils of Nova Scotia are widely affected by natural subsoil compaction, mostly as a result of compact basal till at less than 100 cm depth. Over two thirds of the improved land area is affected. Subsoil compaction is, therefore, a significant problem for agriculture because it affects drainage, tillage and root growth, especially in the Northumberland Shore area, where fragipans also occur.

Most of Prince Edward Island soils are underlain by naturally compact basal till at less than 1 m depth, and this includes approximately 80 percent of the province's improved land. Fortunately, only just over 10 percent of this basal till is very shallow (i.e. < 50 cm depth). Nevertheless, with such a large portion of the improved land affected by subsurface soils of high density, it is a significant soil management problem.

Over one third of the improved land of each of the two regions of New Brunswick has soils with dense basal till within 1 meter of the surface. The combined effects of erosion and compaction in the Potato Belt make this a particularly important limitation, as the incorporation of subsoil into the plough layer by tillage is occurring in some of the eroded upslope positions. Potato yield reductions of 35 percent and higher were reported by study participants on affected soils. In the area south of Newcastle-Chatham, shallow (< 50 cm) fragipans are also a limitation.

A number of techniques have been tried to improve crop yields on lands in Atlantic Canada affected by natural subsurface compact layers. These include:

- French drains (gravel back-fill over tile drains, through the compact layer to the surface) and tile outlets; found to be of limited effectiveness where topsoil is very shallow. They may be combined with subsoiling to increase effectiveness;

- Deep ripping ($250/ha); requires repetition every few years;

- Subsoiling ($300/ha initial cost and $100/ha thereafter). This treatment, where effective, requires repetition every 24 years. Using a duck's foot and wing at approximately 2 ft. depth, experiments in New Brunswick show yield improvements of 10 to 20 percent on corn, potatoes and alfalfa;

- Injection of root growth hormone (BIHD) with subsoiling. Very expensive but very effective (20 to 50 percent yield increase in New Brunswick experiments);

- Land forming as a means of drainage improvement ($400/ha);
- Addition of manure, sawdust or peat moss with subsoiling ($400/ha); extends effectiveness of subsoiling operation up to 5 years;
- Fertilizer and lime injections; being experimented with in New Brunswick.

8.3 CENTRAL CANADA

There are some naturally compact basal tills within 1 metre of the soil surface in the Gaspe Peninsula, and a small number of soils with shallow fragipans south of Riviere-du-Loup. There is also a small area of soil with shallow duric horizons in the Lac-St-Jean region. The total area of these compact subsoils is very small, and affects only 5 percent of the improved land of Quebec. None of the affected areas is intensively used for cultivated crops.

The methods used to ameliorate the effects of subsurface compact layers in Quebec are all mechanical: subsoiling, chisel plowing and the duck's foot cultivator. Subsoiling ($125 to 190/ha) was the only means noted to be effective, and the operation has to be repeated every year.

There do not appear to be any significant areas of shallow compact subsoils in Ontario. A few sites have been identified, but they do not affect the dominant area of any soil polygon at the scale used in this study.

8.4 BRITISH COLUMBIA

Shallow duric horizons are present in a number of areas in the South Coastal Region, such as on some coarse-textured soils south and east of Vancouver, and in the coastal area around Powell River. They also occur in areas on the east coast of Vancouver Island. There is some compact basal till in the Lower Fraser Valley near the United

States border south of Langley and around Aldergrove, and also on the Gulf Islands and Vancouver Island. There is also an area with ortstein layers in the Gibson's Landing area. In all, over 30 percent of the South Coastal Region's improved land area is affected by compact layers, but very little is found at a depth less than 50 cm.

Compact basal till is widely scattered throughout the rest of the province. It affects about 20 percent of the improved and range land in the interior, with the largest percentage falling in the Omineca Region. Most of the affected areas in the Southern Interior Region have compact till at 50 to 100 cm, but in the Omineca Region, over 80 percent is shallower than 50 cm.

Natural subsurface compact layers were indicated by study participants to affect crop yields in only a few specific locations. Within the South Coastal Region, subsurface compact layers were indicated to be a problem for forage production on loess underlain by glaciomarine and morainal soils in the Matsqui and Langley uplands and on coarser textured outwash and alluvial materials in the Hazelmere Valley, as well as glacial till areas of Vancouver Island (Shawinigan soils). In addition, most crops grown on the marine clays of Vancouver Island incur some amount of yield loss as a result of subsurface compact layers. No subsurface compact layers resulting in significantly reduced yields were noted in the Southern Interior, largely because the impacts of such layers were largely masked by irrigation practices. In the Omineca Region, subsurface compact layers have been noted in all cropped land (principally forages) on fluvial soils, in lacustrine soils planted with forages. Yield losses for forage were estimated by study participants to range from 10 to 50 percent where the problem is found.

Measures used in the South Coastal Region to counteract this problem include the following:

- Deep plowing ($75 to 150/ha); generally thought to be ineffective;

- Additional drainage (capital costs of $1,200 to 2,500/ha over and above average on-farm drainage costs); considered to be moderately effective;

- Subsoiling ($25 to 65/ha); considered very effective when combined with drainage works;

- Irrigation: $750 to 1,750/ha for on-farm capital costs (depending upon system employed); plus the capital costs associated with securing a supply of irrigation water (examples of up to $10,000/ha have been noted); plus annual operating costs (excluding capital ownership costs) of $12 to 100/ha, depending upon the system used. Irrigation is often considered very effective to reduce the effects of restricted moisture availability in naturally compact soils, even in areas of low climatic moisture deficits.

9.0 OFF-FARM IMPACTS

9.1 OVERVIEW OF OFF-FARM IMPACTS

The pressure to increase farm productivity has caused changes in agricultural land use patterns and management practices. More intensive cropping systems, new pesticides, and the drainage of formerly low value agricultural land have increased productivity and farm incomes. These practices, however, are increasingly being associated with a number of environmental quality concerns. A decade of studies in some parts of Canada and in the United States have linked agricultural land use to the sedimentation, nutrient enrichment and chemical pollution of water bodies (Sonzogni *et al.*, 1980; Coote, 1980). These processes appear to impose significant off-farm damages which, to date, have not been easily quantified. A study in Ohio, referred to by Wall and Dickinson (1978), suggested that the off-farm costs of damage caused by soil erosion may be more than the on-farm losses.

An increase in the sedimentation of water bodies caused by soil erosion has been considered one of the most serious water pollution problems in the United States (Grant, 1971). Recent studies have shown that agricultural land in the Canadian Great Lakes Basin contributes 650,000 tonnes of suspended sediment to the Great Lakes annually, with a mean suspended sediment yield of 215 kg/ha/yr (Wall *et al.*, 1982). Sediment loading has a variety of effects on rivers and lakes, and society's use of them (Switzer-Howse and Coote, 1984). For example, increased turbidity adversely affects aquatic life and may cause a decrease in commercial and recreational use of the water body; and accelerated sediment deposition increases dredging requirements in harbours and ports and increases flood risks.

The runoff of nutrients and pesticides (associated with erosion on agricultural land) into water bodies has been shown to reduce water quality significantly. Aquatic life, drinking-water supplies and recreational use of the water body may be detrimentally affected. In addition, pesticides which remain in the soil may have long-term sublethal effects on wildlife. These effects have not been adequately quantified.

The effectiveness, applicability and costs of remedial measures in the Great Lakes Basin have been reviewed by Bos (1983). No overall remedial cost estimate is available, but the cost to reduce agricultural sediment and nutrient loading in the Great Lakes Basin to acceptable levels has been estimated to be $0 to $58 per watershed hectare, depending on the farming system, climate and physical characteristics of the site (Phosphorus Management Strategies Task Force, 1980). The most frequently recommended agricultural control measures include conservation tillage practices, vegetative buffer strips and controls on the timing and method of fertilization (Switzer-Howse, 1982). In many cases these measures involve little or no cost to the farmer.

Improved drainage and irrigation practices as well as the development of new crop strains has permitted land, formerly marginal for agriculture, to be cultivated. In these areas, higher levels of inputs are required to maintain yields which may increase the production costs of food. However, the most serious effects of land drainage may be changes in the quantity and quality of streamflow (Found *et al.*, 1976). While the effect of individual drainage projects may be very small, the cumulative effect of a number of projects may influence flood peaks and water levels, particularly if 'wetlands' are drained.

