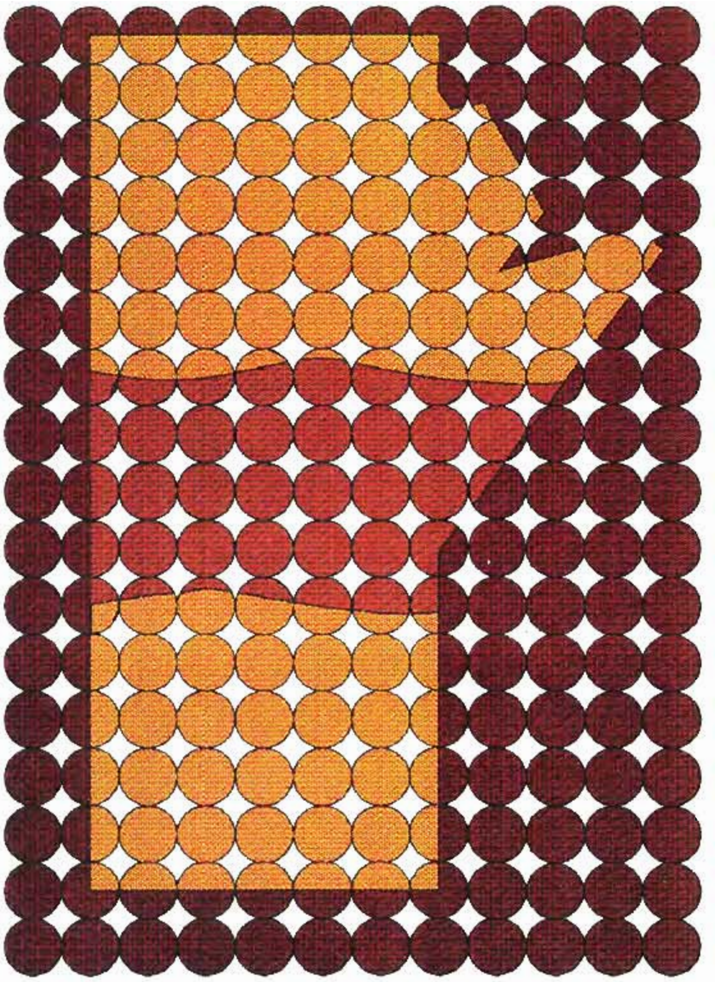

Manitoba Land Resource Unit

Research Branch,
Agriculture and Agri-Food
Canada

Water Erosion Studies in Manitoba - A Status Assessment

Special Report Series 96-3

Agriculture and Agri-Food Canada Research Branch

CMAAS

Manitoba Agriculture

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WATER EROSION STUDIES IN MANITOBA

A STATUS ASSESSMENT

BY

LARRY SLEVINSKY

MARCH, 1995

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Introduction to Report

Soil erosion by water is one of the major degradation factors affecting the long term sustainable quality of Manitoba soils. Knowledge of the processes contributing to water erosion, as well as the extent and risk of its impact on soil productivity are important in the day to day management of both agricultural and non-agricultural lands.

The cost of soil erosion in terms of productivity loss has been estimated in several ways. For example, each eroded tonne of topsoil has been approximated to carry away with it $2 to $5 worth of nitrogen and phosphorus, in addition to other nutrients. From a crop production standpoint, each centimetre of topsoil lost has been valued at 200 kg per hectare of crop yield in the bin every year, for the farmer, his children or grandchildren. Or alternatively, for every centimetre of topsoil lost per hectare, the fertility needed to raise 10 tonne of wheat is lost. These examples show that soil erosion can be costly but they do not include the costs to infrastructure resulting from dissected landscapes, bridges, road washouts, sediment accumulation in constructed ditches, water ways, natural drains, culverts, etc., or it's impact on water quality for livestock, fish, wildlife habitat and domestic consumption.

Visible impacts of water erosion are most common in steeply sloping landscapes. However, water erosion may occur on any landscape when conditions of weather, water volume and water velocity combine to accelerate surface water flow. The severity of these impacts is testament to the need to be diligent in our land use programs whether it is tillage and management of agricultural lands, or harvesting and management of forested lands. It is also strong evidence to show the close connection between land management and water management.

The following pictures are provided to illustrate the nature of some observable impacts of water erosion. From these examples it becomes obvious that sustainable land use in landscapes at risk of erosion must focus on land management practices which in reality manage the water first and the land second. Reducing the amount and rate of surface water runoff will minimize the cost to society for remediation and at the same time protect and preserve a very shallow fragile resource, our productive topsoil.

The following report was commissioned to review all of the relevant water erosion research that has been undertaken in Manitoba in the last decade. It provides a summary review including an annotated bibliography of water erosion research in Manitoba and recommendations for future research activities.

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Soil Erosion by Water in Manitoba

G.F. Mills

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B. Graham

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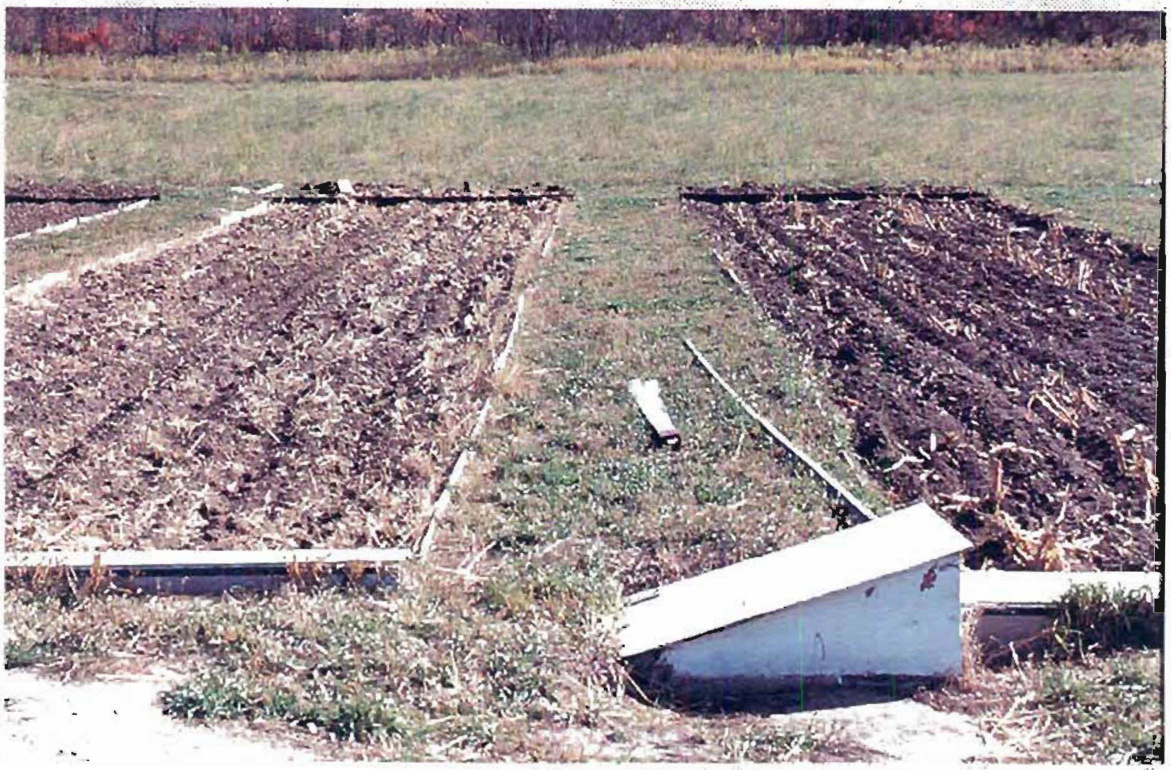

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1.0 Executive Summary

The impact of water erosion on the productivity of the land base in Agro-Manitoba is an ongoing concern. Soil erosion by water is known to affect the long-term productivity of the soil through loss of organic matter, reduction in water holding capacity, decrease in effective rooting depth, deterioration of soil structure, increase in bulk density, increase of soil pH and loss of plant nutrients.

Additional costs due to erosion are related to infrastructure and the environment. Eroded material deposited into drainage systems results in increased maintenance costs. Environmental concerns relate to the effects of sediment and dissolved nutrients, pesticides and herbicides on surface and groundwater quality.

To address these concerns, a series of research studies were initiated in the mid 1970's. The focus of the research was three-fold:

1. To determine the validity of the use and application of the Universal Soil Loss Equation (USLE) under Manitoba conditions.
2. To compile a more reliable estimate of the degree and extent of water erosion in Manitoba landscapes.
3. To determine the effects of soil loss due to water erosion on crop yields.

The purpose of this review of soil water erosion research is to summarize the findings and to provide suggestions for further research and related needs.

The Universal Soil Loss Equation (USLE) was developed for use in the United States. Studies indicated that the successful application of the USLE in Manitoba would require development of a data base of soil, climate, crop and land management information in order for the equation to be applied to Manitoba conditions. Once these factors were determined, the USLE could be utilized to prepare water erosion risk maps for various areas in Agro-Manitoba.

Studies of individual factors in the USLE indicated that measured values for crop management, soil erodibility and soil loss differed from estimated values. Research has shown that soil moisture content and surface roughness resulting from cultivation, combined with additional information on crop rotation, rainfall amounts and rainfall intensity would improve the use and accuracy of the USLE for estimating soil losses.

