THE APPLICABILITY OF THE UNIVERSAL SOIL LOSS EQUATION IN MANITOBA

by

Waldemar Jacob Pauls

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ABSTRACT

Two experimental field sites were constructed on Gretna clay and Leary series in 1984 and 1985, respectively, to test the applicability of the Universal Soil Loss Equation (USLE) under Manitoba conditions. Coshocton samplers were used to collect 1.0% of the water and soil runoff. Four plots, 22.13 by 4.57 m (72.6 by 15 ft), on a uniform 9% slope were established on each site. Each plot had its own continuous crop-management system; alfalfa, wheat, corn and summerfallow. Plot dimensions and slope matched standard 'unit' plots used in the development of the USLE. This design and the lack of conservation practices reduced the topography (LS) and conservation practise (P) factors of the USLE to unity. Data from tipping bucket raingauges located at each site were used to calculate the rainfall erosivity (R) factor. Crop cover counts were done regularly to determine the crop-stage period for each plot. The crop-management (C) factor was determined for each plot for each soil loss occurrence. Soil property data from each site was used in the USLE nomograph equation (NE) and a modified Young and Mutchler (1977) equation (MYME) to estimate the soil erodibility (K) from their properties. Observed C and K values were compared to the values predicted by the USLE.

Rainfall amounts and erosivity (R) values were excessive for 1985, primarily as a result of two heavy August rainfalls. Soil loss ratios and observed K values were extremely variable on both sites. However, the NE and MYME predicted similar K values for each site. The observed

K value was slightly lower than predicted for the Leary sandy loam, and very much lower than predicted for the Gretna clay.

The determination of the USLE's applicability in Manitoba was hindered by poor crop growth, lack of comparable crop-management systems, psuedo-fallow plot conditions, experimental soil textures that were outside the dominant texture range of the soils used in the NE and MYME's development, and the short duration of the study.

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INTRODUCTION

The problem of soil erosion on agricultural land has been recognized by governments, researchers and agricultural workers throughout the world for some time. Attempts have been made in the 20th century to quantify this loss through the use of mathematical equations that could, with small amounts of data, quickly and accurately predict the soil loss from a field segment or watershed area.

The most successful of these equations was the Universal Soil Loss Equation (USLE), a rainfall erosion prediction equation developed as a soil conservation tool by American researchers using data from 24 states east of the Rockies. Testing of the equation in many parts of the world has led to its widespread acceptance and usage with only minor, if any, modifications. Many workers in Western Canada cite their close proximity to the region where the equation was originally developed, the equation's universal application and acceptance, and the lack of anything better, as reasons for their use of the equation in their work. With a renewed concern about soil conservation in the agricultural community as well as the development of soil erosion risk maps by Provincial Soil Survey departments, the use of the equation is growing.

However, Canadian prairie agronomic and meteorological conditions have resulted in higher organic matter contents, different clay mineralogy, a more humid cooler climate and different crop-management systems, in these regions compared to the locations where the American research was conducted. This causes one to question the validity of the equation's relationships under Western Canadian conditions. There is, therefore, a need for a quantitative evaluation of the USLE's applicability in Manitoba.

The purpose of this study was to obtain measurements of soil loss due to rainfall in order to determine how well the USLE would predict the results. The soil erodibility (K) and crop-management (C) factors were singled out for evaluation. A second equation for predicting K, developed by Young and Mutchler (1977), was also examined. Two field sites were established along the Manitoba escarpment where accelerated erosion due to rainfall is prevalent and of concern.

Chapter II

LITERATURE REVIEW

2.1 DEVELOPMENT OF SOIL LOSS EQUATIONS

A discussion of the development of soil loss equations is given by Meyer (1984) in his paper entitled "Evolution of the Universal Soil Loss Equation". The following section is a summary of his article.

The study of soil loss due to rainfall began with the German scientist Wollny (1888), who first looked at soil physical properties that affected runoff and erosion. He investigated factors such as steepness of slope, plant cover, soil type and direction of exposure. He also studied factors affecting percolation, transpiration, evaporation and soil compaction.

Sampson and his coworkers (1918) made the first quantitative measurements of rainfall erosion in the United States in 1912 on overgrazed rangeland in Utah. The research was conducted on two ten-acre plots. Miller and colleagues initiated erosion plot research in 1917 at the Missouri Agricultural Experimental Station (Duley and Miller 1923, Miller 1926, Miller and Krusekopf 1932). Plot sizes were 27.66 x 1.83 m (90.75 x 6.0 ft).

In the 1920's a soil surveyor named Hugh Bennett led the crusade for a greater awareness of soil degradation problems (Bennett and Chapline 1928). Together with L. A. Jones, they established ten experimental stations in nine states using techniques developed earlier by Miller for evaluating runoff and erosion. Most plots were 22.13 x 1.83 m (72.6 x 6.0 ft, .01 acre). Data and findings of the research were published in the 1930's and 1940's. Further sites and experiments were added in the 1940's and 1950's to investigate a wider range of conditions.

The 1930's and early 1940's were golden years for soil conservation research (Nelson 1958). The problem of soil erosion and the need for experimental results were recognized. A pioneering spirit and enthusiasm prevailed among researchers as many began researching fundamental aspects of soil erosion. Availablity of adequate funding for staff and facilites during this time led to the establishment of procedures for soil erosion research. However, there were still many shortcomings to the research. The techniques remained relatively crude. Runoff from storm events was often caught with large tanks in the absence of time-rate information. There was a common experimental design, but little randomization or replication. Only a limited range of treatments were studied and plot conditions often differed from natural farming conditions. Most importantly, few relationships were applicable beyond the local site.

At about this time, equations for calculating field soil loss began to emerge. Cook (1936) identified three major variables involved in soil erosion that later became the basis of soil loss equations. They were:

1. the susceptibility of the soil to erosion,
2. the potential erosivity of rainfall and runoff, including slope gradient and length influences,
3. the degree of protection offered by vegetal cover.

Zingg (1940) used his own data and the research of others to develop an equation emphasizing the effect of slope degree and length.

$$A = C \quad S^{1.4} \quad L^{0.6}$$

where A = average soil loss / unit area
C = constant of variation
S = percent slope (%)
L = length of slope (ft)

Smith (1941) added crop (C) and supporting practice (P) factors to Zingg's equation, giving it the form:

$$A = C \quad S^{1.14} \quad L^{0.6} \quad P$$

This new C factor accounted for the effects of weather, soil and cropping systems.

Browning et al. (1947) added soil erodibility and management factors to Smith's equation. They also prepared tables to simplify field use of the equation in Iowa. Advances and adaptations by other researchers led to a slope-practice method for use in the Corn Belt states.

In 1946, Musgrave led workshops in Cincinnati to broaden the applicability of the equation. The conference reappraised existing factors and added a rainfall factor to produce what became known as the Musgrave equation:

$$A = R^{1.75} \quad S^{1.35} \quad L^{0.35} \quad C \quad B$$

R = maximum 2 year - 30 minute intensity rainfall
C = 100 for continuous rowcrop or summerfallow
B = soil factor, adjusted for rainfall, slope and cover

Unfortunately, most reports on the equation were unpublished.

The Musgrave equation had the following shortcomings:

1. The rainfall factor was not adequate to explain local differences in rainfall erosivity.

2. The reduced slope-length factor resulted in estimated erosion that was too low for some sets of data.
3. Continuous rowcrop and fallow conditions were found to be not interchangeable and the cover effect of the former was highly variable.

The greatest usage of the Musgrave equation has been for estimating gross erosion from large, heterogeneous watersheds and for flood abatement programs.

Smith and Whitt (1947, 1948) proposed a modified equation of the form:

$$A = C\ S\ L\ K\ P$$

C was based on the average annual soil loss from claypan soils for a specific rotation on a 3% slope, 27.43 m long, farmed up and down. The other factors for slope (S), length (L), soil group (K), and support practice (P), were dimensionless multipliers to adjust C to other conditions. The authors recognized the necessity of adding a rainfall factor to the above equation to make it applicable to a wide geographical area.

The responsibility of obtaining and analysing runoff and erosion data from U.S. studies was given to the National Runoff and Soil Loss Data Center, which was established in 1954 under the direction of Walter H. Wischmeier. The Center's goal was to develop an equation whose factors would be 1) free from any geographical orientated base, 2) represented by a single number, and 3) predicted from meteorological, soil or erosion research data on a locational basis. With the help of digital computers and punch cards to organize and store data, 7,000 plot years and 500 watershed years of precipitation, soil loss, and related data were assembled by 1956. At conferences held in 1955-1956, state conservationists used this compiled information in an attempt to reconcile differences among existing equations and extend prediction techniques to regions where no data had been collected. The resulting equation took the form:

$$A = C\ M\ S\ L\ P\ K\ E$$

where A = estimated soil loss
C = crop rotation factor
M = management factor
S = percent slope factor
L = length of slope factor
P = conservation practice factor
K = soil erodibility factor
E = previous erosion factor

E was not evaluated but considered when establishing each soil's permissible soil loss limit. The equation did not include a rainfall factor because there was insufficient data available.

Work by Wischmeier, Smith and others led to the development of a rainfall factor (R) for states east of the Rocky Mountains in 1958-1959, and the combination of the previous crop rotation and management factors (C and M) into a crop-management factor (C) in 1960. These improvements resulted in the present day form of the equation:

$$A = R\ K\ C\ L\ S\ P$$

Freedom from geographic and climatic restrictions afforded by the equation led to it becoming known as the Universal Soil Loss Equation (USLE).

Wischmeier (1972) summarized the differences between the USLE and its predecessors as:

1. A more accurate prediction of level changes of one or more factors due to a more complete separation of factor effects.

2. The inclusion of a rainfall-erosion index providing a more accurate, localized estimate of erosive potential of rainfall and runoff.
3. A quantitative soil erodibility factor that is evaluated directly from research data without reference to any common benchmark.
4. An equation and nomograph capable of computing the erodibility factor for numerous soils from soil survey data.
5. A method of including cropping and management interaction effects.
6. A method of incorporating the effects of local rainfall patterns throughout the year and specific crop cultural conditions in the cover and management factor.

2.2 COMPONENTS OF THE USLE

The USLE was originally developed in British units. Unless otherwise stated, all factor values listed in the literature review will be in British units. A detailed description of conversion factors and units for both British and Metric systems can be found in Appendix 1.

2.2.1 Rainfall erosivity factor (R)

The rainfall erosivity factor (R) can be defined as a quantitative measure of the potential of rainfall impact and turbulence of runoff to dislodge and transport soil particles from the field.

Laws and Parsons (1943) produced detailed drop size distribution data showing that mean drop size increased with rainfall intensity. Other researchers (Laws 1941, Gunn and Kinzer 1949) showed that the terminal velocity of a water drop increased rapidly at first, then more slowly, as the drop size increased. Using these relationships, Wischmeier and Smith (1958) proposed an equation for determining the kinetic energy of natural rainfall:

$$Y = 916 + 331 \log_{10} X$$

where Y = kinetic energy in foot tons per acre inch
X = rainfall intensity in inches per hour

Originally X was given no upper limit. However, work by Carter et al. (1974) and Hudson (1971) showing that median drop size does not increase for intensities exceeding three inches/hour, led to this value being adopted as the upper limit by Wischmeier and Smith (1978). Using the equation, the energy level of a rainstorm (E) could be determined from recording rainguage charts by summing the products of the Y-values and the rainfall amounts for each successive intensity increment.

By correlating soil loss from tilled fallow plots with a number of rainfall characteristics and their interaction effects, Wischmeier and Smith (1958) determined that the product of a storm's total rainfall energy (E) and its maximum 30 minute intensity (I_{30}) was the best single variable for predicting soil loss. This value can be summed for the individual storms within a time period to get a value of the rainfall erosion index (EI)[1] for that time period. No correlation could be found for the relative position of I_{30} during a storm (early, middle, end) and soil loss (Wischmeier 1959).

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[1] The parameter EI is an abbreviation for energy-times-intensity and refers to the erosion index of any storm or specified time period encompassing a number of storms. In contrast, R refers to an annual value equal to the number of erosion index units, plus a factor for runoff from snowmelt.

Erosion-potential distribution curves showing the cumulative EI throughout the year for a given location were introduced by Wischmeier (1959) as a tool to be used with crop cover information to determine the degree to which a cover would be useful and necessary at different times of the year to deter erosion.

An individual storm was defined by Wischmeier and Smith (1978) as one separated from another by at least six hours of no measureable precipitation. Rainfalls of less than one half inch (12.7 mm) were deemed insignificant and disregarded in annual erosion index computations, unless at least one-quarter inch (6.4 mm) fell in 15 minutes.

2.2.2 Soil erodibility factor (K)

The soil erodibility factor (K) for a given soil is an experimentally determined, quantitative value defined as the rate of soil loss (tons/acre) per unit of EI from unit plots[2] on that particular soil. K is used in the equation to differentiate between soils on the basis of their ability to resist erosion based on their specific soil properties.