This section of the study identifies the types of off-farm economic impacts associated with the loss of soil material, nutrients and pesticides from agricultural land; and quantifies these impacts where possible. The discussion focuses on the effects of agricultural soil degradation on the fisheries and water-based recreation; navigation, water storage and conveyance facilities; off-stream water use; and wildlife resources and preservation values. No attempt has been made to look at the off-farm effects of wind erosion.

9.2 FISHERIES AND WATER-BASED RECREATION

Soil-related pollutants reduce the value of freshwater fishing by either reducing the total fish population, or by altering the aquatic environment in a manner which favours coarse fish over more valuable game fish species (National Research Council, 1982). Although marine fisheries are generally less subjected to these pollutants, many marine species reproduce in estuaries or rivers where these water quality problems occur.

Sediment appears to have the greatest effect on aquatic life either by causing physical damage to the species or by damaging its habitat. Increased turbidity from sedimentation may cause physiological stress to fish by clogging their gills and decreasing oxygen exchange capacity. Although this may not be a direct cause of mortality, it can increase the susceptibility of fish to infection by disease-causing micro-organisms (Ritchie, 1972).

Sediment may also cause a decline in the quantity and availability of food. Deposition of sediment may eliminate fish spawning areas and, in marine systems it may cause decreases in the shellfish population by covering oyster beds. In recreational fishing, turbidity interferes with the catch rate by reducing the visibility of lures. Sediment from agricultural land carries with it nitrogen and phosphorous that further decreases the quality of water bodies for fish by increasing the rate of eutrophication.

The economic impact of agricultural sediment on fish and wildlife was estimated in the Ohio study (Wall and Dickinson, 1978) to be only 4 percent of the on-farm cost of erosion. However, commercial and recreational fishing are of considerable economic value to the provinces in our study area (Table 9.1). The importance of good water quality to the fishery is reflected in estimates of its value and of losses due to erosion and sedimentation in Ontario. A study conducted by the Ontario Ministry of Natural

TABLE 9.1. Value Of Recreational And Commercial Fisheries.

	Value (In Millions of Dollars)			
	Atlantic Canada	Quebec	Ontario	British Columbia
Recreational Fishery				
1980 Value[3]	53	194	508	162
1984 Dollar Equivalent[2]	73	268	701	224
Commercial Fishery				
1983 Value[1]	705	56	28	210
1984 Dollar Equivalent[2]	736	58	29	219
TOTAL (1984 Dollars)	$809	$326	$730	$443

[1] Source: Department of Fisheries and Oceans (1983)
[2] Adjusted using change in Consumer Price Index
[3] Source: Ontario Ministry of Natural Resources (1980)

Resources (OMNR) (1980) estimated that the annual value of recreational fishing in Ontario (including money spent on equipment, travel and related activities) is $508 million. An unpublished estimate made by the Ontario Erosion and Sedimentation Coordination Committee (ESCC, 1983) attributed erosion and sedimentation with a loss of $83.7 million in potential sport fishing expenditures. This figure represents 12 percent of total sport fishing expenditures in the province when actual and potential value are expressed in current dollars. Unfortunately, there exist no comparable estimates for the Atlantic Provinces, Quebec or British Columbia.

The losses incurred by the commercial fishing industry are mainly due to decreases in the catch rate of valuable fish species. The value of commercial fisheries in the Great Lakes has declined from a peak value in 1910 of $40 million in current prices (Great Lakes Fisheries Commission, 1975) to less than $30 million in the 1980's, a reflection of declining water quality among other factors.

The fishery can undoubtedly be improved by implementing appropriate remedial control programs. Fifty-one percent of the angling in Ontario takes place in the Great Lakes and the inland waters of Southern Ontario. The OMNR has estimated that the benefits of a 10-year erosion and sedimentation control program in the Great Lakes would exceed 2 million angler days of increased fishing opportunity, valued at about $30 million (ESCC, 1983). This figure represents a one-third recovery of the estimated loss to recreational fisheries caused by sedimentation. It is assumed here that the benefits to the commercial fisheries would be similar.

Two major benefits of phosphorous control programs in the Great Lakes Basin which have already occurred are improved fish habitat and improved aesthetic value of the water for recreational activities. The OMNR has observed that as a result of phosphorous control programs implemented in the early 70's, many degraded fish populations in the Great Lakes have begun to increase without stocking, and species composition has begun to shift back to the more valuable game species. For example, the decline of walleye, yellow perch and smallmouth bass in the Bay of Quinte (Lake

Ontario) had dramatically reversed by 1978, resulting in a significant increase in angling. A similar recovery of the walleye population in Saginaw Bay (Lake Huron) was attributed to the reversal of eutrophication as a result of a phosphorus removal program. The potential for future improvement in many of the Great Lakes bays and harbours is believed to be achievable by controlling of sediment and nutrient inputs from non-point sources.

The effects of agricultural land degradation on fisheries are not likely to be as severe in the remainder of the study area as they are in Ontario. In British Columbia there is little commercial freshwater fishing and the freshwater bodies of the province which support recreational fishing are more heavily affected by logging activity than they are by agriculture. The value of recreational fishing is much lower in Quebec than it is in Ontario, and much of it occurs in water bodies some distance from agricultural areas. In Atlantic Canada, the great majority of the fishery is coastal or offshore. Although the offshore fishery is relatively unaffected by agricultural pollutants, non-point source bacterial pollution is the principal factor in 40 percent of the shellfish closures that occur in Prince Edward Island (personal communication, C. Murphy, Chief, Marine Environment, Dept. of Community Affairs, Charlottetown). Sediment eroded from fields where manure has been spread is a major contributor to this problem.

Other water-based recreational activities, affected by turbidity and nuisance aquatic vegetation caused by agricultural runoff and sediments, include boating, swimming and waterfowl hunting (Clark *et al.*, 1985). Unfortunately no one has attempted to calculate the costs attributable to these impacts in the Great Lakes Basin or elsewhere in Canada.

9.3 NAVIGATION, WATER STORAGE AND CONVEYANCE FACILITIES

Agricultural land degradation has adverse economic effects on navigation, water conveyance systems and water storage facilities as a result of eroded soil which is deposited in water bodies. The major costs of sediment to commercial navigation are incurred through the maintenance dredging of harbours and waterways. In 1983, the ESCC estimated the cost of dredging sediment from harbours, navigation channels, lakes and reservoirs in Ontario to be $12.1 million (including a pro-rated cost of sediment deposition which would shorten the lifetime of provincial reservoirs).

Sediment must also be removed from irrigation canals, roadside ditches and municipal drains. In Ontario, the costs of sediment removal from roadside ditches and municipal drains in 1983 were approximately $3.6 million and $7.2 million respectively, for a total slightly less than the cost of dredging harbours. The Ohio study reported by Wall and Dickinson (1978) estimated that the costs of removing sediment from highway ditches and drains were over three times greater than the cost of dredging harbours, or approximately half the cost of on-farm damage. Such a high figure is realistic in view of the high density of agricultural drainage in Ohio, but would not be representative of most of our study area, except Southwestern Ontario..

Economic impacts which were not estimated include the costs of flooding attributable to sediment; the cost of sediment or chemical damage to water intakes, bridges and other structures; and the cost of accidents and delays to commercial shipping related to sedimentation. Clark *et al.* (1985) estimated the cost of these three impacts attributable to cropland erosion to be $229 million in the United States (1980 dollars), so the amount of damage in Canada due to these causes is likely to be substantial.

The ESCC (1983) estimated that a soil erosion and sedimentation control program in Ontario could reduce economic losses on navigation, water storage and conveyance facilities by one-third over the next ten years.

Many measures aimed at reducing erosion will also be beneficial in reducing peak water flow and will be advantageous to flood control.

9.4 OFF-STREAM WATER USE

In areas where suspended sediment is a problem, the costs of treating water for municipal and industrial use may increase. The cost of building sedimentation basins and adding coagulants to remove pollutants from the water supply increase with the amount of sediment in the water supply. In Ontario, the ESCC (1983) estimated that $500,000 was spent in 1983 on power, labour and chemical inputs to remove the incremental amount of sediment resulting from erosion (mostly from agricultural land). The indirect cost of damage to facilities caused by salts that were removed, and the added cost of treating this water for industrial purposes, are not included in this figure.