The USLE was applied at a generalized map scale of 1:1 000 000 to the landscapes in Agro-Manitoba to identify the risk of water erosion. The degree of risk varied from negligible to severe depending on soil properties, topographic characteristics and land management. Analysis of the map data for the dominant soil types indicated that approximately 1 740 000 ha (28.1 %) are characterized by negligible risk of erosion, 1 959 000 ha (31.6%) have a low risk, 307 000 ha (5.0%) have a moderate risk, 858 000 ha (13.8%) have a high risk and 1 331 000 ha (21.5%) have a severe risk of water erosion.

Simulated erosion studies indicated that yields of wheat and canola were reduced as increasing amounts of topsoil were removed. Finer textured soils were more responsive to restoring productivity with the addition of fertilizer. Coarser textured soils did not achieve the yields of the non-eroded soil even with application of high rates of fertilizer.

Based on the review of erosion studies conducted in Manitoba to date, it appears that existing information for the application of the USLE as a planning tool is adequate to determine annual soil loss levels and to identify the degree of soil erosion risk associated with various soil landscapes in the province.

Additional research is required to enable Manitoba to remain current with more precise erosion risk models such as the Water Erosion Prediction Project (WEPP), which is currently being developed in the United States. There is also a need for better coordination of activities for the timely transfer of user-friendly information related to erosion prevention and land management. For this to occur, there is a need for improved communications and partnerships between the research community, industry, government and producers to provide the required information for making the best possible sustainable resource management decisions.

2.0 Acknowledgements

The author would like to express his appreciation to R.G. Eilers, G.F. Mills, C.F. Shaykewich and F.H. Wilson for their guidance and editing comments in the preparation of this report. Acknowledgement is also extended to W. Michalyna and M.M. Fitzgerald for final edit, compilation and enhancement of the manuscript.

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3.0 Introduction

In Manitoba, water erosion has been recognized as a threat to sustainable agricultural production, especially in soil areas characterized by sloping topography. Erosion occurs on these lands during periods of excess rainfall which results in the detachment and transportation of soil particles by surface runoff, and deposition of material downslope in the same field or at some distance within or beyond the watershed.

The impact of erosion on long term productivity of the soil and crop yields is related to a reduction in water holding capacity and a decrease in effective rooting depth to less than optimum requirements for plant growth. Direct consequences to the soil are loss of organic matter, deterioration of soil structure, increased bulk density, tendency to crust, diminished workability, higher pH and loss of plant nutrients.

Erosion can also cause additional infrastructure costs and environmental concerns. Eroded material is deposited in drainage channels thereby reducing the capacity of the system to remove excess water. Environmental concerns due to eroded sediments and dissolved nutrients in runoff waters leading to potential concentrations of nitrates, phosphates and pesticides into provincial water bodies.

As a result of these concerns, a number of research studies were initiated in Manitoba to obtain information to validate the use of the Universal Soil Loss Equation (USLE) to predict water erosion and to determine the impact of erosion on crop productivity. Upon completion of these erosion studies, it was found necessary to summarize and review the water erosion studies, as well as, to evaluate the results in terms of Manitoba conditions, and to suggest recommendations for future research.

3.1 Description of the Universal Soil Loss Equation (USLE)

One of the most widely used methods of estimating rainfall erosion is the Universal Soil Loss Equation (USLE). The USLE was developed in the United States from over 10,000 plot years of data collected from 49 locations in 24 states. It consists of six interrelated erosion influencing factors whose combination is structured in a multiplicative function. The equation predicts long term average annual soil loss due to sheet and rill erosion from uniform slope segments. Average annual soil losses are based on a 22 year climatic cycle. The purpose of developing the equation was to use it as a soil conservation planning tool for ensuring implementation of appropriate land management practices to minimize soil losses to tolerable levels.

The USLE is expressed as:

$$A = RKLSCP$$

where: A = average annual soil loss per unit area (tonnes per hectare, t ha^{-1}).

R = rainfall erosivity factor - is the number of rainfall erosion index units in a particular storm or year. The index is a measure of the erosive force of a specific rain storm (megajoule millimetre per hectare hour, MJ mm ha^{-1} h^{-1}).

K = soil erodibility factor - is the erosion rate per unit of rain fall erosion index for a specific soil in a cultivated continuous fallow condition (tonne hectare hour per hectare megajoule millimetre, t h MJ^{-1} mm^{-1}).

L = slope length factor - is the ratio of soil loss from a field slope length to that from a 22m long slope on the same soil type and slope gradient (unitless).

S = slope gradient factor - is the ratio of soil loss from the existing slope gradient to that from a 9% slope (unitless). The L and S factors are combined into one term called the LS factor.

C = crop cover and management factor - is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the K factor was evaluated (unitless).

P = soil conservation practice factor - is the ratio of soil loss from contouring, strip cropping or terracing to that with straight row farming, up and down the slope (unitless).

3.2 Objective of the Report

Because the USLE was developed using soil types, crop rotations and land management practices under different climatic conditions than those in Manitoba, it was necessary to conduct research to determine whether the existing equation would be applicable for use in the province. Research experiments were designed to evaluate soil, crop and climatic factors used under Manitoba field conditions and to indicate any modification required for its application in the province. Simulated erosion studies (in which varying amounts of topsoil were removed) were also conducted to evaluate the impact of soil loss on wheat and canola yields at various field locations. As this research effort concluded it was necessary to review and summarize the findings of all water erosion research in Manitoba. Thus, the objective of this report was to document all soil water erosion studies, to evaluate the results in terms of Manitoba conditions, and to suggest recommendations for the direction of future research on water erosion.

The discussion which follows has been divided into five sections. The first section is a review of soil erosion research in Manitoba. The second is an evaluation of the USLE, and its relative weaknesses and strengths. The third section provides recommendations for the direction of future water erosion research studies. The fourth section is a bibliography for this report while the fifth is an annotated bibliography of all erosion work in Manitoba.

4.0 Research Review

The purpose of this section is to identify all of the sources from which soil water erosion information was obtained. It consists of a general overview of erosion studies conducted between 1977 and 1994, a summary of the number of plot years of research conducted from 1983 to 1994, and characteristics of the surface soil and the site condition at the experimental plots.

4.1 Sources of Information

The following agencies at the University of Manitoba were contacted to assess the status of research information on water erosion: Department of Soil Science, Department of Geography, Natural Resources Institute, and the Canada-Manitoba Soil Survey Unit. In addition, the Department of Geography at the University of Winnipeg, was contacted.

A major source of information related to water erosion was available in theses from the Department of Soil Science and papers published in the Manitoba Society of Soil Science Proceedings. Information from Manitoba Agriculture, Agriculture and Agri-Food Canada and PFRA were also obtained from published proceedings.

4.2 Rationale for Water Erosion Research in Manitoba

Over the past few decades the impact of water erosion on the productivity of the soil resource has been identified as a concern by government personnel and rural Manitobans. However, there was no method developed in the province to predict the amount of soil water erosion occurring under varying land uses and management practices. In response to these concerns, research studies were initiated to determine whether the USLE could be adapted and applied to Manitoba conditions to obtain a reliable estimate of the magnitude and extent of water erosion on soil landscapes.

4.3 Evaluation of the USLE Relevant to Manitoba Conditions

Slevinsky and Shaw (1977), indicated in their review of the USLE that in order to apply the equation in Manitoba, values for the erosion factors for Manitoba conditions would have to be determined.

4.3.1 Factor Analysis

R-Factor (MJ mm ha^{-1} h^{-1})

Steele (1979, p.16) determined R-values from 17 years of rainfall data from the Dauphin and Brandon airports. Average annual R-values for these areas were computed to be 783 ranging from 68 to 2264, and 732 varying between 136 and 4425, respectively. These values and ranges were comparable to data used in North Dakota.

In 1985 the measured annual R-value for a Gretna clay (C) and Leary sandy loam (SL) site was determined by Pauls (1987, p.18) to be 2207 and 1273, respectively. In comparison for these same two sites, Wright (1994, p.23) and Wahome (1989, p.20) found the measured average annual R-value from both sites to be about 1117 and 1305, respectively. These values compared favourably to the value of 1160 obtained by Wall et al (1983) for Winnipeg, Manitoba. Black et al (1990) at the Gretna C site from 1986 to 1988 found measured annual R-values to be 1061, 1359 and 407, respectively, resulting in an average annual value of 942. These related to a computed average R-value of 832 for the Deerwood weather station between 1964 and 1987.

In a three year study from 1988 to 1990, Hargrave (1992, p.22) determined R-values at four locations. The values for calculated average annual R-value for the Leary SL, Gretna C, Ryerson sandy clay loam (SCL) and Carroll clay loam (CL) sites were 1006, 885, 749 and 1755, respectively. In comparison, Wahome (1989), in a one year study conducted in 1987, found the measured annual R-value to be 3077 for the Ryerson site and 1303 for the Carroll site.

K-Factor (t h MJ^{-1} mm^{-1})

Shaw (1982) reported that soil survey information at the time did not contain values for the very find sand (VFS) fraction of the soil which prevented the determination of K-values and restricted the application of the USLE. Langman (1983) computed K-values for 22 soils in the RM of Westbourne using the nomograph procedure provided with the USLE. Values ranged from 0.021 for the Almasippi series to 0.050 for the Glenhope series.

Pauls (1987) determined observed K-factor values of 0.0022 and 0.0199, respectively, for the Gretna C and Leary SL soil types. Predicted K-values for these soils using the nomograph equation (NE) resulted in calculated values of 0.0273 and 0.0246. When the modified Young and Mutchler equation (MYME) was used, the predicted K-values were determined to be 0.0187 and 0.0291. The author suggested for the Gretna C the high NE value may be due to the equation's inability to account for the soil's montmorillonite level and its effect on aggregation and clay expansion. Whereas, the high MYME value may be due to the equation's inability to directly account for the Gretna clay's organic matter content which is greater than 4.0%.