Olson and Wischmeier (1963) determined K for some benchmark soils by rearranging the reduced USLE into the form:

$$K = \frac{A}{R}$$

where R was evaluated from climatic data
A = observed soil loss on unit plots

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[2] A unit plot has been arbitrarily defined by Wischmeier and Smith (1978) as being 22.12 m (72.6 ft) long, with a uniform lengthwise slope of nine percent, in continuous fallow, tilled up and down the slope. Here, continuous fallow means that the land is tilled and kept free of vegetation for more than two (2) years. Under such conditions, C, LS and P are equal to one, giving a reduced USLE: A = R K.

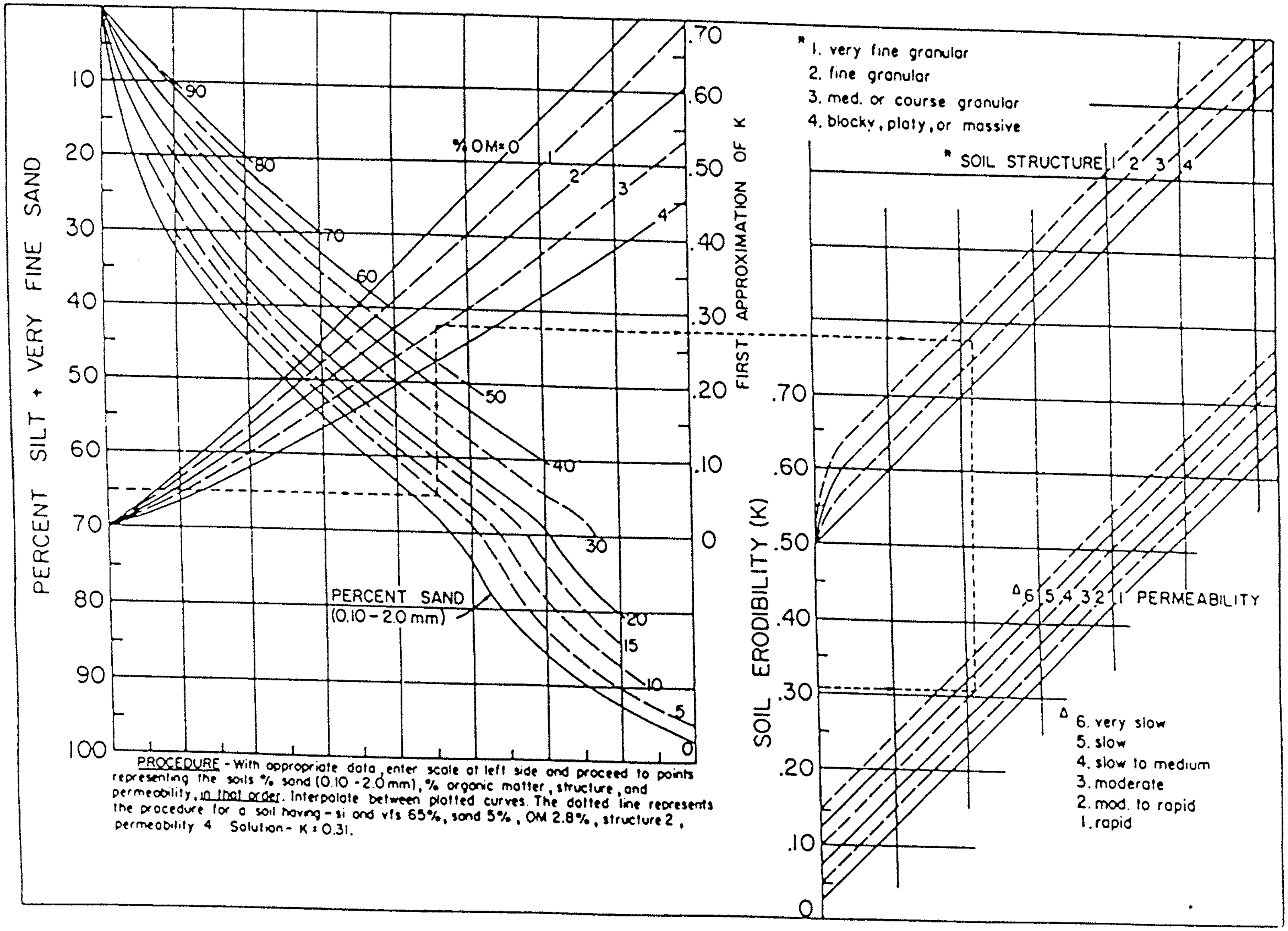
Wischmeier and Mannering (1969) used data from simulated rainfall studies on 55 medium-textured Corn Belt soils to study the effect soil properties had on the variability of soil loss. The resulting equation for estimating K contained 24 variables including 15 soil properties and their interactions. Although the equation was extremely accurate when compared with previously evaluated K values it was too cumbersome and difficult to evaluate to be a practical field working tool.

To overcome this drawback, Wischmeier et al. (1971) developed an equation and corresponding nomograph (Figure 1) for the estimation of K which required only five (5) soil parameters. They were aided in their research by the discovery that erosion was highly correlated with two new parameters; (percent silt + percent very fine sand) and (percent silt + percent very fine sand) x (percent silt + percent sand). The inclusion of these two factors improved the accuracy of predicting K for a soil dramatically. The equation took the form:

$$100K = 2.1\ M^{1.14}(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3)$$

where M = (percent silt + percent very fine sand)
x (percent silt + percent sand)
a = percent organic matter
b = structure code (1 to 4)
c = profile permeability class (1 to 6)

Particle size, percent organic matter and structure code are determined for the upper 15 cm of soil. The permeability class for a soil is determined from the whole soil profile because the controlling soil layer is often below the surface horizon. Ninety-five percent of the K values predicted by the nomograph should be within ±.04 of the measured value. Observed K values range from .03 to .69. The largest differences between observed and estimated K take place in soils outside the medium texture range.



<u>PROCEDURE</u> - With appropriate data, enter scale at left side and proceed to points representing the soils % sand (0.10 - 2.0 mm), % organic matter, structure, and permeability, <u>in that order</u>. Interpolate between plotted curves. The dotted line represents the procedure for a soil having - si and vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4 Solution - K = 0.31.

Figure 1: The soil-erodibility nomograph (after Wischmeier and Smith 1978).

2.2.3 Crop-management factor (C)

The crop-management factor (C) is a dimensionless multiplier defined as the ratio of soil loss from cropped land with certain plant growth and management characteristics to the corresponding loss from tilled continuous fallow. Its value is influenced by vegetal growth, crop sequence, tillage practices, fertility and residue management (Wischmeier 1960).

Wischmeier (1960) defined five crop-stage periods based on the relative uniformity of cover and residue effects. Soil loss from erosion plots under various crop rotations and yield patterns was determined for each of these stages and divided by the soil loss from clean tilled continuous fallow under similar rainfall, soil and topographical conditions. This ratio, the C factor value for a given crop-management condition, was tabulated for some examples by Wischmeier (1960). The following formula was also proposed for determining C for a rotation:

$$C_{(rot)} = \Sigma \text{ (C for each period)(fraction of annual EI for same period)}$$

Wischmeier and Smith (1978) redefined the cropstage periods according to percentage of canopy cover because of the variations in ground protection offered by a crop at a certain time after seeding. Also, the improved and enlarged tables of C values in this publication differentiated between different cropping conditions on the basis of residue cover as opposed to the previous parameter of yield.

2.2.4 Topographical factor (LS)

The slope length factor (L) and the slope gradient factor (S), are usually combined into one component by the formula:

$$LS = \sqrt{l}\,(.0076 + .0053s + .00076s^2)$$

where l = field slope length in feet
s = slope gradient expressed as a percentage

LS is defined as the expected ratio of soil loss per unit area from a field slope to that from a 72.6 ft length of uniform 9 percent slope under otherwise identical conditions. Tables and graphs are available (Wischmeier and Smith 1978) for determining LS quickly and accurately for slope lengths of 6 to 305 m (20 to 1000 ft) and slope percents of 0.1 to 20.

2.2.5 Conservation practice factor (P)

The conservation or support practice factor (P) is a dimensionless qualifier defined as the ratio of soil loss from a field with a support practice in place to the corresponding loss when up and down slope culture is practiced. Possible support practices include contour tillage, stripcropping on the contour and terracing. If no support practices are in place, P assumes the value of one (1). Tables and charts for determining P for different practices are available in handbooks (Wischmeier and Smith 1978).

2.3 UNIVERSALITY OF THE UNIVERSAL SOIL LOSS EQUATION

Wischmeier qualified the use of the term 'universal' soil loss equation in this manner:

> None of its factors utilizes a reference point that has direct geographical orientation ... the model should have universal validity. However, its application is limited to states and countries where information is available for local evaluations of the equation's individual factors. The relationships, graphs and tables presented for evaluation of ... factors cannot be simply transported verbatim to states or countries where the type of rainfall or soil genesis is vastly different. However, a relatively small amount of well designed local research should enable many countries to adapt the soil-loss equation and its basic relationships to their situation.[3]

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[3] Wischmeier, W.H. 1972. Upslope erosion analysis. In Environmental Impact on Rivers. Water Resources Publ., Fort Collins, Colo.

Nearly all data used in the development of the USLE were collected from studies conducted in the Great Plains and Corn Belt regions of the U.S. The USLE's individual factors and the equation as a whole have been tested and evaluated both inside and outside of this region. The result has been the acceptance, rejection, and/or modification of the equation in whole or in part by different members of the world-wide research and agricultural community.

2.3.1 Factor evaluation

2.3.1.1 The rainfall erosivity (R) factor

One of the most researched and modified factors of the USLE has been the rainfall erosivity factor, R. Many different erosivity indices have been proposed and tested. In Zimbabwe, Hudson (1971) found the KE>25 index, the total kinetic energy of the rain falling at intensities of more than 25 mm/h, to be the best indicator of erosivity. Expanding Hudson's research, Elwell and Stocking (1975) determined that EI_5 and EI_{15}, a storm's kinetic energy times its maximum 5- and 15-minute intensity, respectively, were the best predictors of soil loss on plots with high and medium crop cover, respectively. In Nigeria, Lal (1976a,b) reported a good correlation of soil loss with the AI_{30} index, a storm's total rainfall amount times its maximum 30-minute intensity. Foster et al. (1982) proposed a combined rainfall-runoff factor, EIA, which was defined as the product of a storm's maximum 30-minute intensity and the square root of the rainfall times runoff volumes.

Ulsaker and Onstad (1984) regressed soil loss on a tropical soil and 15 erosivity factors including EI_{30} (USLE), KE > 25 (Hudson 1971), EI_{15} (Elwell and Stocking 1975), AI_{30} (Lal 1976a,b), and EIA (Foster et al.

1982). The best overall rainfall erosivity factors were AI_{15} (r^2 = .73), AI_{30} (r^2 = .72), EI_{15} (r^2 = .71) and EI_{30} (r^2 = .69). Even better results were obtained from those variables which combined rainfall and runoff factors, such as EIA (r^2 = .75).

Williams (1975) proposed a modified USLE (MUSLE) for predicting soil loss from watersheds. The rainfall energy factor, R, was replaced with a runoff energy factor $11.8(Qqp)^{0.56}$ where, for each storm event, Q = runoff volume for the watershed in m^3 and qp = the peak runoff rate in m^3/s. Testing of the MUSLE by Smith et al. (1984) on Southern Plains grasslands showed good correlation between measured and predicted soil loss values.

Ateshian (1974) proposed a simpler, less time consuming procedure for determining the rainfall erosivity for Western and North Central states. His equations were based on a proposed generalized distribution curve for storm rainfall and the maximum once in two (2) year, six (6) hour rainfall depth in inches. This method was used to extend the USLE Handbook (Wischmeier and Smith 1978) rainfall erosion index map west of the U.S. Great Plains.

Van Vliet et al. (1976) used Ateshian's procedure to calculate annual rainfall erosion indices for Southern Ontario. Wall et al. (1983) extended the approach to include all areas of Canada east of the Rocky Mountains. Ateshian's formula was also applied to monthly rainfall extremes to determine seasonal distribution patterns. The computed R values and distribution patterns of several stations near the Canadian-U.S. border compared favorably to those determined by Wischmeier and Smith (1965) for northern U.S. locations (Figure 2).

Generalized distribution curves of storm rainfall given by McKay (1970) and Hogg (1981) do not agree with that given by Ateshian (1974) (Figure 3). Hogg analyzed the time distribution of storm rainfall of one (1) hour and 12 hour duration for 35 Canadian stations with 25 year records. He found that, contrary to Ateshian's findings, distribution appeared to be independent of the rainfall intensity, and that substantial differences in distribution between regions were present. McKay's generalized distribution curve was specifically for large prairie rainstorms.

Kachanoski and de Jong (1985) found that the actual annual R value of 340 (SI units) for Saskatoon was best predicted using McKay's approach (R = 350), compared with Ateshian's (R = 850) and Hogg's (R = 170) methods. Kachanoski and de Jong also pointed out that the Ateshian equation overestimated R values for Montana stations that were used by Wall et al. (1983) to verify use of this procedure on the Prairies.