9.5 WILDLIFE RESOURCES AND PRESERVATION VALUES

Wildlife and wildlife-related activities play a large role in outdoor recreational activities. According to a recent federal government study, Canadians spend an estimated $4.2 billion each year on wildlife-related activities, such as hunting, nature photography and birdwatching (Filion *et al.*, 1985). In Ontario, for example, 7.3 percent of the population engaged in hunting activities, while 19.9 percent engaged in non-consumptive wildlife-related activities. In 1981, $1.1 billion and 2.1 billion were spent on consumptive and non-consumptive wildlife-related activities respectively in Atlantic Canada, Central Canada and British Columbia (Table 9.2). As well as a source of revenue, wildlife resources have biological value and are an important component of a balanced ecosystem. Aesthetically, a healthy balanced ecosystem is a resource that provides visual, intellectual and spiritual satisfaction to a wide variety of users.

TABLE 9.2. Expenditures On Wildlife-related Activities.

	Annual Expenditures (In Millions of Dollars)	
	Consumptive	Non-Consumptive
Province		
Newfoundland	72	45
Nova Scotia	105	80
Prince Edward Island	4	5
New Brunswick	67	54
Quebec	292	511
Ontario	316	848
British Columbia	286	591
TOTAL	$1,142	$2,134

Source: Filion *et al.* (1985)

Agricultural activities may directly affect wildlife by decreasing habitat quality and diversity. In recent years, conservation tillage systems have been recommended as a means of decreasing erosion. These systems have the added benefit of improving the habitat quality for wildlife. Conventional tillage practices leave little food or cover, resulting in a poor capacity to support wildlife. Cowan (1982) found that duck populations are 3 to 8 times greater on no-till farms than on farms under conventional tillage. Similarly, pheasant nests (Rodgers and Wooley, 1983), invertebrates, birds, and small mammals (Warburton and Klimstra, 1984) were more abundant in no-till fields than in conventionally tilled fields.

The loss of habitat from agricultural practices and in particular, the loss of wetlands by drainage, is also a consideration. However, in Ontario, the trend toward improving drainage on existing agricultural lands rather than the conversion of new land, has minimized the environmental impacts of habitat loss (Found *et al.*, 1976).

Other impacts of agricultural runoff and erosion include damages to "preservation values". This term has been defined as the value placed on maintaining clean water even if the resource is not directly used. For the United States, damage to preservation values due to cropland erosion has been estimated at $210 million (Clark *et al.*, 1985). No estimates have been attempted for the study area, but given the importance of natural resources to Canadians, both from an economic and lifestyle perspective, it would seem that the value would be high in Canada as well.

9.6 ECONOMIC IMPACT ESTIMATION

Sediment, phosphorus, nitrogen and pesticides removed through soil erosion from agricultural land can cause considerable environmental damage and consequent economic impacts as a result of their entry into water bodies; particularly in intensively-farmed watersheds such as the southern Great Lakes Basin. An estimate of the annual off-farm economic impacts of agricultural land degradation in the province of Ontario is provided in Table 9.3 based on ESCC estimates, converted to

1984 dollars, and factored for the contribution of agricultural land to total damage. The $88.3 million total does not include costs which were discussed in this text but not quantified by the ESCC.

Costs in other study regions could not be interpolated from the Ontario estimates due to the unique situation of the Great Lakes Basin with respect to the intensity of agriculture and the relatively closed watershed. The physical data on sedimentation and runoff have been generated from over two decades of study and projections, while in other study regions, little or no attention has been given to the off-farm economic effects of agricultural land degradation.

It is also likely that the effects in other study regions are much less severe on a "per watershed hectare" basis because agricultural production is less intensive, they possess a lower percentage of cleared land and, in the case of the coastal provinces, the ocean removes or dilutes waste products. Nevertheless, some estuaries (such as the Fraser Delta in British Columbia and those of most major streams in Prince Edward Island) where suspended sediment, nutrients and pesticides eroded from agricultural land are likely resulting in significant, though unquantified, off-farm costs.

In the United States, pollutants directly related to erosion were estimated to cost that nation between $3.2 and 13 billion annually (1980 dollars) in damages and lost opportunities (Clark *et al.*, 1985). The share attributed to cropland erosion was approximately $2.2 billion, allocated as shown in Table 9.4. These figures are order-of-magnitude estimates, and exclude certain indirect environmental effects which would incur long term costs. Nevertheless, the study attempts to put a dollar value on the off-farm effects of erosion which, to our knowledge, have not been quantified anywhere else.

TABLE 9.3. Estimated Annual Off-farm Cost Of Agricultural Land Degradation In Ontario.[1]

	Cost (Millions of $)		% Attributed To Agriculture	Agriculture's Share (1984 $)
	ESCC (1983)	1984 $ [2]		
Dredging Sediment from Harbours (Federal Program)	8.9	9.3	85[3]	7.9
Sediment Damage to Inland Lakes, Reservoirs, Channels	3.2	3.3	85[3]	2.8
Water Treatment Costs	0.5	0.5	85[3]	0.4
Sediment Removal from Road Ditches	3.6	3.8	50[4]	2.0
Sediment Removal from Municipal Drains	7.2	7.5	50[4]	3.8
Recreational Fisheries Losses	83.7	87.4	85[3]	74.3
TOTAL	$107.1	$111.8	-	$91.2

[1] Covers only those off-farm costs estimated by the Provincial Erosion and Sedimentation Control Committee in 1983

[2] 1983 cost multiplied by the Consumer Price Index for 1983-84 (1.044)

[3] Basis: Wall *et al.* (1982) finding that 70 - 100% of suspended sediment in agricultural watersheds was contributed by cropland erosion. The majority of erosion losses in Ontario are expected to occur on agricultural watersheds.

[4] A large portion of sediment found in municipal drains and road ditches comes from bank erosion. A study conducted in the South Nation River Basin (Water & Earth Science Associates, 1981) showed that agricultural land erosion accounted for approximately 2% of municipal drain sediment; however, ditch banks are very unstable in this area. Another study in Southwestern Ontario found that 50% of sediments in municipal drains came from field erosion (Gulley and Bolton, 1983). Other studies assume 100% of sediment in ditches and drains comes from field erosion (e.g. U.S. study reported by Wall and Dickinson, 1978). A value of 50% was chosen for this study.

TABLE 9.4. Annual Off-farm Economic Impact Of Soil Erosion In U.S.A.

	Damage Costs (Million 1980 Dollars)		
Type of Impact	Range of Estimates	Single-Value Estimate	Cropland's Share
In-Stream Effects			
Biological Impacts		No Estimate	
Recreational	950 - 5,600	2,000	830
Water-Storage Facilities	310 - 1,600	690	220
Navigation	420 -800	560	180
Other In-Stream Uses	460 - 2,500	900	320
Sub-Total- In-Stream (Rounded)	2,100 -10,000	4,200	1,600
Off-Stream Effects			
Flood Damages	440 - 1,300	770	250
Water-Conveyance Facilities	140 -300	200	100
Water-Treatment Facilities	50 -500	100	30
Other Off-Stream Uses	400 -920	800	280
Sub-Total - Off-Stream (Rounded)	1,100-3,100	1,900	660
TOTAL - All Effects (Rounded)	3,200 -13,000	6,100	2,200

Source: Clark et al. (1985), p.175

While it is difficult to directly equate the off-farm cost of erosion in our study region with those in the United States without a much better Canadian data base, we attempted to do just this using the Clark report. We made the gross assumption that off-farm costs in both countries occur in direct proportion to their respective areas in row crops. As shown in Table 9.5, the annual off-farm cost of erosion in the study area would fall between $93 and 110 million under this assumption. The $74 million estimate for Ontario, $14.3 million lower than the value calculated from itemized ESCC estimates, suggests that extrapolation by this method may even underestimate the total amount of damage in some areas. From this comparison and what little data are available, we feel that $110 million is a reasonable order-of-magnitude estimate for off-farm impacts in the study area. Nevertheless, further work should be undertaken to itemize the damage and refine the overall estimate, particularly in British Columbia, Quebec and Atlantic Canada.