Wahome (1989) conducted studies to determine measured and estimated K-values for Gretna C and Leary SL soils between 1985 and 1987. The average measured K-value for the three years was 0.031 for the Gretna C and 0.038 for the Leary SL. In comparison, the estimated values using the NE and MYME for the Gretna C were 0.027 and 0.052, whereas, for the Leary SL the values were 0.025 and 0.030. The author suggested that the two equations could possibly be under estimating the K-values for these soils.

In other research studies, Wright (1994) obtained average measured K-values of 0.0650 for the Gretna C and 0.0123 for the Leary SL. In comparison, computed K-values for these soils utilizing the NE were determined to be 0.028 and 0.027, respectively. Measured values of K did not agree well with the values calculated by the nomograph. The NE is most accurate for medium textured soils and is not valid when the sand fraction exceeds 65% or the clay fraction exceeds 35%. The Gretna C and Leary SL soils were at opposite ends of the textural spectrum and both fell outside the textural range of soils for which the nomograph was developed. The Gretna C was found to have a clay content of 50.4% while the Leary SL had a sand content of 74.5%. In this study, measured annual K-values ranged from 0.0100 to 0.0881 and from 0.0064 to 0.0211 for the Gretna C and the Leary SL, respectively. Variations in soil erodibility were identified to be a function of the combined influences of surface roughness and antecedent moisture levels.

Black et al (1990), after a three year study on a Gretna C, determined the average measured K-value to be 0.030. This value was very similar to the value of 0.031 for the adjoining University plots reported by Wahome (1989). A K-value of 0.0273 was calculated for this soil using the NE (Wahome 1989). The results suggested the K-factor for this soil was close to the expected value.

Wahome (1989), in a study conducted in 1987, reported measured K-values for a Ryerson CL and a Carroll CL of 0.005 and 0.001, respectively. The estimated values for the Ryerson SCL using the NE and MYME were computed to be 0.039 and 0.025, whereas the values for the Carroll CL were 0.040 and 0.034. Measured K-values for these soils were much lower than the estimated values possibly due to the residue effects of mulch from the previous crop.

C-Factor

The yearly C-values for corn, wheat and alfalfa on the Gretna C site were determined by Wright (1994) in 1991 to be 1.05, 0.21 and 0.00, respectively; in 1992 the yearly C-values for these same crops were 0.67, 0.56 and 0.00, respectively. On a Leary SL for the same two years the yearly C-values for corn, wheat and alfalfa were 0.60, 0.52 and 0.00 (in 1991) and 0.28, 0.22 and 0.00 (in 1992). Measurements for crop canopy and mulch cover estimates carried out over the course of this study were grouped together. Unfortunately this rendered a comparison between USLE C-factor values and experimentally derived C-factor values to be impossible. Wahome (1989) and Pauls (1987) found that the conditions of the experimental cropping systems were not represented adequately in the USLE data base thereby resulting in large differences between USLE C-factor values and the experimentally derived C-factor values. All of these authors indicated that a longer period of study, comparable crop-management systems and similar summerfallow conditions in the experiments, were needed to adequately characterize average C-values for Manitoba conditions.

Black et al (1990) in a three year study determined measured C-factor values for conventional-till and minimum tillage treatment for wheat-canola-wheat rotations. The mean C-values for the conventional tilled plots for wheat, canola and wheat were 0.508, 0.027 and 0.042, respectively. The average for the rotation was 0.193. For the minimum-till plot for these crops the C-values were 0.347, 0.027 and 0.035, respectively. The average for the rotation was 0.137. As anticipated, the rotational C-factor value was larger for the conventional-till plots than for the minimum-till, which indicated a potential for greater soil loss under conventional tillage. Calculated C-factor values for these rotations using the USLE methodology were 0.227 and 0.206 for the conventional- and minimum-till rotations, respectively.

LS and P Factors

At all research field sites used to evaluate various factor values of the USLE for Manitoba conditions, experimental plots were constructed conforming to standard USLE plot dimensions. A slope length (L) of 22.13m on a 9% slope (S) yields an LS factor of 1.0. Cultivation up and down the slope gradient sets the supporting conservation factor (P) equal to 1.0. The slope characteristics and direction of tillage were chosen to eliminate some of the variables in the USLE.

USLE research activities were designed to evaluate the R, K and C factors of the equation for Manitoba conditions. The LS and P factors of the equation were not part of the evaluation, and therefore in the water erosion studies, values of unity (1.0) for these factors were developed. However, the LS factor has a significant influence on the amount of annual soil water erosion that can occur. As slope length (L) and/or slope gradient (S) increases, the amount of erosion increases. The use of contour tillage and terracing are practices that result in lower P-factor values and thereby result in potentially lower levels of water erosion. Nevertheless, the adoption of these conservation practices in Manitoba is extremely limited.

4.3.2 Plot Years of Water Erosion Research

An equivalent total of 150 plot years of research were conducted over an eight year period, between 1984 and 1992 on water erosion studies in Manitoba. In the United States, 10,000 plot years were conducted over a 22 year period in the development of the USLE. Table 1 summarizes the water erosion research conducted in Manitoba, by date, number of plot years, soil types studied and principal investigator.

Table 1. Summary of Water Erosion Research in Manitoba.

Study Period	No. of Plot Years	Soil Name	Principal Investigator
1984	4	Gretna	Pauls, W.
1985	8	Gretna Leary	Pauls, W.
1986	8	Gretna Leary	Wahome, E.K.
1987	18	Gretna Leary Ryerson Carroll	Wahome, E.K.
1986	16	Gretna	Black, M.E.
1987	16	Gretna	Black, M.E.
1988	16	Gretna	Black, M.E.
1988	16	Gretna Leary Ryerson Carroll	Hargrave, A.P.
1989	16	(the four in 1988)	Hargrave, A.P.
1990	16	(the four in 1988)	Hargrave, A.P.
1991	8	Gretna Leary	Wright, C.R.G.
1992	8	(the two in 1991)	Wright, C.R.G.
Total	150		

4.3.3 Generalized Physical and Chemical Properties of Soils at Water Erosion Sites

General characteristics related to drainage, structure and permeability of the surface horizon for the soil types at each research site as described by the respective investigators are shown in Table 2. Soil physical and chemical properties are presented for the same soil types in Table 3. These soil characteristics and property values are necessary in determining computed

K-values utilizing the nomograph equation. The data used in these tables were extracted from the Manitoba Soil Survey data base. Subsequent to most of these studies, a detailed map and description of the soils at each of the monitoring sites was undertaken by Michalyna (1992) so that the research data could be related to the soil series data base for Manitoba.

Table 2. **Characteristics of Surface Soil at Water Erosion Research Sites.**

Soil Name	Texture	Horizon	Depth (cm)	Drainage	Structure	Permeability
Carroll	CL	Apk	0-20	Well	Fine Granular	Moderate
Gretna	C	Ap	0-19	Imperfect	Prismatic	Very Slow
Leary	LS	Ap	0-18	Rapid	Medium Granular	Very Rapid
Ryerson	L	Ap	0-15	Well	Medium Granular	Moderate

Table 3. **Physical and Chemical Properties of Surface Soil at Water Erosion Research Sites.**

Soil Name	Particle Size Distribution				B.D.	K Sat.	Chemical Analysis			
	VFS	S	Si	C			O.C.	C.E.C.	$CaCO_3$	pH
	(%)				(g cm^{-3})	(cm h^{-1})	(%)	(m.e./100gm)	(%)	
Carroll	0	26	41	33	1.20	3.0	4.0	43	4	7.1
Gretna	5	12	31	52	1.10	0.015	4.4	53	0	7.1
Leary	0	81	15	4	1.60	25.0	2.5	9	0	7.0
Ryerson	12	23	41	24	1.26	3.0	3.1	27	1	7.1

4.4 Evaluation of the USLE

A summary of the recent erosion studies and on the use of the USLE indicates both weaknesses and strengths for its application under Manitoba conditions.

4.4.1 Weaknesses of the USLE With Respect To Manitoba Conditions

The weaknesses of the USLE when applied to Manitoba conditions can be listed as follows.

1. Soil losses due to the effects of freezing, thawing and snowmelt were not taken into account in developing the equation.
2. The equation cannot be used to estimate erosion from specific rainstorm events.
3. The USLE in its present form does not take into consideration the effect of surface runoff on rainfall erosivity.
4. Nomograph used to estimate the K-factor is most accurate for medium textured soils and is not valid where the sand fraction exceeds 65% or the clay fraction exceeds 35% and where soil organic matter levels exceeds 4%. As a result, there is a need to modify the nomograph for prairie conditions and soils.
5. Based on research in Manitoba, residue effects of mulch from the previous crop, tillage and antecedent moisture conditions could account for differences in estimated and measured K-values; therefore, there is a need to modify the equation to include these field conditions for estimating soil loss.
6. Based on research in Manitoba, the prediction equations are over estimating soil erodibility. The high montmorillonite levels of Manitoba soils and its effect on aggregation, clay expansion, and higher organic matter contents are not considered.
7. Average measured soil loss ratios for different crop management and growth stages were affected by extreme variability of soil losses from fallow plot conditions.
8. Variability in rainfall erosivity and soil moisture conditions, unlike conditions where the model was developed, affected the measured and estimated C-value determinations in Manitoba.
9. Antecedent soil moisture and surface roughness due to cultivation as well as differences between antecedent moisture content and moisture at soil saturation point data are required to develop better estimations of soil loss and evaluation of factor values.
10. The USLE does not predict gully or streambank erosion or account for sediment deposition in the same field or watershed.
11. The equation was developed in the United States under different climatic and soil conditions and crop and land management practices than those in Manitoba.
12. Many more plot years of research are needed in order to establish reliable average factor values before modifications of the USLE under Manitoba conditions can be established.