In cooler climates, soil loss associated with snowmelt and rain on frozen ground can be significant. A 10 year study by Burwell et al. (1975) on Minnesota fallow soils showed a soil loss from snowmelt of 6.8% of the annual total. In the U.S. Pacific Northwest, 50 - 90% of the annual erosion can take place under conditions of surface thawing and snowmelt (Wischmeier and Smith 1978; Crops and Soils 1983). The portion of soil loss due to snowmelt for Northern Alberta is estimated to be 80% (Goettel et al. 1981).

In many areas the existing methods of determining R values do not account for this phenomenon. Wischmeier and Smith (1978) recommended that a subfactor Rs be added to the annual R. Rs would be equal to 1.5 times the local December to March precipitation in inches of water. In

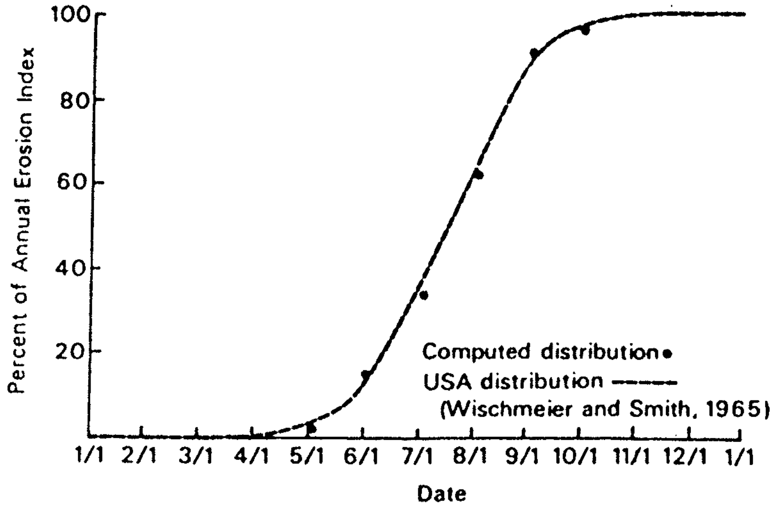

Figure 2: Comparison of computed seasonal distribution of the rainfall erosion index (EI) for Winnipeg to neighboring U.S. stations. (After Wall et al. 1982).

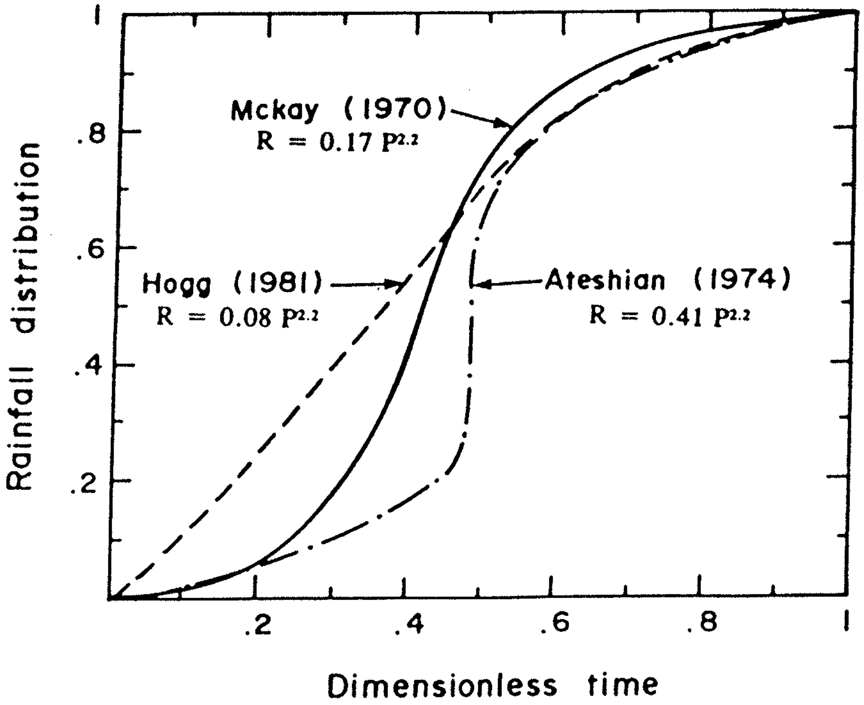

Figure 3: Generalized distribution curves and equations for storm rainfall (P = 2 yr - 6 h rainfall amount in mm). (After Kachanoski and de Jong 1985).

other words, if a location had an annual R value of 100 (in British units), and a water equivalent December to March precipitation of 5 inches, then the adjusted R value would equal 100 + 5(1.5) or 107.5. The seasonal distribution of R would also be altered to reflect the higher annual R value and the inclusion of the time of thaw runoff.

The limited data base and wide area of application of this procedure gave rise to questions as to its validity in all areas. Van Vliet and Wall (1981) measured winter soil loss for three years on spring plowed corn plots in Southern Ontario. They found the December to April losses to be about 10% of annual, compared with the 17% predicted by the USLE.

In their development of a rainfall erosion isoerodent map for Canada, Wall et al. (1983) used a modified approach developed by McCoal et al. (1976) for determining soil loss on Pacific Northwest soils. In Wall et al.'s study, Rs was equal to the percentage of annual precipitation that fell during the months when the soil was frozen. Rs/100 x R then gave a wintertime precipitation index that when added to R adjusted the annual R value to account for winter conditions.

2.3.1.2 The soil erodibility (K) factor

Although a very good field tool, the USLE nomograph for estimating soil erodibility and the equations leading to its development have not been without criticism. In their original study of soil property interactions and their effect on erodibility, Wischmeier and Mannering (1969) found that the derived equation accurately predicted the K value of some benchmark soils, even though the montmorillonite content of several soils was higher than those used in deriving the equation. By measuring soil loss on 20 West coast range and forest soils, Trott and Singer

(1983) found the best erodibility predictor to be a combined smectite plus vermiculite clay mineralogy term. They pointed out the importance of considering parent material and soil genesis, something the USLE nomograph does not do.

Young and Mutchler (1977) have suggested that for northern soils, measured K is poorly correlated to nomograph K values due to less weathering than southern soils. They noted that these soils of the north have a greater amount of montmorillonite which increases aggregation. To show this they calculated the soil erodibility factors from measured soil loss for 13 Minnesota soils, using the formula $K = A/RCLSP$. Nomograph K values were shown to overestimate the erodibility of three (3) soils and underestimate six (6) when compared to the observed values. A new five (5) variable regression equation was proposed for estimating K values from soil properties. It took the form:

$$K = -0.204 + 0.385A - 0.013B + 0.247C + 0.003D - 0.005E \qquad R^2 = .90$$

where A = aggregate index ratio
B = percent montmorillonite in the soil
C = bulk density (g/cm^3)
D = percent silt plus percent very fine sand
E = dispersion ratio

Two variables - aggregate index and percent montmorillonite - explained 75% of the variation. Steele (1979) suggested that this equation may be more suitable to Manitoba soils, as the degree of weathering and percent montmorillonite would be more similar to Minnesota soils than those from the south.

Other models have also been proposed for determining soil erodibility. The New South Wales Soil Conservation Service proposed an Australian erodibility index made up of soil detachability and water transmission components (Charman 1978). Bruce-Okine and Lal (1975) proposed a procedure for using a modified raindrop technique in determining soil erodibility of two (2) tropical soils in West Nigeria. Lindsay and Gumbs (1982) evaluated soil erodibility of four (4) tropical soils using the USLE nomograph, the Australian erodibility index and the modified raindrop technique. The indices correctly predicted the erodibility class of four (4), two (2) and zero (0) soils, respectively.

The nomograph parameters do not account for organic matter levels over four (4) percent. When presenting the nomograph, Wischmeier et al. (1971) reported that whether or how much K changes when organic matter levels exceed four (4) percent was not determined. The practice of nomograph users has been to treat soils with greater than four (4) percent organic matter as if they had four (4) percent (Steele 1979).

2.3.1.3 The crop-management (C) factor

Although C values for standard crop-management systems have proven reliable through use, special tillage or cover situations still appear to need adjustment. This applies to conservation tillage, rangeland and forest areas, and minimally tested cropping systems.

Van Doren et al. (1984) found a 45% increase in soil loss after soybeans compared to corn. This is higher than the USLE prediction of 25% and lower than most other research which reported increases of 43 to 700%. Also, the USLE predicts a 30% decrease in erosion from nontill compared to till. Other researchers report a 56 to 75% decrease. Van Doren et al's study showed a soil loss of 90% lower than predicted by the USLE for a nontill system.

A 24 year study by Burwell and Kramer (1983) on central Missouri clay pan, showed observed soil loss was 54 and 63% of that predicted by the USLE for systems of conventional and conservational tillage of corn, respectively. Jones et al. (1985) found USLE predicted erosion to be double that observed in a six (6) year watershed runoff study. They suggested that possible causes could be an insufficient study period length or a USLE C value which was too high. Wendt and Burwell (1985) also concluded that annual C factor values found in handbooks were too high for conventional, reduced and no-till corn. Dissmeyer and Foster (1981) described new procedures recommended to replace C values in the USLE handbook, Tables 11 and 12, for woodland.

2.3.1.4 The topography (LS) and conservation practice (P) factors

The LS and P factors have also been modified and refined to suit different situations. Originally, mean slope steepness was used for predicting soil loss on irregular slopes. Young and Mutchler (1969) pointed out that soil loss is most dependent on a short slope length immediately above the point of measure. Except where slopes were uniform, average slope was not a good soil loss indicator. Onstad et al. (1967) developed a model for use with the USLE for predicting soil loss on concave and convex slopes, which showed soil loss to be greater on convex slopes than on similar lengthed uniform or concave slopes. Subsequent equations have been derived (Foster and Wischmeier 1974, Wischmeier 1974) for evaluating LS for irregular slopes, changes in soil type along a slope and changes in the crop-management situation along a slope for slope segments of equal and unequal lengths.

Williamson and Kingsley (1974) pointed out the benefits of contour farming. Their study in South Dakota showed a 51% to 82% decrease in soil loss when switching from up-and-down slope tillage to contour tillage on a corn-oats rotation. This compares with an USLE prediction of 50 to 75%. Foster and Highfill (1983) proposed P subfactors to account for interterrace deposition - Pc for conservation planning which would account for losses on each terrace, and Py for sediment yield which would calculate losses from the whole field.

2.3.2 Whole equation evaluation

The USLE has been used in many different areas of the world with varying degrees of success. Hart (1984) measured erosion on mountain rangeland of various slope gradients in Utah under fallow, notill/no cover, and sagebrush/grass vegetation situations. The plots had high organic matter levels. Even though the USLE predicted soil loss amounts that were approximately equal to that measured for the sagebrush/grass plots, Hart noted that the USLE overestimated loss on steep slopes and under dry soil conditions, while it underestimated loss under wet conditions. Hart concluded that the USLE can be used on wildlands if modified for steep slopes, residual roots, high organic matter levels, and antecedent moisture.

A two (2) year study by Aldrich and Slaughter (1983) on subarctic soils revealed that erosion predicted by the USLE was 21% greater than measured on an annual basis, and up to 174% greater on an individual storm basis.

The USLE has also been used in erosion assessment studies and models. Snell (1985) used the USLE to determine the potential erosion from high risk watersheds in Southern Ontario. Muessig et al. (1985) assigned homogeneous USLE factors to 40 acre parcels of land using rainfall, soil survey and aerial photograph data to determine potential soil loss for Minnesota. Two models - CREAMS (USDA 1980) and EPIC (Williams et al. 1983) - have utilized the USLE in their procedures for determining soil productivity losses due to erosion.

In Canada, the use of the USLE has usually been accompanied by a blind trust in its applicability to local conditions. Van Vliet et al. (1976) estimated the average annual erosion on 13 agricultural watersheds in Southern Ontario using the USLE procedure. Losses due to the effects of freezing, thawing and snow melt were not taken into account in the study. Van Vliet et al. pointed out that the difficulty in using this method was that the predicted erosion was not equal to the sediment leaving the watershed, as deposition in the field was not accounted for in the equation.

Actual measurements of soil erosion in Southern Ontario taken over a four (4) to six (6) year period were found to be not significantly different from the USLE predicted losses at $P = 0.1$ (Van Vliet and Wall 1979). Once again, loss from snowmelt and frozen soil was not considered.

Stephens et al. (1985) determined USLE factors for areas in New Brunswick using aerial photographs. An accuracy of 88% ± 1-2% was reported when the method was compared to field soil loss estimates made using existing handbook values. de Jong et al. (1986), also working in New Brunswick, found that soil loss in erosion areas determined by the ^{137}Cesium method correlated well with that estimated by the USLE. Where deposition was occurring with or without simultaneous erosion, the USLE overestimated soil losses.