TABLE 9.5. Estimated Annual Off-farm Impact Of Agricultural Land Degradation In Study Area Based On Projections From National U.S. STUDY

Annual Off-Farm Damage in U.S. (1980 U.S. Dollars)	$2.2 Billion (Clark *et al.*, 1985)
Above in 1984 Canadian Dollars (Using 1980 Exchange Rate and C.P.I. Inflation Factors	$3.5 Billion
U.S. Land Base in Row Crops	Approximately 76 X 10^6 Ha. (U.S. Dept. of Agriculture, 1984)
Damage Cost Per Hectare of Row Crop in U.S. (In 1984 Canadian Dollars)	$46.05

Damage in Study Area Based on U.S. Cost Per Acre of Row Crop:

	Row Crop Area (000 Ha)	Estimated Value of Damage (Millionsof Dollars)
Atlantic Provinces	69	3.2
Quebec	324	14.9
Ontario	1,607	74.0 (91.2)[1]
B.C.(Excluding Peace River)	28	1.3
TOTAL	2,028	93.4 (110.6)[1]

[1] Number in brackets uses Ontario estimate derived from The Erosion and Sedimentation Control Committee figures (see Table 9.3).

10.0 REFERENCES

Anderson, M. and L. Knapik. 1984. Agricultural land degradation in Western Canada: A Physical and economic overview. Reg. Dev. Br., Agriculture Canada, Ottawa, 138 pp.

Arsenault, J.L. 1977. Soil conservation systems in New Brunswick, Canada. Am. Soc. Agr. Eng. Paper No. NA77-201.

Ateshian, J. 1974. Estimate of rainfall erosion index. J. Irr. and Drainage Div. (ASCE) 100(3): 293-307.

Battison, L.A. and M.H. Miller. 1983. Soil erosion and soil productivity in Ontario. Dept. of Land Resource Science, University of Guelph. Guelph, Ont.

Battison, L.A., P.H. Groenevelt, J. Havlin and R.L. Thomas. 1984. Barriers to sustained intense agricultural production on Ontario soils. Notes on Agriculture, University of Guelph, 19(2): 9 -14.

Bolton, E.F., V.A. Dirks and W.I. Findlay. 1979. Some relationships between soil porosity, leaf nutrient composition and yield for certain corn rotations on Brookston clay. Can. J. Soil Science 59: 1-9.

Bos, A. 1983. An update and evaluation of agricultural non-point source control practices for the Great Lakes Basin. Prepared for the Non-Point Source Task Force of the International Joint Commission, Windsor, Ont.

Bureau de la Statistique du Quebec. 1983. Statistiques de l'agriculture, des peches et de l'alimentation; Edition 1983, Quebec.

Clark, E.H., J. Haverkamp and W. Chapman. 1985. Eroding soils; The off-farm impacts. The Conservation Foundation, Washington, D.C.

Coote, D.R. 1980. Agriculture and water quality in the Canadian Great Lakes Basin. Canada Agriculture, 25 (1): 3-6.

Coote, D.R. 1983. Stresses on land under intensive agricultural use. Chapter 7. Stress on land in Canada. Folio No. 6, Lands Directorate, Environment Canada, Ottawa, Ont.

Coote, D.R. 1984. La situation de la degradation des terres agricoles dan l'est du Canada. (In) Cahier de conference, Journee d'information sur la conservation des sots. CPVQ, Ste. Foy, Quebec, 18 October, pp 91-98.

Coote, D.R., J. Dumanski and J. Ramsey. 1981. An assessment of the degradation of agricultural lands in Canada. LRRI Contribution No. 118. Research Branch, Agriculture Canada, Ottawa, Ont.

Coote, D.R., S. Shah Singh and C. Wang. The relative impact of acid rain and nitrogen fertilizers on acidity of agricultural soils in Canada I.: A methodology for assessment. Paper submitted for publication in J. Env. Qual.

Cowan, W.F. 1982. Waterfowl production on zero tillage farms. Wildlife Soc. Bull. 10: 305-388.

Crop Budget Committee. 1985. Crop budgetting aid. Ontario Ministry of Agriculture and Food, Toronto, Ont.

Culley, J.L.B. and E.F. Bolton. 1983. Suspended solids and phosphorous loads from a clay soil: II Watershed study. J. Env. Qual. 12 (4): 498 - 503.

Daigle, J.L. 1984. Experience acquise en conservation des sols au Nouveau-Brunswick. N.B. Ministry of Agriculture, Grand-Sault, New Brunswick.

De Kimpe, C.R., M. Bernier-Cardou and P. Jolicoeur. 1982. Compaction and settling of Quebec soils in relation to their soil-water properties. Can. J. Soil Sci. 62: 165-175.

De Vries, J. 1983. "Degradation effects of soil compaction." *In:* Proc. of the 8th B.C. Soil Science Workshop; Feb. 17-18, 1983. B.C. Ministry of Agriculture and Food, Victoria, B.C.

Department of Fisheries and Oceans. 1983. Canadian fisheries annual statistical review, Volume 15. Ottawa, Ont.

Dube, A. 1975. L'eau et l'erosion des sols. Ressources, 6 (4): 8-15.

Dube, A. and A. Mailloux. 1969. Le mesure de l'erosion a Cap-aux-Corbeaux. Agriculture, 26 (1): 32-36.

Economics Branch. 1984. Agricultural statistics for Ontario; 1983. Publication 20. Ontario Ministry of Agriculture and Food, Toronto, Ont.

Economics Branch. 1984. The economics of producing flue-cured tobacco in Ontario. Ontario Ministry of Agriculture and Food, Toronto, Ont.

Erosion and Sedimentation Control Committee. 1983. A strategy for soil erosion and sedimentation control in Ontario. Unpublished paper. Government of Ontario, Toronto, Ont.

Filion, F.L., S.W. James, J.Ducharme, W. Pepper, R. Reid, P. Boxall and D. Teillet. 1985. The importance of wildlife to Canadians; Highlights of the 1981 National Survey. Can. Wildlife Service, Ottawa, Ont.

Fitzsimmons, J.G. and W.G. Nickling. 1982. Wind erosion of agricultural soils in southwestern Ontario. Rept. 13. Dept. of Geography, University of Guelph, Guelph, Ont.

Found, W.C., A.R. Hill and E.S. Spence. 1976. Economic and environmental impacts of agricultural land drainage in Ontario. J. Soil and Water Cons. 31: 20-24.

Gameda, S., G.S.V. Raghavan, R. Theriault and E. McKyes. 1983. Effect of subsoil compaction on corn production. Am. Soc. Agr. Eng. Paper No. 83-1043.

Grant, K.E. 1971. Sediment: Everybody's pollution problem. Proc. of the 33rd Nat. Farm Ins. Chamber of Commerce, Des Moines, Iowa.

Great Lakes Fishery Commission. 1975. Environmental quality and fishing resources of the Great Lakes - a brief to the International Joint Commission. September, 1975. Ann Arbor, Michigan.

Groenevelt, P.N., S.H. Brunsting and R.R. Simard. 1983. Progress Report, 1983, Dept. of Land Resource Science, Ontario Institute of Pedology, University of Guelph. Guelph, Ont.

Jacques, Whitford and Associates Limited. 1985. Economic study of the extent of soil degradation in Nova Scotia. Prepared for the Regional Development Branch, Agriculture Canada, Truro, Nova Scotia.

Kay, B.D., R.W. Sheard and L.A. Battison. 1984. Overcoming the barriers to yield. Notes on Agriculture, University of Guelph 19(2): 15-20.

King, R. R. 1972. Okanagan PH survey report. B.C. Dept. of Agriculture, Kelowna, B.C.

Land Evaluation Group. 1983. Land evaluation under alternative erosion control policies. Report 4/81-83. School of Rural Planning and Development, University of Guelph. Guelph, Ont.

Linstone, H. A. and M. Turoff, (eds). 1975. The Delphi method: techniques and applications. Addison-Wesley Co., Reading, Mass.

Lyles, L. 1983. Erosive wind energy distributions and climatic factors for the West. J.

Soil and Water Cons. 38: 106-109.

McGiffin, R. 1983. Overview of costs and returns in potato production, Canada. Regional Development Branch, Agriculture Canada, Ottawa, Ont.