4.4.2 Strengths of the USLE With Respect to Manitoba Conditions

The strengths of the USLE when applied to Manitoba conditions can be listed as follows.

1. The USLE can be used as a conservation planning tool to develop and implement soil conservation practices to reduce erosion losses.
2. Success of the equation has been due to its simplicity which makes it easy for non-technical field staff in extension service to apply.
3. The USLE has been successfully used to predict mean annual soil losses from agricultural fields under various land management practices. The greater precision that could be provided by more complex models for predicting how much soil is lost from

a specific storm is as important as estimating whether soil loss exceeds the tolerance level. However, newer models are more complicated, requiring larger data bases with necessary computer facilities, thereby losing the practical field application of the USLE.

4. According to results obtained from PFRA field plots based on three years of data, the USLE was successful in estimating sheet and rill erosion from summer precipitation in Manitoba.
5. On these same PFRA plots, the USLE and data from erosion plots discriminated between minimum-till and convention-till on wheat-wheat-canola rotations.
6. Measured R-values compared favourably with estimated values using USLE procedures for Manitoba conditions (Wright 1994; Black et al 1990).
7. The application of the USLE in Manitoba to rank soil landscapes into high, moderate and low potential for soil loss was helpful in the development of erosion risk maps for Agro-Manitoba.

4.5 Impact of Soil Loss on Crop Productivity

The impact of soil loss on the productivity of the land resource in Manitoba has been identified as an on going concern. To address these concerns, research studies were initiated to determine the effect of soil loss on wheat and canola yields.

Ives (1985, p.17), Kenyon (1987, p.19) and Kapoor Dozois (1991, p.21) conducted simulated erosion studies (top soil removal experiments) to determine the impact on crop yields. They found that soil erosion reduced crop yields. In some cases, the addition of fertilizer restored soil productivity whereas in other instances, the highest rate of fertilizer used was not able to attain yields similar to the undisturbed check strip. Fine textured soils were more responsive to productivity restoration with the addition of fertilizer than coarse textured soils.

4.5.1 Plot Years of Simulated Erosion Research on Crop Productivity

A total of 112 plot years were conducted between 1983 and 1988 on simulated erosion studies in Manitoba. Table 4 summarizes the simulated erosion studies conducted in Manitoba, by date, number of plot years, soil types and principal investigator.

Table 4. Summary of Simulated Erosion Research in Manitoba.

Study Period	No. of Plot Years	Soil Name	Principal Investigator
1983	8	Reinland Newdale	Ives, R.M.
1984	12	Reinland Newdale Pembina	Ives, R.M.
1985	12	Reinland Newdale Pembina	Kenyon, B.E.
1986	24	Reinland Newdale Pembina Ryerson Willowcrest Waskada	Kenyon, B.E.
1986	8	Ryerson Carroll	Wahome, E.K.
1987	24	Reinland Newdale Pembina Ryerson Willowcrest Waskada	Kapoor, A.
1988	24	(the six in 1987)	Kapoor, A.
Total	112		

4.5.2 Generalized Physical and Chemical Properties of Soils at Simulated Erosion Sites

General soil characteristics related to drainage, structure and permeability of the surface horizon for the soil types at each research site are summarized in Table 5. Soil physical and chemical properties are presented for the same soil types in Table 6. The data used in these tables have been extracted from the Manitoba Soil Survey data base.

Table 5. Characteristics of Surface Soil at Simulated Erosion Research Sites.

Soil Name	Texture	Horizon	Depth (cm)	Drainage	Structure	Permeability
Newdale	CL	Ap	0-15	Well	Fine Granular	Moderately Slow
Pembina	L	Ap	0-20	Well	Weak Platy	Moderate
Reinland	L	Apk	0-20	Imperfect	Fine Granular	Moderate
Ryerson	L	Ap	0-15	Well	Medium Granular	Moderate
Waskada	L	Ap	0-15	Well	Medium Granular	Moderate
Willowcrest	FS	Ap	0-15	Imperfect	Single Grained	Rapid

Table 6. Physical and Chemical Properties of Surface Soil at Simulated Erosion Research Sites.

Soil Name	Particle Size Distribution				B.D.	K Sat.	Chemical Analysis			
	VFS	S	Si	C			OC	C.E.C.	$CaCO_3$	pH
	(%)				(g cm^{-3})	(cm h^{-1})	(%)	(m.e./100gm)	(%)	
Newdale	9	21	36	34	1.44	3.0	4.5	39	1	7.2
Pembina	12	30	39	19	1.20	3.0	2.3	21	0	6.7
Reinland	0	84	7	9	1.40	3.0	1.9	15	3	7.5
Ryerson	12	23	41	24	1.26	3.0	3.1	27	1	7.1
Waskada	15	27	36	22	1.25	3.0	2.8	28	1	6.7
Willowcrest	21	67	6	6	1.40	10.0	1.4	11	1	7.2

4.6 Discussion of Research Studies

The objective of the research studies to determine whether the USLE could be adapted to Manitoba conditions was not achieved. With the exception of the R-factor values, research results indicated significant differences between measured and computed USLE K- and C-factor values. The short-term duration of the studies, the absence of comparable crop-management systems, proper fallow conditions, the effects of antecedent moisture levels and surface roughness caused by cultivation accounted for the differences in these measured and estimated factor values, and thereby affected the accuracy of the USLE to predict soil loss by water erosion.

The USLE however, was successfully applied at a generalized 1:1 000 000 map scale to soil landscapes in Agro-Manitoba to identify the risk to water erosion. The degree of risk varied from negligible to severe depending on soil properties, topographic characteristics and land management practices. These estimates of water erosion risk are the only and best predictions that exist for Manitoba conditions. Analysis of the map data for the dominant soil types indicates that approximately 1 740 000 ha (28.1%) are characterized by negligible risk of erosion, 1 959 000 ha (31.6%) have a low risk, 307 000 ha (5.0%) have a moderate risk, 858 000 ha (13.8%) have a high risk and 1 331 000 ha (21.5%) have a severe risk to water erosion.

A review of the research studies indicated that the objective to determine the effect of soil loss on crop productivity was achieved. Results of the research studies showed that wheat and canola yields were reduced with the loss of topsoil. Chemical fertilizers were able to restore soil productivity in some cases, whereas in other instances even the highest rate of fertilizer on coarse textured soils was not able to attain yields similar to the check treatment where no topsoil was removed.

5.0 Recommendations for Future Research

Based on a review of recent water erosion studies conducted in Manitoba the following direction and recommendations are made for future research activities.

1. Further research to validate the use of the USLE is not required for its application in Manitoba. Existing equation information is sufficient to determine annual soil loss and thereby identify soil landscapes in Manitoba with varying levels of erosion risk.

2. Further research studies are warranted to evaluate a new soil erosion model called the Water Erosion Prediction Project (WEPP) in order for Manitoba to be current with other locations in Canada where research activities are presently being conducted. A technology transfer component is needed to facilitate the integration of this research into the diverse range of soil conservation and management practices in Manitoba.

3. Agriculture and Agri-Food Canada research stations in Manitoba should be encouraged to become more actively involved in soil erosion studies as their facilities and expertise are well suited to conduct long term research.

4. There is a need to link crop, tillage and soil property information on a timely basis to determine erosion risk. The amount of residue remaining at the soil surface is one of the most important factors affecting the degree of erosion risk that occurs.

5. Erosion risk information must be presented in a user friendly format, i.e. in single factor maps derived from linkages developed using GIS procedures. Erosion risk assessments should be accompanied with guidelines to assist in the design and implementation of

environmentally sustainable land management programs.

6. There is a need to improve communication and partnership between the research community, industry and extension personnel in developing and providing quantitative erosion information to Manitoba producers, municipalities and other agencies concerned with sustainable agriculture.

7. A committee comprised of research and extension personnel, producers and non-government agencies should be established with a mandate to address agricultural land use issues related to soil erosion. The committee should provide direction for research and extension activities including training needs related to sustainable agricultural production in Manitoba.

8. There is a need to establish a mechanism through which long term support of soil erosion work is provided. This kind of work cannot be completed in three or even five years. Some of the projects listed here had to be discontinued after two or three years because of lack of funding. It is extremely difficult to make significant progress in such an atmosphere of uncertainty.

In summary, although many erosion studies have been conducted in Manitoba, there is a need for more coordination of activities and responsibilities for extension of the research findings. Sustainable agriculture production both now and in the future is dependent on universal acceptance of modern soil conservation practices in order to reduce the level of soil erosion to tolerable limits.

6.0 Bibliography

1. Black, J.M.W., Smith, D.G. and Pauls, W. 1990. Design and Operation of the PFRA Erosion Plots at Miami, Manitoba - PFRA Erosion Plots Miami: Interim Results. 33rd Manitoba Society of Soil Science, Winnipeg, MB. pp. 136-154.

2. Eilers, R.G., Langman, M.N. and Coote, D.R. 1989. Water Erosion Risk, Manitoba, Canada. Manitoba Soil Inventory Land Research Centre, Research Branch, Agriculture Canada. Publication 5257/B.

3. Hargrave, Andrew P. 1991. Nitrogen and Phosphorus Losses in Surface Runoff Due to Rainfall in Manitoba. M.Sc. Thesis, Dept. Soil Science, University of Manitoba.