Steele (1979) tried to apply the USLE to two (2) Manitoba regions using soil survey and climatic data and published reports. Soils with organic matter levels over four (4) percent were given the value of four (4) percent when determining their erodibility from the nomograph. It was found that topography accounts for most of the erosion variation in the regions. Snow melt and frozen soil was not considered in the study. Shaw (1981) cited the difficulties in using soil survey reports for determining USLE factors, pointing out the need for reports to include slope length, percent very fine sand and field permeability data in order for K and L to be derived.

2.3.3 Errors in equation testing and application

In assessing the value of studies that confirm or refute existing USLE factor values and their prediction of soil loss, one needs to keep in mind the length of and replication in the study. The rainfall erosivity (R) value is based on a 22 year weather cycle proposed by Newman (1970). For any given year, R may be equal to less than one half or more than two times the 22 year average. Even ten (10) year averages can significantly bias results (Wischmeier 1976). During USLE testing it was noted that 58 of the 88 deviations greater than 1 ton/acre from the average annual soil loss resulted from the use of data records less than one half of the length of the 22 year rainfall cycle (Wischmeier 1972).

The measured soil erodibility (K) values can fluctuate on a storm basis due to antecedent surface conditions and storm characteristics. Soil may be dry or presaturated, fresh tilled or crusted. Wind direction and velocity as well as time of high intensity rainfall may vary between storms and within storms. The presence of an intermittent fragipan may have a variable effect on soil loss as well.

The average crop-management (C) value may be affected by the time of season, growing conditions, variable residual effects of tillage, and variation in EI distribution.

Wendt et al. (1986) studied the variability of soil loss from 40 side-by-side, clean-tilled fallow plots for 25 natural rainfall events. Excluding small runoff events, event coefficients of variation for soil loss was relatively constant at about 20%. Measurement, collection and sampling error were deemed small compared to the total unexplained variability. The authors suggested within-plot spatial variation in infiltration, erodibility, furrow geometry, and the number, arrangement and breakdown rate of clods as possible causes of variability. Increasing the number of replications decreased the size of the confidence interval dramatically.

The USLE is a statistical equation with variables evaluated by relationships based on the best percentage of variations explained. Refinements needed only for short-run predictions were sacrificed in the interest of conciseness and simplicity so as to produce a convenient working tool for soil conservation planning. Wischmeier (1976) encouraged users of the USLE to use caution, pointing out that applying the equation to situations for which its factor values cannot be determined is a misuse.

One example of misuse is the estimation of watershed yield limits. K, C, L, or S cannot be averaged over a complex watershed. The watershed must be subdivided into homogeneous units and deposition accounted for. Another example of misuse is the application of the equation to specific rainfall events. Using the actual EI and C values, the equation will estimate the average soil loss for numerous reoccurrences of this event on the given field and for that cropstage period. However, soil loss for any one of these events will vary widely in either direction from this average.

One of the most common error sources in USLE usage is poor factor value selection. This can occur when criteria used in selection are not specific enough. For example, applying a particular C value over all corn land without considering management practices is incorrect. Applying C and P values to slope lengths greater than those for which the practice is effective is an error. Extrapolating beyond the range of existing data from which the equation was derived is also an error. When determining slope length, one must note that this extends from the origin of overland flow to deposition or channels. Irregular slopes cannot be averaged but need to be computed from special formulas. The addition of subfactors to the annual EI value may be needed to account for snowmelt in areas of cooler climates and hurricanes in subtropical areas.

It is also stressed that the equation predicts sheet and rill erosion from slope segments represented by specific topographical factors. This is different from field sediment yield which includes all soil loss on slopes less all deposition in the field.

2.3.4 Metric conversion

With an increasing international acceptance of the USLE and the continuing push for adoption of the International System of Units (SI) worldwide, the need to convert the USLE to metric units and dimensions is obvious. Several researchers have proposed different procedures for accomplishing the conversion.

Wischmeier and Smith (1978) included procedures for computing factor values in metric, but these were for an older metric system using different units and conversion factors than the SI system. Others have attempted to include conversion values that would give factor values similar to those for the original British system (Mitchell and Bubnezer 1980; USDA supplement 1981). Foster et al. (1981) have given a method of converting the USLE to true SI units while keeping the factor values significantly different from existing values so that they are distinquishable as such. Additional details on metric conversion are given in appendix A, page 80.

2.4 SYSTEMS FOR MEASURING SOIL LOSS

Mitchell and Bubnezer (1980) identified five (5) areas of equipment needed for runoff plots:

1. plot boundaries to define the measured area;
2. collecting equipment to catch and concentrate runoff from the plots;
3. conveyance equipment to carry runoff to a sampling unit;
4. sampling unit to aliquot the runoff and soil loss into manageable quantities; and
5. storage tanks to hold aliquot portions of runoff and soil loss for analysis.

Many different devices, including soil mounds, sheet metal strips and wooden planks, have been used to isolate experimental runoff plots from the surrounding area. Pointing out that these materials are expensive or subject to deterioration, Hudson (1957) proposed the use of flat asbestos-cement planks set on edge and supported by round steel pegs.

In order to be effective, border depth below and height above ground needed to be sufficient to prohibit water movement, vegetative growth, and rodent tunnelling across them (Dendy et al. 1979). Common depths and heights are 5 to 30 cm and 7 to 25 cm, respectively (see Table 1).

Collectors located at the lower end of the plot usually consist of a sheet metal trough buried in the soil to a depth that will allow runoff to flow over its front lip and, unimpeded, into the trough. Dendy et al. (1979) recommended that troughs be wide enough for easy cleaning (20-25 cm) and be sloped to their middle at at least five (5) percent. It was also suggested that, for wide plots (i.e. 6-10 m), runoff be concentrated by appropriately positioned plot borders before it enters the collectors. Hudson (1957) also reported that the troughs should remain covered during rainfall events, as significant error could result during light rains.

The conveyance equipment most often is a variable length pipe or rectangular channel, connecting the collector to a sampling unit. The conveyor should have only sufficient slope for good drainage (Parsons 1954). If a flume is included in the design, the channel should match its width.

Total sampling systems (TSS) which collect all the runoff in large storage tanks have been used for small plots (Table 1). The water-sediment mixture is measured, then sampled for further laboratory analysis. Slot-type samplers are preferred because they can be used on larger areas and sample volumes are reduced to manageable quantities.

Multislot divisors, first discussed by Geib (1933), subsample runoff by causing it to pass through five (5) to 15 rectangular slots, only one

TABLE 1

Designs used in runoff and soil loss studies

Researcher(s)	Type of Study*	Boundary Devices†	Collector Design	Flume Type	Sampling Unit
Aldrich and (1983) Slaughter	P	wooden borders	covered rain gutter		TSS
Batchelder (1972) and Jones	P	metal strips d=15 h=15			TSS
Cordukes (1950) et al.	P		metal trough		slot divisor
Greer (1971)	P			H	coshocton
Gumbs and (1982) Lindsay	P	metal strips d=12 h=10			
Hudson (1957)	P	asbestos-cement d=7 h=7	brick channel	HS	Geib 1/7 divisor
Jones et al. (1985)	W			H	chickasha
MacGregor (1966)	P	metal strips d=5 h=25	metal trough	H	coshocton
Menzel (1978) et al.	W			V-notch wier	pumping samplers
Nickolaichuk (1978) and Read	W	earth dykes		H	periodic manual sampling
Smith (1984) et al.	W			flumes or wiers	suspended sediment samplers
Van Vliet (1979) and Wall	P			HS	silt-sampling wheel
Wendt et al. (1986)	P				1/9 multi-slot divisor
Williamson (1974) and Kingsley	P	metal strips d=10 h=10	concrete trough		divisors

* P = fractional -hectare plot
W = watershed
† d = depth of boundary device in cm
h = height of boundary device in cm

(1) of which passes its aliquot to another collection tank. This effectively divides the sample. Sludge tanks for collecting the majority of the sediment are located between the conveyance channel and the divisor, while one (1) to three (3) aliquot tanks are located after the divisor. Flumes are also located on the conveyance channel if flow-rate information is desired. Runoff volumes and sediment losses are determined by water depth measurements and subsampling the solution while hand mixing.

Another automatic, continuous sampling slot-type device is the Coshocton sampler, first developed by W. H. Pomerene in the mid-1940's (Parsons 1954). The unit consists of a small H flume which discharges runoff water over a slightly inclined water wheel, causing the wheel to rotate. An elevated sampling slot mounted on the wheel extracts an aliquot as it passes through the discharge, once per revolution. The subsample is passed through the base of the wheel into storage tanks. Runoff volume and sediment losses are determined in a similar fashion as described for multislot divisors. The portion of runoff sampled is 1/3, 1/2 or 1 percent of the total, depending on the model. Parsons (1954) found sampling error increased significantly at discharge rates over 80 percent of flume capacity.

For design purposes of all fractional-hectare runoff measuring systems, it is assumed that the maximum runoff rate is equal to the maximum five (5) minute rainfall rate and sample storage space is equal to the aliquot portion of the maximum 48 hour runoff event (Mutchler 1963).

Other methods have been designed to sample runoff from small watersheds. Dendy (1973) developed a system whereby a transversing slot moved back and forth through the flow nappe of a Parshall flume. The portion of the flow extracted was further reduced by sample splitters. The system was good for computing sediment concentration, but poor for determining total sediment or runoff volumes, because the portion of flow extracted decreased as discharge increased.

Automatic pumping samplers have been used for watersheds when remoteness, or flashiness of runoff are involved or when good concentration graphs are required. An example is the widely used modified Chickasha sediment sampler, which is able to sample 28 pint bottles in 12 hours (Allen et al. 1976, Miller et al. 1969). The pump is activated by an increase in stream depth and fills each bottle at a preset time interval.

Chapter III

MATERIALS AND METHODS

The objective of this study was to obtain measurements of soil loss due to rainfall for the purpose of evaluating the crop-management (C) and the soil erodibility (K) factors of the USLE under Manitoba meteorologic and agronomic conditions. To accomplish this, field experiments were initiated to quantify runoff from natural rainfall events for different crop-management systems and soil types.

The C value was experimentally determined by dividing the soil loss from a cropped plot, Ac, by that from the fallow plot, Af, or C = Ac/Af. The C values determined in this way were compared to those given by Wischmeier and Smith (1978) for similar crop-management conditions. Cover counts were used to determine the crop stage period of each crop at the time of a soil loss occurrence.

The K was experimentally determined by dividing the loss from fallow, Af, by the erosion index, EI, or K = Af/EI. This measured K value was compared to K values calculated from soil property data using the USLE nomograph equation (NE) and a modified Young and Mutchler equation (MYME). The NE, previously described in the literature review, has the form:

$$100K = 2.1\ M^{1.14}(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3)$$

where M = (percent silt + percent very fine sand)
x (percent silt + percent sand)
a = percent organic matter
b = structure code (1 to 4)
c = profile permeability class (1 to 6)

In their original development of a K predicting equation, Young and Mutchler's (1977) multiple regression of variables was biased by the use of an inconsistent number of replications for each soil. Eleven soils were replicated four (4) times while two (2) soils had five (5) and ten (10) replications, respectively. Measured K values from each replication were used in the regression. Regressing the average measured K value for each soil with its soil property values gave a new equation (MYME):

$$K = -0.146 + 0.33A - 0.0058B + 0.225C + 0.0019D - 0.0035E \qquad (R^2 = .89)$$

where A = aggregate index ratio
B = percent montmorillonite in total soil
C = bulk density (g/cm^3)
D = percent silt plus very fine sand
E = dispersion ratio.

Measured K and soil property values used in this multiple regression are listed in appendix D. The soil properties used in the NE and MYME will be defined in section 3.2, pages 48 and 49.

3.1 FIELD EXPERIMENT

3.1.1 Site locations and descriptions

Two experimental field sites were selected in the escarpment and Agassiz beach landscape areas of South-Central Manitoba. They were chosen on the basis of their uniform slopes and contrasting surface textures.

The first site was surveyed in May, 1984 and established later that summer. It was located near Miami (legal description NE2-5-7W) on an imperfectly drained Gretna clay, developed on Cretaceous clay overwash or outwash of weathered shale clay derived from escarpment ravines (Ellis and Shafer 1943). The site has a southerly exposure and a recent continuous cropping history.

The second site was surveyed in October, 1984 and established in the spring of 1985. It was located near Roseisle (legal description NW 18-6-7W) on a well drained Leary sandy loam underlaid by sandy material (Ellis and Shafer 1943). The site has a westerly exposure and a cropping history of a wheat-wheat-summerfallow rotation. Site locations are shown in Figure 4.

Four plots, 22.13 x 4.6 m (72.6 x 15 feet), were constructed at each site, on a uniform 9% slope. These length and gradient parameters were so chosen because they matched the dimensions of the standard erosion (unit) plots used most frequently in the development of the USLE. The topographical factors of the equation (LS) are numerically equal to 1.0 under these standard plot conditions, and thus are eliminated when analyzing other factors in the equation. The width measurement was chosen to facilitate the use of field machinery on the plots and so the total plot area would equal 0.01 ha.