McKyes, E., E. Stemshorn and R. Bousquet. 1980. Damage to agricultural fields by construction traffic. Trans. ASAE. 23 (6): 1388-1391.

National Research Council. 1982. Impacts of emerging agricultural trends on fish and wildlife habitat. Commission on Natural Resources. National Academy Press, Washington, D.C.

Ontario Ministry of Natural Resources. 1980. The loss of fishing opportunities from soil erosion and sedimentation. *In:* Strategy for soil erosion and sedimentation control in Ontario. Toronto, Ont.

Pesant, A. R. 1984. The dangers of growing corn on hilly terrain. Canada Agriculture, 30 (2): 34-36.

Phosphorous Management Strategies Task Force. 1980. Phosphorous management for the Great Lakes. Prepared for the International Joint Commission, Windsor, Ont.

Prairie Farm Rehabilitation Administration. 1983. Land degradation and conservation issues on the Canadian Prairies. PFRA, Regina, Sask. 326pp.

Prince Edward Island Department of Agriculture. 1983. Agricultural statistics - Vol. 18 and review of agriculture; 1983. Charlottetown, P.E.I.

Raghavan, G.S.V., E. McKyes, F.Taylor, P. Richard, E. Douglas, S. Negi and A. Watson. 1979. Corn yield affected by wheel compaction in a dry year. Can. Agr. Eng. 21(1): 27-29.

Raymond, R., A. Mailloux and A. Dube. 1965. Pedologie de la Region du Lac-Saint-Jean. Min. de l'Agric. et de la Colonisation, Quebec, Bull, Tech. No. 11.

Regional Development Branch. 1984. Handbook of selected agricultural statistics; 1984. Agriculture Canada, Ottawa, Ont.

Ripley, P.O., W.Kalbfleisch, S.J. Bourget and D.J. Cooper. 1961. Soil erosion by water. Publ. 1083. Research Branch, Agriculture Canada, Ottawa, Ont.

Ritchie, J.C. 1972. Sediment, fish and fish habitat. J. Soil and Water Cons. 27: 124-125.

Rodgers, R.D. and J.B. Wooley. 1983. Conservation tillage impacts on wildlife. J. Soil and Water Cons. 38: 212-213.

Sadler, J.M. 1979. Soil erosion and organic matter depletion: Effects of current row-crop management in the Atlantic Region of Canada and the implications for soil productivity. Proc. Soil Erosion Workshop, N.S.Ag. Coll., Truro, N.S. April 17-19.

Sadler, J. M. 1982. Effects of soil degradation on barley production. Paper pres. at CSSS meeting, Vancouver, B.C. July 11-15.

Shelton, I.J., G.J. Wall and W.T. Dickinson. 1984. A proposed methodology for mapping provincial soil loss potential. Ontario Institute of Pedology Pub. No. 84-4.

Sonzogni, W.C., G. Chesters, D.R. Coote, D.N. Jeffs, J.C. Konrad, R.C. Ostry and J. B. Robinson. 1980. Pollution from land runoff. Jour. Env. Sci. and Tech., 14 (2): 148-153.

Standing Committee on Agriculture, Fisheries and Forestry. 1984. Soil at Risk. A report on soil conservation, Senate of Canada. Hon H.O. Sparrow (Chmn). Ottawa.

Statistics Canada and New Brunswick Dept. of Agriculture and Rural Development. 1983. Agricultural statistics; 1983; Province of New Brunswick. Fredericton, N.B.

Stephens, P., J-L. Daigle and J. Cihlar. 1982. Use of sequential photographs to detect and monitor soil management changes affecting cropland erosion. J. Soil and Water Cons. 37(2): 101-105.

Stewart, A. and M.D. Sudom. 1984. Agricultural soil erosion, degradation and conservation in Newfoundland and Labrador. Brief presented to the Standing Senate Committee on Agriculture Fisheries and Forestry; Halifax, May 10, 1984.

Stewart, N.E. and D. Himelman. 1975. Soil erosion studies on Prince Edward Island. Am. Soc. Agr. Eng. Paper No. NA75-211.

Stewart, N.E. 1976. Erosion of agricultural lands in the Maritime Provinces. Prepared for the A.P.A.S.C.C. Task Force on Soils. Charlottetown, P.E.I.

Switzer-Howse, K.D. 1982. Agricultural management practices for improved water quality in the Canadian Great Lakes Basin. Research Branch, Agriculture Canada, Ottawa.

Switzer-Howse, K.D. and D.R. Coote. 1984. Agricultural practices and environmental conservation. Agriculture Canada Pub. 1772/E. 27pp.

Van Vliet, L.J.P., G.J. Wall and W.T. Dickinson. 1978. Soil erosion from agricultural land in the Canadian Great Lakes Basin. Int. Joint Commission, PLUARG Task Group C Report, Windsor, Ont.

Wall, G.J. and W.T. Dickinson. 1978. Economic impact of Erosion. Notes on Agriculture, U. of Guelph, 14 (3): 10-12.

Wall, G.J., W.T. Dickinson and L.J.P. van Vliet. 1982. Agriculture and water quality in the Canadian Great Lakes Basin: II. Fluvial sediments. J. Environ. Qual. 11(3): 482-486.

Wall, G.J. and G. Driver. 1982. Cropland soil erosion; Estimated cost to agriculture in Ontario. Prepared by the Ontario Institute of Pedology for the Ontario Ministry of Agriculture and Food, Guelph, Ont.

Wang, C. and D.R. Coote. 1981. Sensitivity classification of agricultural land to long-term acid precipitation in eastern Canada. Research Branch, Agriculture Canada, Ottawa, Ont.

Warburton, D.B. and W.D. Klimstra. 1984. Wildlife use of no-till and conventionally tilled corn fields. J. Soil and Water Cons. 39: 327-330.

Water and Earth Science Associates Ltd. 1981. Erosion - sedimentation study. Prepared for the South Nation River Conservation Authority, Berwick, Ontario.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall-erosion losses. A guide to conservation planning. USDA Agric., Handbook. No. 537.

Woodruff, N.P. and F.H. Siddoway. 1965. A wind erosion equation. S.S.S.A.P. 602-608.

APPENDIX A:

LIST OF STUDY PARTICIPANTS

APPENDIX A:

LIST OF PARTICIPANTS

NEWFOUNDLAND

Mr. Dale Sudom, Director
Land and Soils Branch
Newfoundland Dept. of Rural, Agricultural and Northern Development

Mr. Ross Travers
Horticulturalist
Newfoundland Dept. of Rural, Agricultural and Northern Development

Mr. Jeff Whalen
Soil Surveyor
Newfoundland Dept. of Rural, Agricultural and Northern Development

Mr. Gary Kirby
Soil Surveyor
Newfoundland Dept. of Rural, Agricultural and Northern Development

Mr. Don Trenholm
Soil Laboratory Supervisor
Newfoundland Dept. of Rural, Agricultural and Northern Development

Mr. Ted Cahill
Provincial Drainage Specialist
Newfoundland Dept. of Rural, Agricultural and Northern Development

Mr. A.F. RaymentAgronomist
Federal Research Station
Agriculture Canada

NOVA SCOTIA

Mr. Jamey Oxley
Regional Development Branch
Agriculture Canada
Truro

Mr. John Higgins
Engineer
Nova Scotia Dept. of Agriculture
Truro

PRINCE EDWARD ISLAND

Mr. Chris Pharo
Soil and Water Management Program
Agriculture Canada

Dr. John McLeod
Research Scientist
Agriculture Canada

Dr. Martin Carter
Research Scientist
Agriculture Canada

Dr. Linnell Edwards
Research Scientist
Agriculture Canada

Mr. Conrad Veer
Soil Survey Unit
Land Resource Research Institute
Agriculture Canada

Mr. Richard Veinot
Soil Chemist
P.E.I. Dept. of Agriculture

Mr. Norbert Stewart
Plant Industry Branch
P.E.I. Dept. of Agriculture

Mr. Harvey Mitchell
President, P.E.I. Soil and Crop Improvement Association

Mr. Don Himelman
Island Drainage

NEW BRUNSWICK

Dr. Lin Chow
Agriculture Canada Research Station
Fredericton

Mr. Herb Rees
Agriculture Canada Research Station
Fredericton

Mr. Bill Pryor
Regional Development Branch
Agriculture Canada
Fredericton

Mr. Renald Cormier
Regional Development Branch
Agriculture Canada
Fredericton

Dr. Abe Ghanem
Plant Industry Branch
N.B. Dept. of Agriculture and Rural Development
Fredericton