4. Ives, R.A. and Shaykewich, C.F. 1984. Effect of Soil Erosion on Soil Productivity. 27th Manitoba Society of Soil Science Annual Meeting, Winnipeg, MB. pp. 149-153.

5. Ives, Rose M. 1985. Effect of Simulated Soil Erosion on Wheat Yields. M.Sc. Thesis,

Dept. Soil Science. University of Manitoba.

6. Ives, R. and Shaykewich, C. 1985. The Effect of Soil Erosion on Soil Productivity: Preliminary Findings of a Two Year Study. 28th Manitoba Society of Soil Science Meeting, Winnipeg, MB. pp. 30-34.

7. Jenkins, C., Shaykewich, C.F. and DeJong, E. 1984. Potential for the Use of Cesium-137 as a Tracer for Soil Erosion in Manitoba. 27th Manitoba Society of Soil Science Meeting, Winnipeg, MB. pp. 181-187.

8. Kapoor, A. and Shaykewich, C.F. 1990. Simulated Soil Erosion and Crop Productivity. 33rd Manitoba Society of Soil Science Meeting, Winnipeg, MB. pp. 111-124.

9. Kapoor Dozois, A. 1991. Effect of Simulated Erosion on Crop Productivity. M.Sc. Thesis, Dept. Soil Science, University of Manitoba.

10. Kenyon, Brian E. 1987. Effect of Simulated Erosion on Canola Productivity. M.Sc. Thesis, Dept. Soil Science, University of Manitoba.

11. Kenyon, B.E. and Shaykewich, C.F. 1987. Simulated Erosion Effect on Canola Yields. 30th Manitoba Society of Soil Science Meeting. Winnipeg, MB. pp. 76-86.

12. Langman, M.N. 1983. Quantification of Erosion Potential for Soil Resource Inventories in Manitoba. 26th Manitoba Society of Soil Science Meeting, Winnipeg, MB. pp. 44-52.

13. Michalyna, W. 1992. Soil Characterization of the Water Erosion Monitoring Sites, Manitoba. Manitoba Land Resource Unit, CLBRR, Agriculture Canada, Winnipeg.

14. Pauls, W. and Shaykewich, C.F. 1986. Measurements of Soil Erosion by Rainfall. 29th Manitoba Society of Soil Science Meeting, Winnipeg, MB. pp. 158-164.

15. Pauls, Waldemar, J. 1987. The Applicability of the Universal Soil Loss Equation in Manitoba. M.Sc. Thesis, Dept. Soil Science, University of Manitoba.

16. Seecharan, R. 1980. Environmental and Socio-Economic Implications of Land and Water Resource Planning in the Eden Creek Watershed. Natural Resource Institute Practicum. 114 pp.

17. Shaw, G.A. 1980. Predicted Soil Erosion by Water for Various Soil Types in Manitoba. 24th Manitoba Soil Science Meeting, Winnipeg, MB. pp. 63-70.

18. Shaw, G.A. 1982. Use of Soil Survey Data in Soil Erosion Studies. 25th Manitoba Soil Science Meeting, Winnipeg, MB. pp. 82-84.

19. Shaykewich, C.F., Hargrave, A.P. and Wahome, E.K. 1991. Effect of Antecedent Soil Moisture on Rainfall Erosion in Manitoba. 34th Manitoba Soil Science Meeting, Winnipeg, MB. pp. 202-219.

20. Slevinsky, L.F. and Shaw, G.A. 1977. Application of the Universal Soil Loss Equation in Manitoba. 21st Manitoba Soil Science Meeting, Winnipeg, MB. pp. 137-141.

21. Steele, Brian J. 1979. Application of the Universal Soil Loss Equation in Manitoba. B.Sc. Thesis, Dept. of Soil Science, University of Manitoba.

22. Tajek, J., Pettapiece, W.W. and Toogood, K.E. 1985. Water Erosion Potential of Soils of Alberta: Estimates Using a Modified USLE. Agric. Can. Tech Bull. No. 1985-29, Ottawa, ON. 35 pp.

23. Wahome, E.K. and Shaykewich, C.F. 1988. Measurement of Water Erosion in Manitoba. 31st Manitoba Society of Soil Science Meeting, Winnipeg, MB. pp. 79-88.

24. Wahome, Ephantus K. 1989. Soil Erosion Measurements Under Natural Rainfall for Evaluating the Universal Soil Loss Equation in Manitoba. M.Sc. Thesis, Dept. Soil Science Thesis, University of Manitoba.

25. Wall, G.J., Dickson, W.T. and Greuel, J.W. 1983. Rainfall Erosion Indices for Canada East of Rocky Mountains. Can. J. Soil Sci. 63:271-280.

26. Wright, Charles R. G. 1994. Modelling Soil Erosion due to Natural Rainfall in Manitoba. M.Sc. Thesis, Dept. Soil Science, University of Manitoba.

7.0 Annotated Bibliography

The following review provides a comprehensive summary of water erosion studies in Manitoba between 1977 and 1994.

7.1 Department of Soil Science Theses

1. Steele, Brian J. 1979. Application of the Universal Soil Loss Equation in Manitoba. Bachelor of Science Thesis. Dept. of Soil Science, University of Manitoba.

The objective of the thesis was to calculate average yearly rainfall erosion losses from selected soils under four different crop rotations by applying the USLE to two areas in Manitoba. The four different crop rotations used were mouldboard plowing, continuous alfalfa, stubble mulch and summerfallow. Crop stage periods were defined according to seasonal data found in the

Manitoba Agricultural Yearbook.

Rainfall erosivity (R-value) was determined from 17 years of rainfall data from the Dauphin and Brandon airports. Soil erodibilities (K-values) for five associations selected from each of the Grandview and Rossburn-Virden map sheets were calculated according to soil data from published reports. Representative length and percent slope (i.e. the LS-factor) values were assigned for each of the soil associations.

Based upon the application of the USLE and the results obtained, Steel (1979) presented the following observations:

1. The monthly distribution of rainfall erosivity was similar in Brandon and Dauphin with peak values occurring in July.
2. The average R value (given in imperial units) for Brandon was 46, ranging from 4 to 133, while in Dauphin the value was 43, varying between 8 and 260. These values and ranges were comparable to values found in North Dakota.
3. The topographic factor (LS-values) accounted for most of the differences in erosion between the selected soils.
4. For the topographic features for soils of the Brandon area the order of decreasing erosion losses were: Harding clay loam, Newdale clay loam, Carroll clay loam, Souris fine sandy loam, and the Marringhurst sandy loam. In the Dauphin area, the order was: Meharry (deep phase) clay loam, Meharry clay loam, Isafold clay loam, Edward clay loam and Dauphin clay.

2. Ives, Rose M. 1985. Effect of Simulated Soil Erosion on Wheat Yields. Master of Science Thesis. Dept. of Soil Science, University of Manitoba.

In this study, the objective was to evaluate the effects of simulated soil erosion using scalping experiments on wheat yields at three sites in southern Manitoba. In the scalping experiments, four levels of top soil were removed (0, 5, 10 and 20 cm) with three levels of fertilizer (a control, an intermediate and a high rate) application superimposed on the removal treatments. Two sites were established in the Spring of 1983, with one located on a Reinland loamy very fine sand (LVFS) and the other on a Newdale clay loam (CL). In 1984, a third site was established on a Pembina clay loam (CL). At all sites, and for both years, Benito wheat was grown.

In 1983, fertilizer applications had no significant effect on wheat yields even where 20 cm of topsoil were removed. However, in 1984 the highest fertilizer rate significantly increased yields wherever more than 5 cm of topsoil was removed. Neither the soil temperature nor soil moisture content adversely affected grain yields on the eroded plots.

During 1983 and 1984, precipitation was below normal at both the Reinland LVFS and the Newdale CL sites. Consequently, different weather conditions could possibly produce different soil erosion - soil productivity relationships. On the Pembina CL soil under a more normal growing season precipitation, wheat yield on the non-eroded soil receiving the highest fertilizer rate was 3.81 t ha^{-1}. Where 20 cm of top soil was removed, yields were 0.74, 1.21 and 2.55 t ha^{-1} for the zero-rate, intermediate rate and highest rate of fertilizer application, respectively. These results indicated that it was beneficial to add extra fertilizer to soils that were severely eroded. Other data also showed that additional fertilizer did not restore the Pembina CL to its original productivity.

Ives (1985) concluded that soil erosion reduced crop yields, although additional inputs (such as fertilizer) could improve productivity of eroded soils. She also noted that depending on soil characteristics and management practices the original productivity of the soil may not be completely regained. It was suggested that in future studies many more site years of data are warranted utilizing various crops including an economic analysis of the yield results. Further, the variability in soil erosion - crop yield relationships, from site to site and from year to year, emphasizes the site specificity of such research and the need for long term studies.

3. Pauls, Waldemar J. 1987. The Applicability of the Universal Soil Loss Equation in Manitoba. Master of Science Thesis. Dept. of Soil Science, University of Manitoba.

The purpose of this thesis was to obtain actual measurements of soil loss due to rainfall and to compare how well the USLE would predict erosion losses under Manitoba conditions. Two field sites were established: one site was on a Gretna clay in 1984 and the other was on a Leary sandy loam in 1985. Four plots on a uniform 9% slope were established on each site. Each plot had its own continuous crop management system: that is, alfalfa, wheat, corn and summerfallow. Data from tipping bucket rain gauges located at each site were used to calculate the rainfall erosivity (R) factor. The crop management (C) factor (percent ground cover) was determined for each plot for each soil loss occurrence. Soil property data from each site was used in the USLE nomograph equation and a modified Young and Mutchler equation to estimate the soil erosivity (K) values. Observed C and K values were compared to the values predicted by the USLE.