3.1.2 Equipment description

Spruce boards, 2.0 x 18 cm inserted 8 cm into the soil along the plot periphery, made an effective barrier to water movement onto or off the plot. Removable end boards allowed for access onto the plots by field equipment. Adjacent plots were separated by a 1 m grassed walkway.

A 4.6 m (15 foot) long aluminum trough[4] was installed at the base of each plot to collect the runoff and direct it into an H flume. The trough was 28.6 cm (11.25 inches) wide and was sloped at 10% from one end to the other. The lower end of the trough was bolted to the flume

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[4] Supplier: Canadian Rogers Western (1971) Ltd. 1109 Winnipeg Ave., Winnipeg, Manitoba R3E 0S2

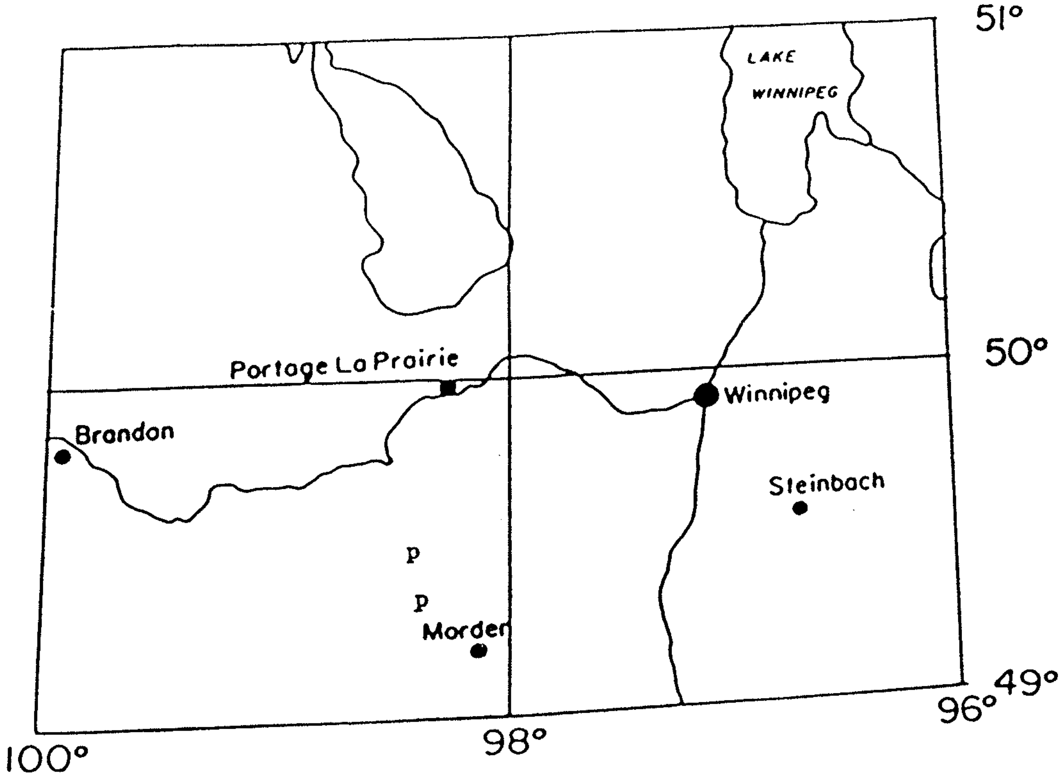

Figure 4: Location of experimental field sites.

and sealed at this joint with silicone. The trough was dug into the soil such that the edge against the plot was 5 cm (2 inches) below the soil surface. This allowed for unrestricted flow of runoff soil and water into the trough. The back of the trough was 30 cm (12 inches) above the soil surface to provide support for the attachment of a hinged plywood lid. Angle iron was suspended 15 cm (6 inches) above the trough's front edge to provide support for the lids.

Coshocton samplers[5] were chosen as the means of sampling the runoff and sediment (Figure 5). A 61 x 76 cm (24 x 30 inch) patio block was used as a base to support a steel rod stand which in turn supported the sampler and a water level recorder.[6] The sampler consisted of a 15 cm (6 inch) high H flume which directed a stream of runoff water onto a finned wheel causing the wheel to rotate. The 30 cm (12 inch) diameter wheel had on its surface an elevated slot running the radial length of the wheel. As the wheel was propelled, the slot passed under the flow once per revolution. At this time, runoff flowed into the slot and collected in a holding pan under the wheel. Since the area of the slot was 1% of the wheel, the sampler collected 1% of the runoff and sediment. The runoff then flowed by gravity through piping into removable 20 L collection containers that were connected in series and filled sequentally.

Attached to the side of the flume was a stilling well in which the float from the water level recorder was housed. Runoff water entered this well through holes in the side of the flume. Float, and therefore water level height, were recorded on the water level recorder. Using

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[5] Supplier: Engineering Laboratory Design Inc. Box 278 Lake City, Minnesota 55041 USA

[6] Supplier: Belfort Instrument Co. 1600 S. Clinton Street Baltimore, Maryland 21224 USA

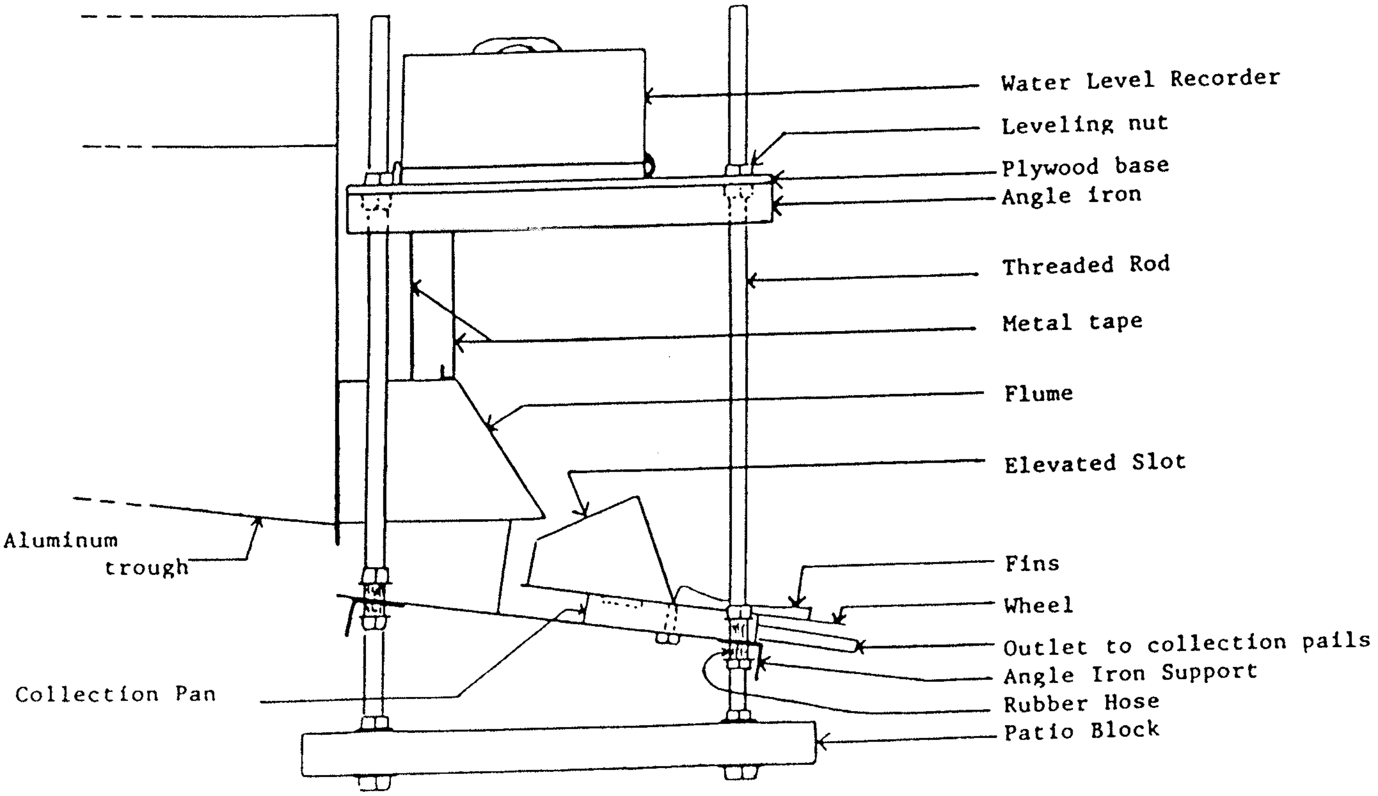

Figure 5: Side view of Coshocton sampler, water level recorder and lower trough end.

the relationship between water level and flow rate obtained during calibration, the runoff rate during each storm was calculated.

The sampler, stand, water level recorder and containers were housed in a large plywood box, the top of which doubled as a swing-back lid for easy access. Drainage pipes sloped at 1% led away from each box in order to remove uncollected soil and water. Excavation for the troughs, samplers and drainage pipes was accomplished by a municipal back hoe.

Burnett (PFRA report 1983, unpublished) reports that the most severe storm in 18 years of records for the site area deposited 8.4 cm of rain in six (6) hours in 1968. Collection system capacity was designed to accommodate maximum flow rates of 5.7 L/s at 80% flume capacity and total runoff on the summerfallow plot of 5.7 cm. Collection container capacity was 60, 40, 40, and 20 L for summerfallow, wheat, corn and alfalfa plots, respectively, reflecting the expected decrease in runoff on cropped plots.

Tipping bucket and standard rainguages were installed on each site a short distance from the plots. A method described by Wischmeier and Smith (1978) was used to compute the EI from the tipping bucket rainguage charts for each rainfall. Rainfall intensity data from a weather station located between the two sites was used in instances when there was a large discrepancy between data from the standard and tipping bucket rainguages on site. A rainfall event was defined as per the following criteria:

1. a period of rainfall separated from another period by at least six (6) hours of no measurable rainfall; and

2. at least 12.7 mm of precipitation fell during the rainfall period, or at least 6.4 mm fell in 15 minutes or less.

After each significant rainfall, the plots were checked for runoff. If runoff had occurred, the used collection containers were exchanged with empty ones and the soil that had settled out in the troughs was collected. These samples were then oven-dried and weighed. The weight of soil collected in the containers was multiplied by 100 and added to the weight of soil in the trough to determine total soil loss from each plot. If a subsequent soil loss event occurred before the containers could be exchanged, the consecutive events were analyzed together as a single event.

3.1.3 Field operations

Four different crop-management systems - 1) continuous alfalfa, 2) continuous wheat (residue removed, stubble cultivated), 3) continuous corn (residue removed, stubble cultivated), and 4) continuous summerfallow - were represented by one plot each on each site. The Gretna clay was seeded in 1984 and 1985, the Leary sandy loam in 1985 only. Varieties used were Rambler alfalfa, Benito wheat and Pioneer 3995 corn. Seeding and fertilizing were done according to guidelines outlined in Field Crop Recommendations for Manitoba. For weed control, Embutox E, Hoe-grass II and Aatrex Plus were used on the alfalfa, wheat and corn plots, respectively.

Alfalfa was underseeded to wheat seeded at one-half rate (50 kg/ha) in the establishment year. The year 1985 became the establishment year for both sites as the catch on the Gretna clay in 1984 was too poor to maintain a stand. The alfalfa seed was broadcast on the prepared seedbed and harrowed over twice. All wheat was drill seeded and corn was hand planted. Row spacings for wheat and corn were 18 cm (7 inches) and 91 cm (36 inches), respectively. Wheat and corn plots were tilled once before seeding and once after harvest with a 2.3 m wide cultivator equipped with sixteen shovels (15 cm wide). Corn plots were also row cultivated twice during the growing season. Summerfallow plots were shallow tilled every three to five weeks with the previously described cultivator. All of the tillage operations were done up and down the slope in order to remove the conservation practice factor (P) from the analysis, i.e. P = 1.

Harvesting of all wheat took place at crop maturity. Corn was harvested at about 65% whole plant moisture. Stubble height ranged from 10-20 cm for wheat and 5-10 cm for corn. Whole plant samples were taken from three one square meter areas on each cropped plot, representing the upper, mid, and lower slope. All plant residues were removed from the plots after harvest. Plant dry matter and seed yield were determined for all crops where applicable. Alfalfa and corn samples were dried to constant weight at 80°C. Wheat samples were dried at room temperature and threshed to determine seed yield.

Tables 2 and 3 contain a summary of the field operations of the Gretna clay and Leary sandy loam sites, respectively, for 1985.