Mr. Robbie Hinds
Potato Production Division
N.B. Dept. of Agriculture and Rural Development
Fredericton

Mr. John McMillan
Plant Industry Branch
N.B. Dept. of Agriculture and Rural Development
Fredericton

Mr. Karel Michalica
Plant Industry Branch
N.B. Dept. of Agriculture and Rural Development
Fredericton

Mr. Clare Gartley
Head, Soil-Water Section
N.B. Dept. of Agriculture and Rural Development
Fredericton

Mr. Jean-Louis Daigle
N.B. Dept. of Agriculture and Rural Development
Grand Falls

Mr. Arnold Banks
Agricultural Engineer
N.B. Dept. of Agriculture and Rural Development
Moncton

Mr. Maurice Maillet
President, N.B. Federation of Agriculture

Fredericton

Mr. Lance Bishop
President, Victoria County Soil and Crop Improvement Chapter
Arthurette

QUEBEC

M. Jean-Paul Jacob
MAPAQ
St. Louis de France

Mr. Robert Beaulieu
MAPAQ
Iberville

M. Hubert Frechette
MAPAQ
Marieville

M. Gilbert Sylvestre
St. Louis de Gonzaque

Dr. Jean-Marie Lancery
Univ. du Quebec a Trois-Rivieres
Trois-Rivieres

M. Remi Asselin
Nicolet

M. Claude Bernard
Ministere de l'environnment
St-Foy

Mr. Jean-Marc Cossette
Equipe Pedologique Federale
St-Foy

Mlle. Flore Fornier
Universite de Laval

Mr. Warren Grapes
Sawyerville

M. Francois Therien
MAPAQ
Rock Forest

M. Lucius Belzile
Ferme Experimentale
Agriculture Canada
La Pocatiere

Dr. Alain Pesant
Agriculture Canada
Lennoxville

M. Denis Brouillard
MAPAQ
Coaticook

Mr. J.M. Wauthy
Ferme Experimentale de Normandin
Agriculture Canada
Normandin

M. Denis Gingras
Deslisle

M. Roger Menard
CEPEP Alma
Alma

M. Pierre-Leon
GauthierSt-Leon

M. Michel Lamontagne
MAPAQ
St. Felicien

M. Claude Simard
MAPAQ
Alma

M. Jules Bossanyi
MAPAQ
Alma

M. Gilles Ouellet
St. Felicien

M. Benoit Harvey
Delisle

ONTARIO

Dr. Walter Findley
Agriculture Canada Research Station
Harrow

Mr. Galen Driver
Manager, Soil and Energy Management
OMAF, Plant Industry Branch
Guelph

Mr. Jim Arnold
Assistant Manager, Soil Management and Conservation
OMAF, Plant Industry Branch
Guelph

Ms. Jane Sadler-Richards
Soil Conservation AdvisorOMAF
Clinton

Mr. Art Bos
Upper Thames River Conservation Authority
London

Mr. Harvey Wright
Soil and Crop Specialist
OMAF
Guelph

Mr. Howard Lang
Soil Conservation Advisor
Grand River Conservation Authority
Cambridge

Dr. R. Sheard
Department of Land Resource Science
University of Guelph

Dr. Murray Miller
Department of Land Resource Science
University of Guelph

Dr. Charles Baldwin
Head, Soils Section
Ridgetown College of Agriculture Technology

Mr. Gary Roberts
Soil Conservation Advisor
OMAF
Ridgetown

Mr. Elbert van Donkersgoed
Research and Policy Director
Christian Farmer's Federation of Ontario
Guelph

Mr. Peter van Adrichem
Soil Conservation AdvisorOMAF
Kemptville

Ms. Dorothy Halley
Soil and Crop Specialist
OMAF
Nepean

Mr. Gilles Quesnel
Soil and Crop Specialist
OMAF
Kemptville

Mr. Bill Curnoe
Kemptville College of Agricultural Technology
Kemptville

Mr. Claude Weil
Head, Engineering Department
Alfred College of Agriculture and Food Technology
Alfred

Mr. Gerald Brown
Area Director, Ontario Soil and Crop Improvement Association
Newcastle

Mr. Don MacDonald
Ontario Soil and Crop Improvement Association
Wolfe Island

Mr. Ronald McCoy
Stittsville

Dr. Julian Proulx
Director, Experimental Farm
Kapuskasing

Mr. Walker Riley
Soil and Crop Specialist
OMAF
North Bay

Mr. Will Hermans
OMAF
Renfrew

Mr. John Rowsell
New Liskeard College of Agricultural Technology
New Liskeard

Mr. Peter Egli
Ontario Soil and Crop Improvement Association
Mannitaki

BRITISH COLUMBIA

Mr. Craig Brownlee
B.C. Ministry of Agriculture and Food
Kelowna

Mr. Grant Kowalenko
Agriculture Canada
Agassiz

Mr. Harvey Sasaki
B.C. Ministry of Agriculture and Food
Victoria

Mr. John Hansen
Agriculture Canada
New Westminister

Mr. Laurens van Vliet
Agriculture Canada
Vancouver

Mr. Martin Driehuezen
B.C. Ministry of Agriculture and Food
Surrey

Mr. Norm Sprout (retired)
formerly of B.C. Ministry of Agriculture and Food
Victoria

Mr. Ron Bertrand
B.C. Ministry of Agriculture and Food
Victoria

Mr. Bob Louie
B.C. Ministry of Environment
Victoria

Mr. Herb Luttmerding
B.C. Ministry of Environment
Kelowna

Mr. Al Van Ryswyk
Agriculture Canada
Kamloops

APPENDIX B:

SAMPLE QUESTIONNAIRE

Name: ________________________________

PART 1: EROSION

The types of erosion covered here are sheet, rill, gully and wind.

The following level (or degree or severity) descriptions will be used in subsequent questions on erosion.

Level 1. Little of no erosion has occured. The soil may have a few rills or places with thin A horizons, but not to an extent to alter greatly the thickness and character of the A horizon. Except for soils having very thin A horizons, the surface soil consists entirely of A horizon throughout nearly all of the delineated area. Up to about 25% of the original A horizon, or original plow layer in soils with thin horizons, may have been removed from most of the area. Level is to be used for comparison with Levels 2 and 3.

Level 2. Moderate erosion has occured. The soil has been eroded to the extent that ordinary tillage implements reach through the remaining A horizon, or well below the depth of the original plow layer in soils usually with a thin A horizon. Generally, the plow layer consists of a mixture of the original A horizons and underlying horizons. Mapped areas of eroded soil usually have patches in which the plow layer consists wholly of underlying horizons. Shallow gullies may be present. Approximately 25 to 75% of the original A horizon or surface soil may have been lost from most of the area.

Level 3. Severe erosion has occurred. The soil has been eroded to the extent that ail or practically all of the original surface soil, or A horizon, has been removed. The plow layer consists essentially of materials from the B or other underlying horizons. Patches in which the plow layer is a mixture of the original A horizon and B horizon or other underlying horizons may be included within mapped areas. Shallow or deep gullies are common on some soil types. Where wind erosion is relevant, blowouts may be common.

==

1.1 From your knowledge of the province (or portion of the province) what percentage of cropland would you estimate to be in each of the 3 erosion levels? (The total should be 100%).

______% Level 1 ______ % Level 2 ______ % Level 3

1.2 From a provincial perspective, the following crops and rotations appear to be of most concern with respect to erosion:

1) Potatoes, grown in rotation with grain and hay
2) Tobacco, grown in rotation with rye
3) Soybeans, grown in rotation with grain and potatoes
4) Processing peas, grown in rotation with grain and potatoes
5) Vegetables, (fresh or processing)
6) Continuous feed grain

Please select up to 5 of these crops to answer the questions on the chart on page 2 (or choose other(s) if you wish). To fill in the chart, you may have to base your answers on the soil texture or other soil/terrain conditions upon which the crop is predominantly grown. Please indicate this below for your selections, once you have examined the next page.