The results for 1985 proved to be inconclusive in determining the applicability of the USLE under Manitoba conditions for a number of reasons. The reasons were as follows.

1. The comparison of soil loss ratios and the evaluation of the C-factor were hindered by the absence of directly comparable crop management systems and poor crop development.
2. Observed K-values were variable and often were sufficiently affected by equipment to permit reliable comparisons with the nomograph equation and the modified Young and Mutchler equation predicted values.
3. Site selections had several limitations as neither experimental soil had significantly more than 4% organic matter. Soil property values of the Gretna clay and Leary sandy loam were outside the range of values of the soils used in the Young and Mutchler

equation. Both soils were on the border of the textural range of soils that constituted the bulk of the data used to develop each prediction equation.
4. The absence of appropriate fallow conditions and the intermittent failure of the equipment to sample and collect one percent of the runoff hindered proper USLE factor evaluation.
5. The short duration of the study was a major limiting factor as the R, K and C values for the individual storms showed extreme variability for the one year of data collection.

The author concluded that before the applicability of the USLE could be determined, the following conditions warranted attention.

1. Better crop growth in plot areas was needed for adequate evaluation of soil loss ratios for all crop stage periods.
2. Establishment of other sites with soil types having organic matter levels much greater than 4% was required to increase the data base for evaluating prediction methods.
3. Better maintenance of fallow conditions that meet literature specifications are required for a more accurate comparison of soil loss ratios and K-values.
4. Additional plot years of data are needed to verify the use or modification of the USLE in Manitoba.

4. Kenyon, Brian E. 1987. Effect of Simulated Erosion on Canola Productivity. Master of Science Thesis. Dept. of Soil Science, University of Manitoba.

The purpose of the research was to quantify the effect of several levels of simulated soil erosion on canola yields. Simulated erosion sites were developed on six soil types in Manitoba ranging in texture from a loamy very fine sand (LVFS) to a clay loam (CL). Levels of topsoil removal were 0, 5, 10 and 20 cm. Each level of topsoil removal was treated with no fertilizer, a recommended soil test rate of fertilizer and approximately twice the recommended rate of fertilizer.

Depending upon the soil type, canola yields where 20 cm of topsoil was removed were reduced to 27-50% of the check treatment. Generally, for the finer textured soils, fertilizer applications at the recommended rate increased yields over that of the check, whereas the double rate did not significantly increase yields beyond the recommended rate. For the coarser textured soil types (Reinland LVFS and Willowcrest FS), fertilizer applications did not restore canola yields when 20 cm of topsoil was removed. Other factors such as physical and chemical characteristics of the subsoil rather than soil fertility may have limited crop growth.

Yields were not restored where 10 and 20 cm of topsoil was removed at the Waskada SCL site. Fertilizer applied at the recommended rate and twice the rate did not increase yields over the control treatment where no fertilizer had been added and no top soil was removed. A layer of gravel and coarse material occurred at the 20 to 30 cm depth. With increasing removal of topsoil exposure of this type of subsoil material likely restricted the root growth of canola and subsequent yields on the plots.

The application of fertilizer on the various soils where topsoil was removed increased crop residue production. As the depth of topsoil removal was increased and no fertilizer was added, straw production decreased. The quantity of crop residue and the nutrient concentration of the straw was increased with fertilizer application. Therefore, application of fertilizer to eroded soils resulted in more crop residue for erosion protection and an increase in the nutrient contents of the surface soil by increasing the nutrient concentration in the straw.

The author concluded that the data from this study could be used to make economic analysis of canola grown on eroded or eroding soils.

5. Wahome, Ephantus, K. 1989. Soil Erosion Measurements Under Natural Rainfall for Evaluating the Universal Soil Loss Equation in Manitoba. Master of Science Thesis. Dept. of Soil Science, University of Manitoba.

Field experiments on soil erosion were conducted in 1986 and 1987 on Gretna clay (C), Leary sandy loam (SL), Ryerson sandy clay loam (SCL) and Carroll clay loam (CL) soils. The purpose of the study was to develop a data base for evaluating the soil erodibility (K) and crop management (C) factors of the USLE under Manitoba conditions. Crop management treatments were continuous cropping (including alfalfa), conventional tillage wheat, minimum tillage wheat, conventional tillage corn and summerfallow.

Soil losses were observed to be extremely variable among different crop management treatments and soil types, as well as, the measured K and C factor values. The measured K-values were compared to those estimated using the USLE nomograph equation (NE) and the modified Young and Mutchler Equation (MYME). The estimated values for each equation were similar for all soils except the Gretna C soil. The average measured K-values for the Gretna C and Leary SL soils were comparable to the NE estimated values. These values showed that the two equations could possibly be underestimating the K-values for these soils. The measured K-values for the Ryerson SCL and Carroll CL soils were extremely low, possibly because of the effects of the previous crop residues.

The effects of antecedent soil moisture and cultivation in modifying observable soil losses, and the measured K and C factor values were found to be important. The author suggested there was a need for the modification of the USLE to account for the effects of these field factors in order to ensure an accurate estimation of soil loss. A comprehensive field data base based on antecedent soil moisture and surface roughness due to cultivation needs to be developed before this can be accomplished. Data on moisture content differences between antecedent soil moisture and moisture at saturation points are also necessary.

The absence of appropriate fallow conditions and comparable crop management treatments for this study made it difficult to obtain a direct comparison between the measured and estimated soil loss ratios. This was mainly due to the residual effects of mulch from the previous crop which tended to modify soil losses from fallow.

The data base developed up to 1987 from experimental results cannot be considered conclusive in achieving an effective evaluation of the USLE application in Manitoba. Therefore, there was a need to continue the study to obtain accurate average factor values from the equation.

6. Kapoor Dozois, A. 1991. Effect of Simulated Erosion on Crop Productivity. Master of Science Thesis. Dept. of Soil Science, University of Manitoba.

Simulating soil erosion to assess its effects on productivity was the focus of this study conducted in southwestern Manitoba. Six sites were used in the 1987 and 1988 field experiments. Soil types ranged in texture from a loamy very fine sand (LVFS) to a clay loam (CL). At each field location, four levels of topsoil were removed and three levels of fertilizer were applied. The sites were planted to wheat and canola, in 1987 and 1988, respectively.

Nutrient concentrations at mid season were significantly lower without fertilizer than with fertilizer applications. The effect of topsoil removal on nitrogen concentrations was noted at the Willowcrest FS site, where 0 and 5 cm scraped plots had nitrogen concentrations significantly higher than 10 and 20 cm scraped plots.

Wheat and canola yields were found to be adversely affected by topsoil removal. Depending on the soil type and degree of simulated erosion, productivity losses could be reduced by the addition of fertilizer. On the Pembina CL soil in 1987 where no fertilizer had been applied and no topsoil was removed, yields were approximately 50% of those achieved by adding the recommended rate to the eroded plots. Doubling the fertilizer application resulted in increased yields slightly above those achieved by applying the recommended rate of fertilizer. In contrast, on thc coarser textured soil of the study, even the highest rate of fertilizer was not able to overcome the effects of topsoil removal. The Willowcrest FS showed a continuous decrease in yields with each increment increase in topsoil removal for all fertility levels. It was concluded that characteristics native to the soil were responsible for the reductions in yield as fertility was not a limiting factor.

Regression analysis of the experimental data showed fertility to have the greatest influence on yields; topsoil removal had a lesser and negative influence on yields. Regression coefficients were highest for topsoil removal from the coarser textured soils, reinforcing the conclusion that these soils are adversely affected to a greater extent by topsoil removal than finer textured soils.

Data from this project can be used to illustrate the losses in productivity of a soil based on the amount of soil eroded and the fertilizer available. The regression equations that were developed can give approximations for relative yields based on the amount of soil that has been lost and the amount of nutrients that were available. The research reinforced the need for soil nutrient enhancing and implementation of soil conservation practices.

The author suggested that current information should become available to farmers to indicate the improved management required to offset soil erosion; there was a need to transfer this information to people who are most likely to benefit from it. This in turn would encourage implementation of conservation techniques into good crop production - land management systems.

7. Hargrave, Andrew P. 1992. Nitrogen and Phosphorus Losses in Surface Runoff Due to Rainfall in Manitoba. Master of Science Thesis. Dept. of Soil Science, University of Manitoba.

Four experimental field sites comprised of the Gretna clay (C), Leary sandy loam (SL), Ryerson sandy clay loam (SCL) and Carroll clay loam (CL) were monitored for nitrogen and phosphorus losses in surface runoff between 1988 and 1990. At each site, five continuous crop managements systems (alfalfa, corn, wheat minimum till, wheat conventional till and fallow) were randomly assigned. The minimum till wheat treatment was not included on the Gretna C and Leary SL sites.

Soil loss was found to increase with the maximum 30 minute intensity rainfall events and the erosivity index, but was not greatly influenced by total rainfall or the duration of rainfall. Higher antecedent moisture contents prior to rainfall initiated runoff at an earlier time and therefore increased total soil loss. Crop stage did not seem to influence soil loss, however, crop type did. Alfalfa was very effective in reducing soil loss, whereas wheat was more effective than corn or fallow. Soil loss was highest from the fine textured Gretna C followed by the coarse textured Leary SL. In comparison, the medium textured Carroll CL and Ryerson SCL had much lower soil losses.