TABLE 2

Summary of field operations for Gretna clay in 1985

	Date	Operation (Rate)	Equipment used (Size)
Wheat	Apr. 29	cultivation	cultivator (2.3 m)
	Apr. 29	broadcast 34-0-0 (.27 t/ha)	hand spreader
	Apr. 29	seed wheat (.1 t/ha)	press drill (1.5 m)
	Apr. 29	band 11-55-0 (.08 t/ha)	press drill
	Apr. 30	harrow	harrow
	June 13	Hoe-grass II (3.5 l/ha)	back pack sprayer (15 l)
	July 5	cultivation	cultivator
	July 9	seed wheat (.1 t/ha)	press drill
	Oct. 2	deep till	cultivator
Corn	Apr. 29	cultivation	cultivator
	Apr. 29	band 11-55-0 (.08 t/ha)	press drill
	Apr. 30	harrow	harrows
	May 23	seed corn (75,000 plants/ha)	jab planter
	June 10	row cultivation	cultivator
	June 13	side dress 34-0-0 (.27 t/ha)	manual
	June 14	spray Aatrex plus (5.0 l/ha)	back pack sprayer
	July 9	row cultivation	cultivator
	Aug. 2	spray malathion	back pack sprayer
	Sept.25	harvest - residues removed	sickle mower (.9 m) rake
	Oct. 2	deep till	cultivator
Alfalfa	May 23	broadcast 11-55-0 (.12 t/ha)	hand spreader
	June 7	cultivate	cultivator
	June 10	broadcast wheat (.05 t/ha) alfalfa (10 kg/ha)	hand spreader
	June 10	harrow	harrows
	Aug. 2	spray malathion	back pack sprayer
	Oct. 2	harvest - residues removed	sickle mower - rake
Fallow	Apr. 29	cultivation	cultivator
	June 10	cultivation	cultivator
	July 5	cultivation	cultivator
	July 30	cultivation	cultivator
	Sept. 5	cultivation	cultivator
	Oct. 2	deep till	cultivator

TABLE 3

Summary of field operations for Leary sandy loam in 1985

	Date	Operation (Rate)	Equipment used (Size)
Wheat	May 22	cultivation	cultivator (2.3 m)
	May 22	seed wheat (.1 t/ha)	press drill (1.5 m)
	May 22	band 11-55-0 (.08 t/ha)	press drill
	June 19	spray Hoe-grass II (3.5 l/ha)	back pack sprayer (15 l)
	Aug. 2	spray malathion	back pack sprayer
	Sept.10	harvest - residues removed	sickle mower (.9 m) rake
	Oct. 21	deep till	cultivator
Corn	May 22	cultivation	cultivator
	May 22	band 11-55-0 (.08 t/ha)	press drill
	May 23	seed corn (75,000 plants/ha)	jab planter
	May 23	harrow	harrows
	June 7	row cultivation	cultivator
	June 19	spray Aatrex plus (5.0 l/ha)	back pack sprayer
	July 9	row cultivation	cultivator
	Aug. 2	spray malathion	back pack sprayer
	Sept.25	harvest - residues removed	sickle mower - rake
	Oct. 21	deep till	cultivator
Alfalfa	May 22	cultivation	cultivator
	May 22	seed wheat (.05 t/ha)	press drill
	May 22	band 11-55-0 (.08 kg/ha)	press drill
	May 23	seed alfalfa (10 kg/ha)	hand spreader
	May 23	harrow	harrows
	June 19	spray Embutox E (3.0 l/ha)	back pack sprayer
	Aug. 2	spray malathion	back pack sprayer
	Sept.10	harvest - residues removed	sickle mower - rake
Fallow	May 22	cultivation	cultivator
	June 7	cultivation	cultivator
	July 5	cultivation	cultivator
	July 30	cultivation	cultivator
	Aug. 28	cultivation	cultivator
	Oct. 21	deep till	cultivator

3.1.4 Cover measurements and crop stage periods

A modification of the point-line method, described by Wischmeier and Smith (1978), was used to determine the percent canopy and mulch cover. These two variables are defined, respectively, as

> the percentage of the field area that could not be hit by vertically falling raindrops because of canopy interception ... and ... the percentage of the field area that is covered by pieces of mulch lying on the surface.

A 150 cm (5 ft) rope with ten evenly spaced markings, was randomly placed ten times across each plot at a 45 angle to the crop rows. The number of markings that had their vertical line of sight to the ground blocked by a plant part or mulch piece became the percent cover. When the crop height reached 15 cm the rope was replaced with a horizontal bar that was marked every 15 cm. The bar, which reached to the grassed walkway on either side of the plot, was suspended over the canopy by two dual-pod stands. A thin, 5 mm wooden dowel was vertically positioned between the bar and the soil surface at ten consecutive, randomly chosen marks. The number of times at least one plant part contacted the dowel became the percent cover. The bar and stands were repositioned, and the procedure replicated ten times per plot.

Canopy cover counts were done regularly during the growing season, while mulch cover counts were done before emergence and after harvest. Count values were used to determine the crop stage period and aid in choosing appropriate USLE C values for comparison with experimentally determined values.

Crop stage periods given by Wischmeier and Smith (1978) were modified to account for the presence of a winter period and the absence of turn-plow tillage. A descriptive comparison of the two systems is given below.

Wischmeier and Smith (1978)	Modified System
Period F (rough fallow) - turn plowing to secondary tillage.	Period W (winter) - last fall tillage to first spring tillage.
Period SB (seedbed) - Secondary tillage until the crop has developed 10% canopy cover.	Period SB (seedbed) - first spring tillage until crop has developed 10% canopy cover.
Period 1 (establishment) - end of SB until crop has developed 50% canopy cover.	Period 1 (establishment) - end of SB until crop has developed 50% canopy cover.
Period 2 (development) - end of period 1 until canopy cover reaches 75%.	Period 2 (development) - end of period 1 until canopy cover reaches 75%.
Period 3 (maturing crop) - end of period 2 until crop harvest.	Period 3 (maturing crop) - end of period 2 until crop harvest.
Period 4 (residue or stubble) - harvest to plowing or new seeding.	Period 4 (residue or stubble) - harvest until final fall tillage.

3.2 SOIL CHARACTERISTICS

For the purposes of soil property determinations, ten soil samples, taken to a depth of 15 cm, were removed from the two field sites in the grid pattern shown in Figure 6. Samples were taken on either side of position 6 because soil disturbance took place there when the drainage pipes were installed. Soil property determinations from 6L and 6R were averaged to derive a value for position 6. The soil properties determined from these samples included particle size analysis, percent organic matter, aggregate index and dispersion ratio. Bulk density was determined in the field, while structure code, permeability class, and percent montmorillonite were estimated from soil survey data and field observation. Soil erodibility, K, was calculated for each grid position using the NE and MYME, and then averaged to obtain an estimated K for each site from eachequation. (Soil characteristics for each grid position on each site are given in Appendices C and D.)

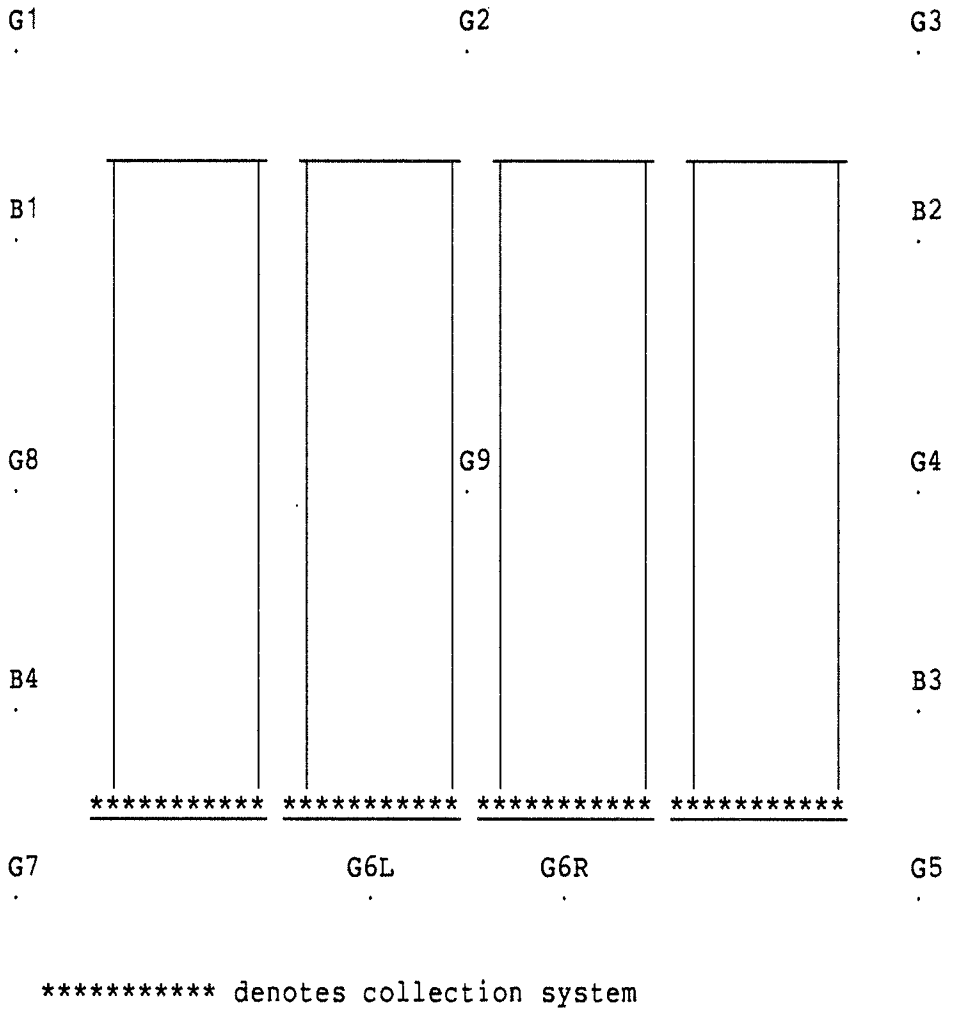

Figure 6: Plot diagram showing grid (G) and bulk density (B) sampling positions.

1. Particle size analysis. Percent sand, silt and clay were determined using the standard pipette sampling method described by Kilmer and Alexander (1949). The components of the sand fraction were determined using a mechanical shaker.[7] Percent gravel was determined by weighing the pebbles left on a 2 mm sieve after wet sieving a 100 g soil sample. Size fractions were divided according to the Canadian classification system (Canada soil survey committee 1978).
2. Organic matter. Organic matter content was determined using the 1934 Walkley-Black chromic acid oxidation method. An automatic titrator was used to back titrate excess $K_2Cr_2O_7$ with $FeSO_4$.
3. Aggregate index. A 200 g soil sample was sieved through a 9.5 mm and a 2.0 mm sieve for 15 minutes on a mechanical shaker. The weight of the 2 - 9.5 mm fraction was divided by the weight of the rest of the soil sample.
4. Dispersion ratio. A modification of a procedure described by Middleton (1930) was used to determine the 20 micron suspension percentage. A 500 mL acrylic cylinder was filled to a volume of 400 mL with distilled water at room temperature. An equivalent of 10 gm of oven dry soil was added. The mouth of the cylinder was stoppered and turned end over end for 20 cycles. The sample was placed on a bench and sampled with a 10 mL pipette at a depth of 10 cm after the appropriate settling time according to Stokes Law for particles greater than 20 microns. The percent silt and clay (<50 microns) was determined using the standard pipette sampling method described by Kilmer and Alexander (1949). The dispersion ratio was calculated using the following formula:

---

[7] Supplier: Humboldt Mfg. Co. Chicago, Illinois 60656 USA

$$\text{Dispersion ratio} = \frac{\text{Suspension percentage}}{\text{\% silt + \% clay}}$$

5. <u>Bulk density</u>. A field determination of bulk density was accomplished using a 25 cm^3 core sampler. The oven dry weight of the soil retained in the sampler was divided by the sampler volume. Samples were taken at two depths (0-7.5, 7.5-15 cm) close to the four corners of the site (Figure 6). Bulk density for each grid position was estimated as follows:

position	How determined
1	BD1
2	(BD1 + BD2)/2
3	BD2
4	(BD2 + BD3)/2
5	BD3
6	(BD3 + BD4)/2
7	BD4
8	(BD4 + BD1)/2
9	(BD1+BD2+BD3+BD4)/4

Average gravimetric water content of the soil at time of sampling was also determined.

6. <u>Structure and permeability</u>. Soil surface structure and profile permeability were estimated for both sites based on soil survey reports, field observations and consultation with M. Langman (Manitoba Soil Survey).

7. <u>Percent montmorillonite</u>. The procedure for determining the percent montmorillonite in the clay fraction usually involves x-ray difraction and specific surface area measurements. However, difficulties involved in carrying out such a procedure and the fact that, at best, the resulting value is an estimation with large confidence intervals, prompted an estimation of percent montmorillonite based on a comparison of values for soils with similar clay fractions. A paper by Madden (1974) provided the values for other soils.

Chapter IV

RESULTS AND DISCUSSION

Data gathered from both sites in 1985 included rainfall amount and duration, soil loss amounts, crop and mulch cover counts, flow rate characteristics of runoff, and various soil property values. Data collection took place during the sites' operational period which began on May 9 for Gretna clay and June 4 for Leary sandy loam. Both sites ceased operation on October 25, 1985.