	Crop Selection	Rotation (if different from above)	Soil/Terrain Conditions (if applicable)
1.			
2.			
3.			
4.			

Note: The questions on page 2 are to be answered for the selected crop. However the crops they are rotated with may make a difference on some of your answers.

1.3 Level 1 Erosion (Little or no erosion)

1.3.1 What yield for the selected crops would you expect, assuming "average" growing conditions (degree days, rainfall, growing season). Circle units you are answering in:

bu/acre tonne/ha

1.3.2 What fertilizers (names or formulas) and rates of application would be used annually to produce the selected crops if grown on land with little or no erosion? Circle units you are answering in:

lb/acre kg/ha

1.4 Level 2 Erosion (Moderate)

1.4.1 If the selected crop is grown on moderately eroding (Erosion Level 2) land, what percentage yield reduction (i.e. less) would you expect without taking any compensation or correction measures?

1.4.2 If additional fertilizer(s) would normally be applied to compensate for the effects of moderate erosion on productivity, how much extra would be applied? (Use same units as in 1.3.2. Write "0" iffeel fertilizers would not be used to compensate for yield reductions.) What is the total per acre (or per hectare) dollar value of the additional fertilizer(s)?

1.4.3 Even with the additional fertilizer(s), you might still expect a lower yield than on land with little or no erosion. If so, what percentage yield reduction would you expect, compared with Level 1?

1.5 Level 3 Erosion (High)

1.5.1 If the selected crop is grown on severely eroding (Erosion Level 3) land, what percentage yield reduction (compared with Erosion Level 1) would you expect without taking any compensation or correction measures?

1.5.2 If additional fertilizer(s) would normally be applied to compensate for the effects of severe erosion on productivity, how much extra would be appliiroVEF and above that used on land withMile or no erosion? (Use same units as in 1.3.2.) What is the total per acre (or per hectare) dollar value of the additional fertilizer(s)?

1.5.3 Even with the additional fertilizer(s), you might still expect a lower yield on land with little or no erosion. If so, what percentage yield reduction would you expect, compared with Level 1.

PART 1: EROSION (Continued)

1.6 Given the present rate of soil erosion occuring in the province, what percentage of cultivated land would you expect to be in a higher erosion level five years from now?

From Erosion Level 1 to Erosion Level 2 ________%
From Erosion Level 2 to Erosion Level 3 ________%
From Erosion Level 1 to Erosion Level 3 ________%

1.7 One method of combatting soil loss due to erosion would have been to include a forage with those selected crops/rotations which do not include one. From your experience, what percentage improvement in the year 1 crop (selected crop) yield on Erosion Level 2 land would be reasonable to assume if the forage had been part of the previous rotation?

Crop	Rotation	% Yield Improvement Erosion Level 2 Land)

1.8 List (or briefly describe) one or two of the most common general measures recommended to control moderate or severe erosion in your region (excluding crop rotation). Provide typical per unit area costs if applicable and readily available. (Use space on back if necessary.)

1.9 What would be its (their) major disadvantages from the point of view of the farmer?

PART 1: EROSION (Continued)

1.10 How much (if any) of a yield difference compared with Erosion Level 1 land would you expect with any of these measures if implemented on Erosion Level 2 land? Indicate if this would vary over a period of 5 years.

Measure	Yield Difference (Year 1)	Yield Difference (Year 5)
__________	____________%	__________%
__________	____________%	__________%

1.11 What additional problems are frequently experienced by farmers as a result of erosion. These may include: (1) addition of extra soil herbicides or pesticides to replace those lost in eroded soil; (2) having to recontour fields or fill in gullies; (3) maintenance/repair of drainage outlets; (4) loss of formerly productive farmland; (5) added machinery fuel or travel costs; or (6) extra wear and tear on machinery. Please indicate if any particular soil/terrain conditions (e.g. texture, slope, wetness) are applicable.

PROBLEM	SOIL/TERRAIN CONDITIONS

1.12 What soils and crops are most affected by wind erosion in the province?

PART 2: ACIDIFICATION

2.1 Please use the chart below to indicate soil/crop combinations for which acidity is a problem:

- Place an "X" in the upper left corner of each square where acidity is already a problem.
- Place an "X" in the lower right corner of each square where you feel acidity is increasing as a problem (i.e. lowering of pH is increasingly affecting yields, or increasing amounts of lime are needed to offset this effect).

Crop	Sandy Soils	Loamy Soils	Clayey Soils

2.2 On what percentage of land is lime not used to control acidity when it should be?

__________ %

2.3 On what percentage of lands in your region where lime is being used to control acidity, are actual rates of application...

Above recommended levels __________ %

At recommended levels __________ %

Below recommended levels __________ %

2.4 What factors are deterring farmers from more widespread usage of lime to combat soil acidity?

2.5 What does lime cost in your province or region?

PART 3: SOIL SURFACE COMPACTION AND STRUCTURE DETERIORATION

Note: This section deals only with surface compaction induced by farming practices. The problem of natural subsurface compact layers is covered in the next section.

Susceptibility of agricultural soils to surface compaction and structural deterioration is being mapped across the country according to its surface texture, drainage class and machinery impact normally associated with given cropping systems.

3.1 Please use the table below to indicate soil-crop combinations in your region where surface compaction is a problem, as well as the percentage yield reduction range which can be expected as a result of the problem (e.g. 20 to 30%).

Percentage Yield Reduction Due to Surface Compaction On:

Crop	Sandy Soils	Loamy Soils	Clayey Soils
Potatoes			
Cereal Grains			
Tobacco			
Other			

3.2 Please indicate below those solutions which have been tried in your region to control surface compaction, their approximate cost per acre (or per hectare) and how effective they have been (e.g. very effective; moderately effective; ineffective).

Solutions Tried	Cost Per Acre	How Effective?

PART 4: NATURAL SUBSURFACE COMPACT LAYERS (e.g. brick clays)

4.1 Please indicate those soil-crop combinations in the province which are most affected by subsurface compact layers.

CROP	SOIL (or Parent Material)	% YIELD REDUCTION RELATIVE TO SOILS WITHOUT COMPACT LAYERS

4.2 Indicate below the solutions which have been tried in your region, their approximate costs per acre (or hectare) and how effective they have been (e.g. very effective; moderately effective; ineffective).

Solutions Tried	Cost Per Acre	How Effective?

4.3 Are there any soil-surficial material-crop combinations for which natural subsurface compact layers have been an advantage in cultivation (eg. to retain water)? If so, please indicate these conditions below and note where in the province they are known to occur.

PART 5: DRAINAGE

5.1 What are the most common crops grown on imperfectly or poorly-drained soils? What yield improvements can be expected, in general, for each of these crops when drainage improvements are implemented?

		PERCENTAGE YIELD INCREASE FROM IMPROVED DRAINAGE ON:	
	Crop	Imperfectly Drained Soil	Poorly-Drained Soil
i)			
ii)			
iii)			
iv)			

5.2 What crops grown on imperfectly or poorly-drained soils in your region are typically replaced by higher value crops following the installation of drainage systems? What yield can be expected with the replacement crops?

	Original Crop	Replacement Crop(s)	Replacement Crop Yield (bu/acre)
i)			
ii)			
iii)			
iv)			

5.3 Please indicate below what you feel are representative costs of systematic and random field drainage installations.

	RANDOM FIELD DRAINAGE	
	Tile Drainage	Surface Drainage
Installed cost (incl. materials)	$ ________/100 ft.	$ _________/100 ft.
Average annual maintenance cost	$ ________/100 ft.	$ _________/100 ft.

	SYSTEMATIC FIELD DRAINAGE	
	Tile Drainage	Surface Drainage
Installed cost (incl. materials)	$_______/acre	$________/acre
Based on _______ foot spacing	____________	____________
Average annual maintenance cost	$_______/acre	$________/acre

5.4 What would be the representative area drained on both sides of a random drainage line installed in the province (or your region)?

______________ ft

5.5 What portion of the province (or your region) is not adequately served by streams or municipal drainage ditches, to remove runoff from field drainage systems?

PART 6: OTHER

6.1 If most or all of your answers are based on your knowledge of a certain part of the province, please indicate the part of the province upon which your answers were based. If the geographic basis of your answers differed according to subject matter (e.g. erosion, acidity), please indicate this as well.