Total nitrogen losses on the Gretna C in 1990 were 455, 272 and 418 kg ha^{-1} accounting for 95%, 90% and 86% of total nitrogen loss during the three years study from corn, wheat and fallow treatments, respectively. Similarly, total phosphorus losses in 1990 were 94% (193 kg ha^{-1}), 91% (112 kg ha^{-1}) and 89% (216 kg ha^{-1}) of the total three year losses for the same soil. Total nitrogen and phosphorus losses were significantly lower from the alfalfa treatments. Losses from the wheat treatments were lower than from corn and fallow treatment.

Total nitrogen concentrations were higher from post harvest residues than during the growing season. Total nitrogen concentration in runoff sediment was highest from alfalfa treatment and lowest from the corn and fallow treatments. Total nitrogen concentration in runoff sediment was highest from the medium textured and lowest from the coarse textured soils.

There was no statistically significant seasonal variation in total phosphorus concentrations in runoff sediments. Seasonal variation in total phosphorus concentrations was not consistent over the range of soil textures and crop types. There was no consistent difference in mean total phosphorus concentrations among crop type. Total phosphorus concentration was highest from the Gretna C and Ryerson SCL and lowest from the Leary SL.

For the most part, concentration of nitrates was far below 0.8 mg g^{-1} in the runoff water, which is generally regarded as the maximum concentration acceptable for drinking water. All concentrations were lower with larger storms. Therefore, these results indicated that there is a very slight hazard of nutrient loading, especially where runoff is limited by good land management practices.

The author concluded due to the temporal variability of rainfall and moisture conditions, a much larger data base was needed to better quantify nitrogen and phosphorus losses.

8. Wright, Charles R.G. 1994. Modelling Soil Erosion Due to Natural Rainfall in Manitoba. Master of Science Thesis. Dept. of Soil Science, University of Manitoba.

The purpose of this thesis project was to continue data collection for evaluating the application of the USLE for Manitoba conditions. Two water erosion sites, one on a Gretna clay (C) and the other on a Leary sandy loam (SL) were monitored in 1991 and 1992. At each site, four continuous crop management systems of fallow, corn, wheat and alfalfa were represented. Measurements of soil loss amounts, peak runoff rates, rainfall amount and intensity, crop measurements such as seed yields and antecedent soil moisture levels were conducted on each site.

Measured K-values were found not to compare well with the calculated USLE nomograph K-values for the soil studied. Measured average annual R-values from both sites were about 1117 MJ mm ha^{-1} h^{-1} which compared favourably to the value of 1160 MJ mm ha^{-1} h^{-1} obtained by Wall et al (1983) for Winnipeg, Manitoba. A comparison of USLE C-values proved to be impossible due to differences between field measurements and measurements required for determining USLE C factor values. Observed soil losses, soil loss ratios and soil erodibility values were extremely variable and were dependent upon rainfall characteristics, plot surface morphology and antecedent soil moisture conditions.

The author indicated that future research should focus on developing rainfall recording systems which are capable of measuring high intensity surges in violent storms. In addition, techniques capable of measuring soil roughness and drainage efficiency across plots should be developed. This may be accomplished by developing a clod size index based on the number and size of clods. Drainage efficiency may be better quantified by measuring rill patterns and/or rill density. Antecedent soil moisture levels need to reflect changes in soil water content between sampling dates and soil loss events. The author suggested that this may be accomplished by using evapotranspiration models for the cropped treatments and a soil evaporation model for the fallow treatment.

Wright (1994) concluded that not only should a soil erosion model be capable of predicting soil losses, but it should also include a soil renewal component on soil specific pedogenic processes. In other words, the model should answer the following: how much soil was being lost and how fast was it being regenerated?.

7.2 Papers Published in the Manitoba Society of Soil Science Proceedings.

1. **Slevinsky, L.F. and Shaw, G.A. 1977. Application of the Universal Soil Loss Equation in Manitoba. 21st Manitoba Soil Science Meeting, Winnipeg, Manitoba. pp. 137-141.**

The authors indicated in 1977 there was no method developed in Manitoba to quantitatively predict the amount of water erosion under varying land uses and management practices. They introduced the Universal Soil Loss Equation which had been developed in the United States and had been applied in southern Ontario.

Another term identified as being related to the equation was called the Soil-Loss Tolerance (T). This term denoted the maximum rate of soil loss that will permit a high level of crop productivity to be sustained economically over time. Tolerance levels are arbitrary determinations based on the maintenance of adequate soil depth favourable for crop production over time. When erosion is to be limited to a maximum allowable tolerance rate, the term "A" in the equation is replaced by "T", and the equation is re-written in the form:

$$CP = T/RKLS$$

where:

T = the soil tolerance expressed in terms of tons per acre per year.

The paper indicated that in order to apply the USLE in Manitoba, the following activities were required.

1. The installation of recording rain gauges to develop R-values which are indicative of the erosivity of summer rain storms.
2. The sampling of soil at the series level to determine the erodibility of soils subject to water erosion.
3. The determination of crop management factors for crop rotations, and vegetative covers grown in the province.
4. The establishment of soil loss tolerance levels for soils subject to water erosion.

The authors noted that the USLE had proven to be a successful tool in soil and water conservation programs in the United States. The use of the equation in Manitoba would greatly aid in the development and implementation of erosion control measures and the design of programs for soils subject to water erosion.

2. Shaw, G.A. 1980. Predicted Soil Erosion by Water for Various Soil Types in Manitoba. 24th Manitoba Soil Science Meeting, Winnipeg, Manitoba. pp. 63-70.

The author discussed the application of factor values of the USLE for calculation of predicted water erosion for several Manitoba Soils. Since contour tillage, strip cropping on the contour and terracing were not common practices in Manitoba, the P-factor for the erosion calculation was assigned a value of one. Values from North Dakota were assigned for the topographic factor (LS) and the crop management factor (C) as there were no values determined for Manitoba.

The rainfall factor (R) was computed from 17 years of rainfall records between 1960 and 1976, from recording rain gauge data from the Brandon weather station. The computed R-value (in imperial units) was 46. This value was rounded off to 50 for use in predicted erosion calculations, for southwestern Manitoba. Soil sampling and laboratory analysis were conducted on various soil associations to determine erodibility (K-factor) by the nomograph method. Calculated K-values for the Firdale, Pembina and Harding soil associations (in imperial units) were 0.26, 0.23 and 0.20, respectively.

Predicted annual soil losses in tons/acre/year for the Firdale, Pembina and Harding soils under continuous fallow (C-factor = 1.0) were 35.1, 31.1 and 27.0, respectively. In comparison, under continuous crop rotation of small grains (C-factor = 0.19), the values were 6.7, 5.9 and 5.1 tons/acre/year. To reduce the amount of erosion to a more tolerable level, land management should incorporate crop rotations that eliminate fallow, maintain more crop residue after harvest, or include other crops such as forages in the rotation.

It was also recommended that additional soil sampling and mechanical analysis, particularly the very fine sand fraction was required to establish K-values for Manitoba soils. There was also a need to determine the representative percent slope and slope lengths (LS-values) for the various soil associations. This type of information would be required to produce a potential water erosion risk map for the province.

3. Shaw, G.A. 1982. Use of Soil Survey Data in Soil Erosion Studies. 25th Manitoba Soil Science Meeting, Winnipeg, Manitoba. pp. 82-84.

The author outlined how the use of soil survey data for soils of the Boissevain-Melita area could be utilized in the erosion studies and some of the shortfalls of the soil data and maps. A soil erodibility factor (K-value) for water erosion could be determined by a soil nomograph method provided the following soil parameters are known:

1. percent silt and very fine sand

2. percent sand
3. percent organic matter
4. soil structure
5. soil permeability

All the soil parameters to determine a K-value were contained in the soil survey report with the exception of values for percent very fine sand. It was further identified that soil survey presently assigned percent slope for each map unit but not the length of the slope. Both, the percent slope and the length of slope are required to determine the LS value of the USLE. In the field application of the USLE these slope factors are combined and a value for the two factors are obtained from published charts.

The author also suggested that the report (Boissevain-Melita) had not been widely used by extension staff or planners because the terminology was often unfamiliar and information was not in a readily usable form. The report would be more valuable to users if coloured thematic maps were produced for:

1. soil texture
2. topography
3. erosion
4. dryland capability
5. irrigation suitability

He further stated that the accuracy of soil erosion prediction would improve if soil surveys were to gather additional soil physical data and produce single factor maps from the original soil data.

4. Langman, M.N. 1983. Quantification of Erosion Potential for Soil Resource Inventories in Manitoba. 26th Manitoba Society of Soil Science Meeting, Winnipeg, Manitoba. pp. 44-52.

The objectives of the paper were to:

1. present a methodology for quantifying erosion potential in Manitoba soil surveys
2. test the methodology in the re-survey of the Rural Municipality of Westbourne
3. illustrate possible approaches to the presentation and interpretation of soil erosion data in soil survey reports.

In the methodology section of the paper the soil property for deriving K-values and the significance of each soil parameter to water erosion were presented as follows:

Soil Texture - erodibility tends to increase with greater silt content
- erodibility tends to decrease with greater sand and clay contents
- silt and very fine sand often have greater erodibility potential

Organic Matter - erodibility tends to decrease as organic matter content increases (up to 4% organic matter)
- the magnitude of the effect is related to texture

Structure - structure grade and size affect erosion
- good soil structure stabilizes the soil and reduces the detachment and transport of soil particles.

Permeability - the net effect of decreased soil permeability was increased runoff which increased the potential for dislodgement of soil particles.