4.1 SOIL LOSS

A summary of soil losses and rainfall characteristics for 1985 is given in Table 4. Soil loss was extremely variable on both sites in 1985, surpassing the generally accepted tolerable soil loss limit of 11 t/ha on all plots except alfalfa. Low soil loss values for the Gretna clay plots on August 5th may have been a result of sedimentation on the rotating Coshocton sampler wheel, causing a stoppage in rotation and a interruption in sampling. Runoff for the storm ending on August 17th exceeded the capacity of the collection system on all plots; therefore, results for that date are given as minimum soil loss values. Actual soil loss in 1985 was likely much greater than the values shown for all eight (8) plots.

One would expect that the Gretna clay would be more affected by antecedent moisture conditions than the Leary sandy loam due to a lower infiltration rate and a higher water holding capacity for the Gretna

TABLE 4

Summary of rainfall and soil loss data for 1985

Date	Total Rainfall (mm)	Maximum 30 min Intensity (mm/h)	Rainfall Erosivity Factor R (MJ mm ha^{-1} h^{-1})		Soil loss (t/ha) from			
					alfalfa	wheat	corn	fallow
GRETNA CLAY								
May 12	38.2	26.7	188.20	E*	-	0.57	0.56	0.56
29	17.6	9.8	32.51	E	-	0.13	0.63	0.25
31	10.2	3.9	6.08		-	0.05	0.09	0.64
June 8	11.2	8.8	18.83	E	-	0.05	0.07	0.61
22	14.2	17.8	55.25	E	-	-	-	-
23	5.6	4.5	4.02		-	-	-	-
24	9.6	10.4	18.39		-	-	-	-
25	11.4	6.4	13.31		0.11	0.46	1.04	0.19
28	20.6	3.8	11.52	E	-	0.51	1.38	-
July 13	9.4	16.8	41.35	E	-	-	-	-
16	4.4	7.8	6.83		0.10	0.08	0.10	0.10
20	9.0	8.6	14.52		0.04	0.03	0.02	0.03
Aug. 5	62.4	46.2	660.54	E	0.18	0.34	0.35	0.15
12	23.8	10.6	42.80	E	0.03	0.07	-	-
17	130.4	35.0	932.03	E	>3.83	>18.99	>10.34	>28.82
23	11.4	6.4	12.20		-	-	-	-
Sept. 20	12.8	3.6	5.83	E	0.01	0.05	0.01	0.08
Oct. 23	26.4	24.4	143.06	E	1.23	0.17	0.25	0.24
TOTAL	428.6		2207.27		>5.53	>21.49	>14.85	>31.66
LEARY SANDY LOAM								
June 14	4.0	1.4	0.74		-	-	-	-
16	12.0	8.8	19.93		-	-	-	-
21	4.4	3.7	2.71		-	-	-	-
25	15.0	5.6	13.93	E	0.04	0.04	0.04	0.03
28	19.2	4.5	12.77	E	-	-	-	-
July 20	7.8	13.6	23.57	E	1.14	1.45	0.91	0.33
Aug. 5	62.4	46.2	660.54	E	0.95	12.89	8.57	11.83
12	23.0	8.8	35.64	E	0.12	0.70	0.95	3.46
17	123.0	18.0	432.73	E	>0.40	>3.92	>12.33	>35.29
23	11.0	8.0	14.37		-	-	-	0.07
Sept. 14	5.6	5.4	5.41		-	-	-	-
20	13.8	2.4	4.04	E	-	0.08	0.01	0.01
28	4.2	2.9	1.68		-	-	-	-
Oct. 23	20.2	11.2	45.71	E	0.03	0.05	0.05	0.05
TOTAL	325.6		1273.77		>2.72	>19.44	>23.34	>52.05

* E indicates occurrence of a rainfall event as defined by criteria outlined in Methods and Materials, page 39.

clay. This would cause the soil to remain wet and vulnerable to runoff longer after a rain. The Gretna clay also has a tendency to shrink when dry, causing surface cracks to develop which would increase initial infiltration and act as catch-basins to soil-laden runoff. The Leary sandy loam, with its high infiltration rate, low water holding capacity, and low shrink-swell potential, has a less variable soil moisture content and should be less affected by antecedent soil moisture.

There was evidence, on the Gretna clay site, that soil loss was, at times, affected by antecedent moisture conditions. Some rainfall events (June 22, July 13) occurred after a prolonged rain-free period and produced no runoff from any plot on this site. Some rainfalls (May 31, June 25, July 16, 20, Aug. 5, 12, 17) occurring a short time after other rainfalls, produced soil losses, even though some of their EI values were small. However, this trend was not always consistent, as some rainfalls (Sept. 20, Oct.23) occurring after long rain-free periods produced significant soil losses, while other rainfalls (June 23, 24, Aug. 12, 23) occurring shortly after a rainfall produced little or no soil loss. The expected trend of soil loss being unaffected by antecedent moisture conditions on the Leary sandy loam was evident throughout the operational period with the possible exceptions of June 25, August 12 and Sept. 20 when previous rainfalls may have had an effect on the amount of soil loss that occurred on these days.

4.2 RAINFALL CHARACTERISTICS

The characteristics and erosivity index values of all 1985 rainfalls of a minimum 4.0 mm are summarized for both the Gretna clay and Leary sandy loam sites in Table 4. The total EI represents only an approximation of the annual R value for 1985, since spring rains before the operational period and an adjustment factor for winter conditions (Rs) were not included. In spite of this, erosivity index values for the period exceeded Wall et al.'s (1983) estimate of the annual R value of 1160 for both sites.

The criteria proposed by Wischmeier and Smith (1978) and adopted in this study to define a rainfall event, would exclude 7 (May 31, June 23, 24, 25, July 16, 20, August 23) of the 18 rainfalls over 4 mm for the Gretna clay, and 6 (June 14, 16, 21, August 23, September 14, 28) of the 13 rainfalls over 4 mm for Leary sandy loam. The actual decrease in the total R value would only be 3.4 and 3.5%, respectively. More importantly, at least one plot registered soil loss after 4 'non-event' rainfalls (May 31, June 25, July 16, 20) on the Gretna clay site. This compared to soil loss after one 'non-event' rainfall (August 23) on the Leary sandy loam site. These soil losses were insignificant, amounting to less than 3.0 and 0.1% of the operating period total for the Gretna clay and Leary sandy loam fallow plots, respectively. They occurred when soil moisture levels were high.

On the other hand, two rainfall events (June 22, July 13) on the Gretna clay and one (June 28) on the Leary sandy loam produced no measurable soil loss from any plot. The Gretna clay rainfalls occurred after an extended rainfall free period and dry soil surface conditions prevailed. The Leary sandy loam rainfall had a relatively low R value.

The rainfall data for 1985 is characterized by a large total rainfall amount and two major storms ending on August 5 and August 17. These two storms made up 72.7 and 86.0% of the total erosivity index for all measured rainfalls for Gretna clay and Leary sandy loam, respectively. They indicate the potential for highly erosive rainfall events to take place in the area. Losses that occurred at this time were minimized by good crop cover conditions.

4.3 CROP-MANAGEMENT (C) FACTOR

Crop growth conditions on both sites were generally good in spring with adequate moisture levels and moderate temperatures prevailing. However, a relatively dry period from late June to early August, coupled with the high water tension characteristic of the Gretna clay and low water holding capacities and fertility levels for Leary sandy loam, resulted in poor crop growth throughout the period. Precipitation and wind associated with August storms produced excessive moisture conditions and plant structural damage. Slight aphid and grasshopper damage was evident on all crops, while borer damage to corn was extensive. Large wildlife damage was also evident on all crops, especially corn.

Chemical spray contamination led to the dessication of the Gretna wheat plot in late June. Reseeding took place in early July. Low moisture conditions and grasshopper damage caused poor germination and a poor stand on this plot for the remainder of the growing season. Final yields for all crops were below the average for the site areas. Yield data is given in Table 5.

TABLE 5

Crop yield data for 1985

Crop	Total Above Ground Dry Matter (kg/ha)	Seed Yield (kg/ha)
GRETNA CLAY		
corn	4020	-
wheat	-	-
alfalfa	13	-
wheat (alfalfa)	2900	1140
LEARY SANDY LOAM		
corn	4330	-
wheat	3980	1510
alfalfa	2760	-
wheat (alfalfa)	1080	1030

4.3.1 Cover counts

Mulch and crop cover (Table 6) values were combined with field operation information to produce a graphical display of cover for each crop on each site (Figures 7 and 8). The limitations to crop growth described in the previous section resulted in lower than expected cover values for all crops. Neither the Gretna clay nor the Leary sandy loam corn plot reached the second crop stage (50 to 75 % canopy cover), and neither wheat plot reached the third (75 % canopy cover to harvest). The alfalfa plot with its nurse (wheat) crop reached the third crop stage on the Leary sandy loam, but only the second crop stage on the Gretna clay due to a thin alfalfa stand on the latter. (The reader is referred to section 3.1.4, page 45, for a more detailed description of crop stages.)

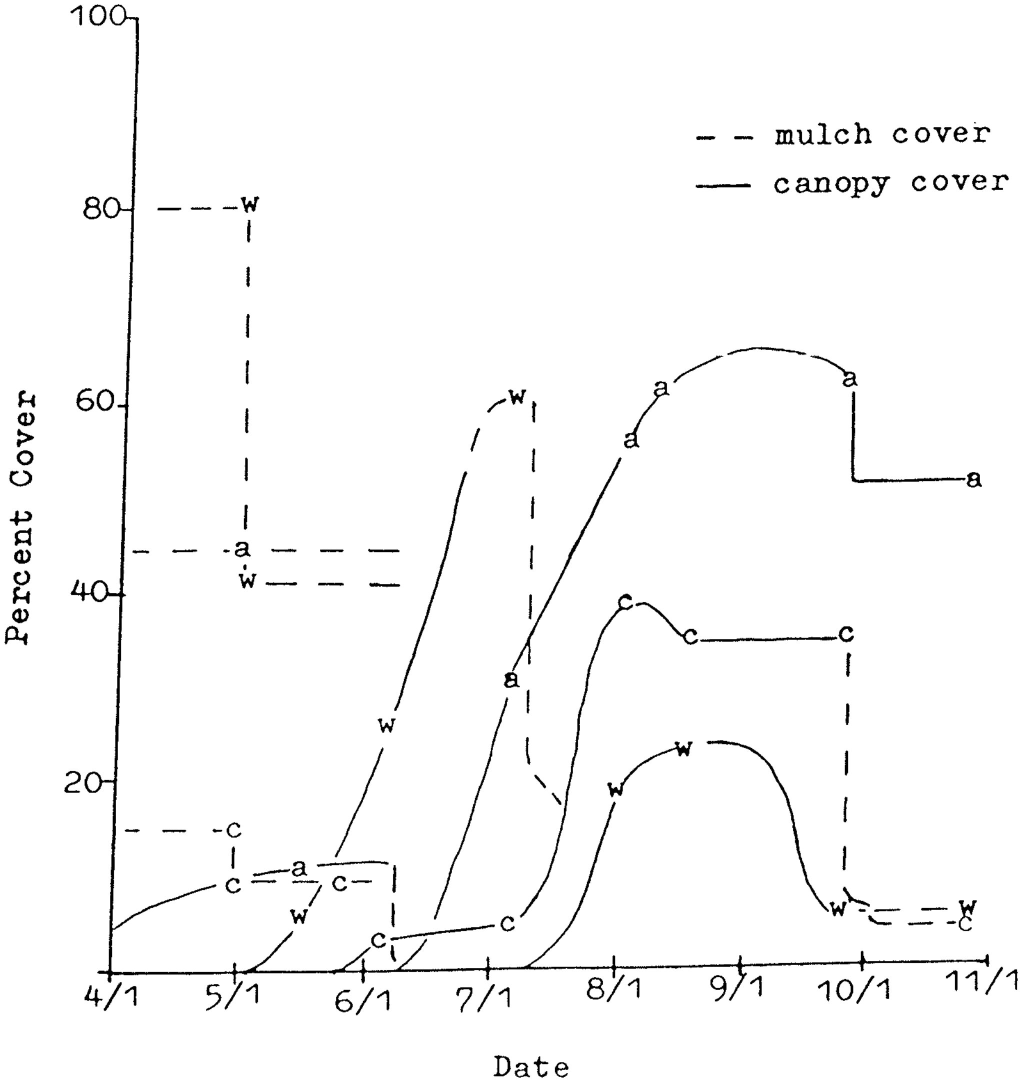

Figure 7: Mulch and crop cover levels as affected by crop growth and field operations in 1985 for Gretna clay (a = alfalfa, c = corn, w = wheat).