6.2 Please indicate the general basis of the numbers provided in each part of the questionnaire.

1 = Based on research or field experience with the problem in a variety of settings or a number of farms.

2 = Based on research or field experience with the problem in a few settings or farms.

3 = Based on experience with 1 or 2 comparable situations, or on word-of-mouth information.

	Part	Basis
1.	Erosion	
2.	Acidity	
3.	Compaction	
4.	Subsurface Compact Layers	
5.	Drainage	

6.3 Please note any problems you had with the way specific questions were worded. If possible, suggest how they could be improved.

6.4 If you have any further comments with regard to the questions, your answers, etc., please write on the back of this sheet or any of the questionnaire sheets; or attach a separate sheet of paper.

APPENDIX C

TERMS OF REFERENCE:

Estimating the Extent, Severity and Economic Impacts of Soil Degradation and Limitations in Eastern Canada and Southern British Columbia

TERMS OF REFERENCE

Estimating the Extent, Severity and Economic Impacts of Soil Degradation and Limitations in Eastern Canada and Southern British Columbia

1. OBJECTIVES

1.1 To estimate the extent and severity of soil degradation and limitations in eastern Canada and southern British Columbia.

1.2 To estimate the on-farm and off-farm economic impacts of soil degradation in eastern Canada and southern British Columbia.

1.3 To estimate the costs of controlling soil degradation and of making soil improvements in eastern Canada and southern British Columbia.

2. SCOPE

The study should be as quantitative and as detailed as possible, given data, time and budgeting constraints.

2.1 Geographic areas to consider are agricultural crop producing areas in:

Southern and Western Ontario
Eastern and Central Ontario
Northern Ontario
St. Lawrence Plain (Quebec)
Lac St. Jean region (Quebec)
Eastern Township (Quebec)
New Brunswick
Prince Edward Island
Nova Scotia
Newfoundland
British Columbia (excluding Peace River area)

2.2 Soil landscape maps of the cultivated land area in each relevant region should be prepared. Appropriate mapping scales may vary depending upon the region, but should be of sufficient detail to allow meaningful sub-regional interpretations of degradation risk to be made.

2.3 Cropping systems to consider, in cooperation with the Land Resources Research Institute (LRRI), are:

Field Crops:
wide row monoculture (corn, soybeans);
wide row-close rotation (corn, wheat);
wide-row-close row-forage rotation (Corn, oats, hay);
close row-forage rotation (oats, hay);
forage monoculture (hay, pasture)
Specialty Crops:
tobacco, potatoes, fruits, vegetables.

2.4 Land-use tables and/or maps of each relevant region, derived from 1981 Census land-use data, should be prepared at scales equivalent to the soil landscape maps in 2.2.

2.5 Degradation and soil limitation parameters to consider are:

wind erosion;
water erosion;
acidity;
surface compaction;
subsurface compact layers (hardpans).

2.6 For each degradation/limitation type, three to five severity classes should be defined in as quantitative a manner as possible, and should allow for links to the economic analysis (see below).

2.7 Generalized risk maps and tables describing the aerial extent of each class of each degradation problem should be prepared for input to the economic portion of the study.

2.8 The extent and severity of degradation problems derived in 2.7 should be independently verified by polling available experts in each region and through comparisons with existing studies.

2.9 For each crop group in each relevant region, the effects of different degradation classes of each degradation type on increased inputs required to maintain yields, or where this is infeasible, on yields, should be estimated.

2.10 Using the physical information derived in 2.9 (above), assumptions on the spread of degradation types, and current data on farmgate crop prices and input costs, the current (1985) farm gate financial impact of soil degradation and soil limitations should be calculated.

2.11 Agriculturally induced soil degradation also generates off-farm societal costs from the siltation and non-point source chemical pollution of water bodies. In the case of the latter, livestock management practices may also contribute to the problem. The current annual off-farm costs of these "externalities" should be estimated.

2.12 Estimates of the costs of controlling degradation or improving limitations in each region should be made.

2.13 Discuss the confidence levels which apply to the physical and economic results; compare estimates derived here with existing published information on the impacts of soil degradation; outline where knowledge gaps exist and assess the priority associated with filling these gaps.

3. METHODOLOGY

3.1 Data (in tabular and map form) on the extent and severity of soil degradation and limitations will be prepared by the Land Resource Research Institute (LRRI):

3.1.1 LRRI will complete maps of eastern Canada which portray the probability of occurrence of severe erosion events;

3.1.2 LRRI soil survey and mapping offices across eastern Canada and in British Columbia will prepare base maps of soil landscapes in cultivated areas of relevant regions. These maps will provide sufficient information to derive some of the Universal Soil Loss Equation (USLE) parameters, as well as parameters to determine the severity of other forms of degradation or limitations;

3.1.3 LRRI land-use specialists in Ottawa will use 1981 agricultural census data to generate agricultural land-use data for each soil polygon within the cultivated areas of relevant regions to derive the remaining USLE parameters, and other parameters to determine other forms of degradation or limitations;

3.1.4 LRRI, in consultation with Regional Development Branch (RDB) and a consultant, will design and define the various degradation classes for each degradation or limitation type. Three to five classes are desirable;

3.1.5 LRRI will establish degradation criteria for each degradation limitation type and will apply these criteria to land-use and soil landscape maps to generate maps and tables of the extent and severity of soil degradation and limitations.

3.2 Data describing the economic impacts of soil degradation and limitations on both the agricultural sector and society (externalities) will be prepared by a consultant under the supervision of RDB. The consultant will also attempt to verify, to some extent, the physical extent and severity data generated by LRRI. As well, the consultant will attempt to estimate the costs of correcting agricultural soil degradation and limitations in eastern Canada and southern British Columbia.

3.2.1 Local checks on: estimates of the extent and severity of degradation produced by LRRI, estimates of the impact of soil degradation/limitations on yield reductions or increased inputs, and estimates of the costs of controlling degradation will need to be derived by polling/interviewing soils and crop specialists in each region. A series of structured interviews with groups of regional experts, using the Delphi Approach (or a similar technique) to reach a consensus, is recommended as a highly desireable approach to deriving quantitative estimates where no published information exists. Where difficulties in reaching consensus opinions occur, some discussion of reasons will be expected. This work will be undertaken prior to the receipt of LRRI's physical data, and after the development of degradation classes.

3.2.2 The questions to be asked at these structured interviews will be developed jointly by LRRI, Regional Development Branch and the consultant in the early stages of the project.

3.2.3 Upon completion of the interviews, the consultant will combine the unit area impact information with current crop and input prices and with the physical data on the extent and severity of degradation to Onerate estimates of the regional on-farm costs of soil degradation or limitations. It would be desireable to estimate the total annual on-farm costs of a specific degradation or limitation type according to the <u>value of incremental inputs</u> required to sustain production in spite of the physical soil conditions. In most cases, however, costs may have to be estimated using the <u>current value of reduced yields,</u> or by using a combination of the two approaches.

3.2.4 Based on interview results, the consultant will estimate the off-farm costs of agriculturally induced soil degradation.

3.2.5 Based on interview results, the consultant will attempt to estimate the costs of controlling soil degradation within the study area.

4. PRODUCT DEFINITION

The final products of this project will take the form of a working paper. The paper will concentrate on a region-by-region description of the physical degradation problems in eastern Canada and southern British Columbia and will be accompanied by maps and tabular data. It will also concentrate on a region-by-region description of the effects of degradation on agricultural productivity in physical and economic terms. It will also cover "externality" costs, the costs of correcting soil degradation, a comparison of this study's results with those of other similar studies (an assessment), and an assessment of knowledge gaps.

5. DELIVERABLES/TIMETABLE (See Table 1)

6. RESPONSIBILITIES

6.1 LRRI is responsible for the overall completion of the physical study of the extent and severity of soil degradation and soil limitations.

6.2 LRRI and RDB will work jointly with the consultant on the finalization of degradation severity classes.

6.3 RDB is responsible for the overall completion of the economic analysis of the costs of degradation and soil limitations.

6.4 LRRI and RDB will work jointly with the consultant on the finalization of the structured interviews.

6.5 LRRI and RDB will co-author the final report.

Chris Lok
0085W
April 9, 1985