K-values based upon determination of the above soil properties were computed for 22 different soil series. The K-values (given in imperial units) ranged from a value of 0.16 for the Almasippi series to a value of 0.38 for the Glenhope series. An erosion hazard class from 1 to 6 was also assigned to each soil series. In the Glenhope and Almasippi series, the hazard ratings were 4 and 2, respectively.

Of the 22 soils sampled in the RM of Westbourne, the erosion classes predicted that 19 soils have little or no water erosion hazard.

A nomograph was developed for a site specific selection of crops for erosion control on a given soil and slope conditions in the soil survey of Westbourne. Values for C-factors for cropping systems were adopted from North Dakota. It was identified that if average slope length measurements were included in survey reports, the nomograph could be manipulated without any additional field measurements.

The author concluded that calculation of erosion indices would greatly increase erosion information with little additional work. Erosion indices could be used to locate potential erosion hazard areas to make erosion hazard-crop rotation decisions, to determine the areal extent of erosion, or to quantify the site specific erosion potential.

5. Jenkins, C., Shaykewich, C.F and De Jong, E. 1984. Potential for the use of Cesium-137 as a Tracer for Soil Erosion in Manitoba. 27th Manitoba Society of Soil Science Meeting, Winnipeg, Manitoba. pp. 181-187.

The purpose of the study was to evaluate the potential of using Cesium-137 as a tracer to determine the amount of soil erosion that had occurred over a period of time. Sample sites were chosen from which erosion had taken place (knoll position of a landscape) as well as those on which erosion sediment had accumulated (depression position of a soil landscape). A check site where no erosion had taken place since at least around 1960 was also sampled. For this purpose newly broken land adjacent to cultivated fields and/or abandoned school yards were used.

Soil types selected for sampling were from the Firdale, Carroll, Erickson and Gilbert Associations. Samples for Cesium-137 were taken from the 0-10, 10-20 and 20-30 cm depths for the Gilbert sampling sites, whereas for the other sites, samples were taken from the 0-10 and 10-20 cm depths. For each soil type and depth, percent sand, silt, and clay, organic matter, bulk density and Cesium-137 concentrations were determined.

Based on data from the Firdale site, extensive erosion had occurred since 1960. Using the concentrations of Cesium-137 on the knoll location, it was calculated that 8.4 cm of soil was removed. At the Carroll site, Cesium-137 and organic matter measurements indicated severe erosion had occurred on the knoll with significant accumulations on the mid-slope and depressional locations. At the Gilbert site, the highest organic matter content occurred at the 20-30 cm depth. Therefore, the top 20 cm of soil was determined to be overburden material, covering the original surface horizon. However, the 20-30 cm sampling depth had no Cesium-137 indicating, erosion had taken place prior to 1960. As for the Erickson soil, it was difficult to estimate the amount of erosion as samples were not taken deep enough at the reference site.

6. Black, J.M.W., Smith, D.G. and Pauls, W. 1990. Design and Operation of the PFRA Erosion Plots at Miami, Manitoba - PFRA Erosion Plots Miami, Interim Results. 33rd Manitoba Society of Soil Science Meeting, Winnipeg, Manitoba. pp. 136-154.

PFRA installed 16 erosion plots near Miami, Manitoba during 1984 to 1985. The objectives of the erosion plot study were:

1. to gather and interpret data in order to test the USLE in southern Manitoba
2. to verify, or if necessary, modify existing adjustments of the USLE to accommodate erosion from snow melt
3. to evaluate the soil erodibility (K) and crop cover (C) factors of the USLE for local soils and crop rotations
4. to evaluate the effect of minimum tillage on runoff and erosion from small plots
5. to compare and demonstrate the effects of local rotations and cropping practices on erosion and runoff.

The plots were installed on an imperfectly drained Gretna clay (C). The site had a southern exposure and was characterized with slopes from 11.3 to 12.5%. The authors discussed the design, operation and sampling methods employed on these plots.

The plots were maintained using farm equipment and similar tillage practices to those on the adjoining farm lands. The following rotations were employed on the plots:

1. continuous fallow
2. wheat-wheat-canola (convention till)
3. wheat-wheat-canola (minimum till)

The mean K-factor for the three years (1986-1988) calculated from the summer fallow plots was determined to be 0.0296 t h MJ^{-1} mm^{-1}. This value was similar to value of 0.0307 reported by Wahome (1989) from the adjoining university plots. A calculated K-factor of 0.0273 for the Gretna soil using methodology developed in the United States was reported. This suggested that the rainfall K-factor for this soil was close to the expected value.

In the conventional tilled plots, the measured C-factor for the rotation was determined to be 0.193, whereas for the minimum tilled plots, the value was 0.137. Therefore, the erosion potential under conventional tillage was greater than under the minimum tillage as the C-factor was greater. Calculated C-factors for these rotations using methodologies developed in the United States were 0.227 and 0.206, for the conventional and minimum tilled rotations respectively.

Based on the results of the study, the authors concluded:

1. that the USLE was successful in estimating water erosion in southern Manitoba
2. that both the USLE and the erosion plot results discriminated between minimum and conventional tillage rotations
3. that the USLE may have potential for selection of conservation practices to control water erosion in southern Manitoba.

Note: References 4, 6, 8, 11, 14, 19 and 23 identified in the Bibliography (Section 6.0) were papers presented at the Soil Science Meetings by graduate students related to their graduate research studies.

7.3 Other Sources

1. Seecharman, R. 1980. Environmental and Socio-economic Implications of Water and Resource Planning in the Eden Creek Watershed. Natural Resource Institute Practicum. 114 pp.

One of the objectives of the study was to estimate soil erosion from summer rainstorms under existing and proposed land use practices. Estimation of soil loss from water erosion from the watershed was determined by the use of the USLE. Soil loss tolerance levels within the study area were assumed to be 0.9 t ha^{-1} for soils of the Granville Association and 1.8 t ha^{-1} for the Clarksville and Wapus Associations. Establishment of tolerance levels was based on soil properties, soil depth, topography and prior erosion. The lower tolerance level assigned to the Wapus and Clarksville soils was due to the high shale content found in the profiles.

The land base of the watershed was used for agricultural production: 75% of the area was under cultivation. The main crops included, small grain, alfalfa, and tame hay. The gross annual soil loss for the Eden Creek Watershed (approximately 4575 ha in size) was estimated to be 483,288 tons. Approximately 40% of the total area cultivated within the watershed was above the maximum soil loss tolerance level under 1979 land use conditions.

Land use options that are required to reduce soil losses to a tolerable level for Eden Creek watershed were identified as follows:

1. Option A: If the C-value is 0.05 or less, fields should be replanted with native vegetation or trees.
2. Option B: If the C-value is between 0.06 and 0.10, fields should be changed to a continuous forage rotation.
3. Option C: If the C-value is between 0.10 and 0.15, fields should be changed to 2/3 forage and 1/3 crop rotation.
4. Option D: If the C-value is between 0.16 and 0.18, fields should be changed to 1/2 forage and 1/2 crop rotation.
5. Option E: If the C-value is equal to or greater than 0.19, fields should be changed to a continuous cropping rotation.

Based on the analysis for the entire Eden Creek watershed, the following changes were necessary to maintain soil losses within tolerance levels:

1. 57 ha should be changed to option A.
2. 137 ha should be changed to option B.
3. 153 ha should be changed to option C.
4. 27 ha should be changed to option D.
5. 254 ha should be changed to option E.
6. The remainder of the cultivated fields required no land use changes.

Based on the forgoing analysis the author recommended that:

1. soil tillage practices should be reduced for erosion control
2. forage production should be increased in the watershed especially in areas that are severely eroded
3. contour farming should be encouraged
4. crop residue should be retained on fields after harvesting.

2. Eilers, R.G., Langman, M.N. and Coote, D.R. 1989. Water Erosion Risk - Manitoba. Canada-Manitoba Soil Inventory. Land Resource Research Centre, Research Branch Agriculture Canada. Publication 5259/B.

Total annual erosivity (R_t) was calculated from the sum of the rainfall erosivity (R) and the snow melt erosivity (R_s). Erosivity of rainfall was estimated with the procedure of Wischmeier and Smith using the maximum 6 h rainfall expected once every two years (p). Values of p, were converted to R using the following equation.

$$R=0.417p^{2.17}$$

where p = normal 2-year, 6 h rainfall (mm).

Erosivity of snow melt (R_s) was estimated using the modified procedure for conditions in Alberta by Tajek et al (1985). The procedure computed the water equivalent of the average amount of snow on the ground at the end of March. The value of (R_s) was calculated as follows:

$$R_s= F\text{-}S\text{-}D$$

where: S = normal snow depth on March 31 (mm)
D = density of snow (g cm^{-1})
F = 1.0 when metric units were used.

Values of R_t were computed for all climatological stations in the province having rainfall intensity and snow cover data. Transparent overlays at a scale of 1:1 000 000 were prepared for use with the Soil Landscapes of Canada Map Series. An assigned value of R_t was estimated for each soil polygon from these overlays.

The USLE was applied at a generalized map scale of 1:1 000 000 to the landscapes in Agro-Manitoba to identify the risk of water erosion. The degree of risk varied from negligible to severe depending on soil properties, topographic characteristics and land management. Analysis of the map data for the dominant soil types indicated that approximately 1 740 000 ha (28.1 %) are characterized by negligible risk of erosion, 1 959 000 ha (31.6%) have a low risk, 307 000 ha (5.0%) have a moderate risk, 858 000 ha (13.8%) have a high risk and 1 331 000 ha (21.5%) have a severe risk of water erosion.