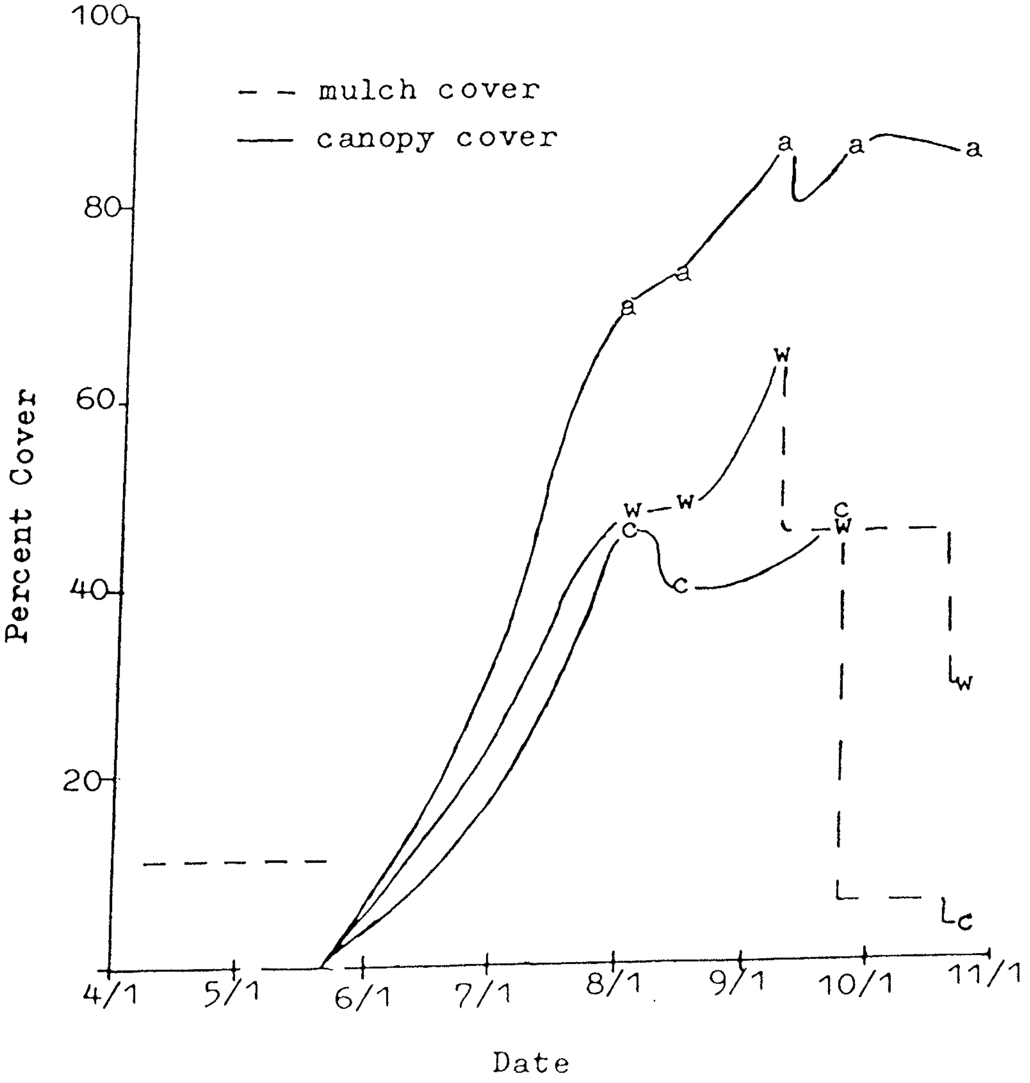

Figure 8: Mulch and crop cover levels as affected by crop growth and field operations in 1985 for Leary s l (a = alfalfa, c = corn, w = wheat).

4.3.2 Soil loss ratios

Soil loss ratios (i.e. the soil loss from cropped plots divided by the soil loss from fallow) as given in Table 6 were determined for all rainfalls that caused soil loss on the fallow plots. Theoretically, the ratio values should be less than one, as summerfallow was set up to represent the least possible erosion resistance condition.

TABLE 6

Ratio of soil loss from cropped treatment to that from fallow for 1985

Date of storm	Soil Loss Ratios Alfalfa	Wheat	Corn	Crop Stage Period (Estimated % Cover) Alfalfa	Wheat	Corn	Estimated Soil Loss Ratios* Alfalfa	Wheat	Corn
GRETNA CLAY									
May 12	0.00	1.02	1.00	-	SB(3)	SB(0)	-	0.79	-
29	0.00	0.52	2.52	-	1(17)	SB(1)	-	0.62	-
31	0.00	0.08	0.14	-	1(18)	SB(1)	-	0.62	-
June 8	0.00	0.08	0.11	-	1(30)	SB(3)	-	0.62	-
25	0.58	2.42	5.47	1(20)	2(55)	SB(4)	0.62	0.42	-
July 16	1.00	0.80	1.00	1(40)	SB(8)	1(12)	0.62	0.79	-
20	1.33	1.00	0.67	1(48)	1(15)	2(32)	0.62	0.62	-
Aug. 5	1.20	2.27	2.33	2(57)	1(19)	2(37)	0.42	0.62	-
17	~0.13	~0.66	~0.36	2(62)	1(22)	2(34)	0.42	0.62	-
Sept.20	0.13	0.63	0.13	2(65)	SB(6)	2(34)	0.42	0.79	-
Oct. 23	5.13	0.71	1.04	4(51)	W(5)	W(4)	0.22	-	-
LEARY SANDY LOAM									
June 25	1.33	1.33	1.33	1(60)	1(40)	1(30)	0.55	0.55	-
July 20	3.45	4.39	2.75	2(60)	1(40)	1(30)	0.43	0.55	-
Aug. 5	0.08	1.09	0.72	2(70)	1(46)	1(42)	0.43	0.55	-
12	0.03	0.20	0.27	2(70)	1(46)	1(40)	0.43	0.55	-
14	0.01	0.28	0.45	2(70)	1(46)	1(38)	0.43	0.55	-
17	~0.01	~0.11	~0.35	2(71)	1(47)	1(39)	0.43	0.55	-
Sept.20	0.00	8.00	1.00	4(82)	4(44)	1(45)	0.06	-	-
Oct. 23	0.60	1.00	1.00	4(83)	W(28)	W(3)	0.06	-	-

* after Wischmeier and Smith (1978)

The inconsistencies and variability in the soil loss ratios are difficult to explain. Gretna clay corn values are high early in the seedbed (SB) period as the cover and tillage conditions are similar to that of summerfallow. However, this does not explain the low values later in the same period. There was evidence throughout the year that the rotation of the sampling wheels on the summerfallow plot was hindered by high sediment load in the runoff, which may have decreased the loss from summerfallow at times, giving artificially high ratios for those storms.

Extremely high values for the first two soil loss events on the Leary sandy loam may have been an anomaly since the plots were returning to equilibrium after installation. Lower than expected values determined for the next four soil loss events may have been partially caused by broken and bent plants that due to their decreased heights, lowered the velocity, and therefore the energy level of intercepted raindrops. Also, broken plant parts lying on the soil surface absorbed raindrop impact and intercepted runoff. Poor crop growth throughout the season led to poor stubble protection after harvest. Sedimentation on the wheels may have been a factor in the last soil loss event of the year.

The literature specifies that fallow plots used in the determination of soil loss ratios must be tilled and kept vegetation free for at least two years. As well, they must be plowed and placed in conventional corn seedbed condition each spring. They should be tilled as needed to prevent surface crusting and vegetative growth. The year 1985 was only the second year of fallow for both sites. Soil loss was probably reduced by the residual mulch cover, incorporated residues and the residual effect of the previous crop system. Soil loss was also affected by the absence of spring plowing. Cultivation, the only form of tillage used on the fallow plots, was delayed at times due to excessive subsurface moisture conditions, allowing surface crusting to take place, especially on the Gretna clay. The interaction of all these plot conditions may have affected the soil loss from the fallow plots and therefore the observed soil loss ratios for each crop-management system.

4.3.3 Comparison of C values

Differences in the experimental crop-management systems and those described in tables of soil loss ratios given by Wischmeier and Smith (1978 Tables 5, 5a, 5c) made direct comparison of the ratios difficult. The reclassification of the crop-stage periods (section 3.1.4) and the low cover values throughout the growing season increased the difficulty.

Wischmeier and Smith gave soil loss ratios for one system of grain after grain with residue removed. However, in their example the stubble was disked under as opposed to the procedure of cultivation used in this study. Values for this system as given in the literature are listed in Table 6 according to the appropriate crop stages for the Gretna clay wheat plot. The same system was used in the establishment year of the Gretna clay alfalfa plot. The effect of the alfalfa growth was to be reflected in higher cover values in crop stages 3 and 4. For two months after harvest of the wheat cover crop, the alfalfa cover was included with the wheat stubble in cover determinations. Thereafter the crop was considered to be established meadow. No winter period for alfalfa was allowed for in the literature.

All Leary sandy loam crops were seeded into summerfallow with grain residues. A number of grain on summerfallow systems proposed by

Wischmeier and Smith were differentiated on the basis of the residue cover. Since pre-emergence cover counts were not taken on this site, choosing a comparable crop-management system from those given by Wischmeier and Smith (1978) was difficult. However, it was noted that grain residue cover was very low in spring, and therefore the ratios of the system with 10% cover were listed in Table 6 for relative comparison with the experimental values determined for the wheat and alfalfa plots.

Too many differences existed in the tabulated and experimental crop-management systems for corn to permit comparison. Systems with field cultivation as the only tillage were given, but none included removing residues. All residue removal systems included spring or fall turn-plowing. There was no system of corn on summerfallow given.

4.4 SOIL ERODIBILITY (K) FACTOR

4.4.1 Predicted K values

A summary of the average soil property values for each site is given in Table 7. The structure code value of 4 given to each soil was based on a classification of very hard coarse angular to sub-angular blocky structure for the Gretna clay and weak to very hard medium sub-angular blocky structure for Leary sandy loam. A permeability class of 6 was given to the Gretna clay based on its swelling potential, massive structure when wet and the presence of shale in the profile. No consideration was given to infiltration via large surface cracks that developed when the soil was dry, because runoff was more likely to take place when the soil was wet. The Leary sandy loam was given a permeability class of 2 because, even though initial infiltration was rapid, the Bt horizon may have been sufficiently developed to slow infiltration somewhat.

TABLE 7

Average soil property values for the field sites.

Site	% silt + v.f.sand*	% silt + sand	% Organic Matter	Structure Code	Permeability Class	Aggregate Index	% Montmor-illonite†	Bulk Density‡	Suspension Percentage	Dispersion Ratio
Gretna clay	30.10	49.59	4.28	4	6	0.193	15.72	1.44	15.01	19.12
Leary sandy loam	24.15	88.95	0.85	4	2	0.115	3.45	1.54	3.19	12.98

*Soil properties are defined on pages 48 and 49.

†percentage of total soil.

‡in g/cm^3.

For the purposes of estimating percent montmorillonite in the total soil, Plum Coulee (Ap horizon), with a fine to coarse clay ratio of 2.7:1 and a 42% and 2% montmorillonite content in the fine and coarse clay fractions respectively, was assumed to have clay minerology similar to both the Gretna clay and Leary sandy loam. The values for the Plum Coulee soil were combined with particle size data for Gretna clay and Leary sandy loam to derive an estimate of the percent montmorillonite in each study soil.

Due to the change in bulk density with soil water content in some soils, samples for the determination of this property were taken shortly after a rainfall while soil moisture levels were fairly high. Average gravimetric water contents of the bulk density samples were 28% for Gretna clay and 14% for Leary sandy loam.

Calculated and observed K (t h MJ^{-1} mm^{-1}) values are listed in Table 8. From the nomograph equation (NE), a K value for Gretna clay of 0.0273 was calculated. This compares to 0.036 for Austin clay, the only clay textured benchmark soil used in the NE's original verification (Wischmeier et al. 1971). The low content of preferentially eroded particle sizes - silt and very fine sand - and the high organic matter content, with its effects on aggregation and soil strength, combined to produce a low K value in the Gretna clay. This was offset, however, by the high structure code and permeability class values for the soil.

All but two of the nine Gretna clay soil samples recorded organic matter levels higher than the 4.0% upper limit. When an upper restriction of 4.0% was placed on all grid positions, the average organic

TABLE 8

Observed and Predicted K Values

			K $(t\ h\ MJ^{-1}\ mm^{-1})$		
	EI $(MJ\ mm\ h^{-1}\ ha^{-1})$	Af $(t\ ha^{-1})$	observed*	NE† $\bar{X} \pm S\bar{x}$	MYME† $\bar{X} \pm S\bar{x}$
GRETNA CLAY	1275.24	2.84	0.0022	0.0273 ± 0.0021	0.0187 ± 0.0027
LEARY SANDY LOAM	841.04	16.76	0.0199	0.0246 ± 0.0018	0.0291 ± 0.0030

*K observed = Af/EI.
†These equations are described on pages 33 and 34.

matter level for the site fell to 3.79% and the K value rose to 0.0279. This was a 2.2% increase in the K value from the non-restricted value of 0.0273.

The Leary sandy loam's estimated K value as calculated by the NE was 0.0246. This compared to 0.036 for Cecil sandy loam, the only benchmark soil of that texture used in the NE's original verification (Wischmeier et al. 1971). The Leary sandy loam had a low silt plus very fine sand content and high permeability, which together promote low soil erodibility. These were offset by the very low organic matter content, and the blocky structure of the soil which did little to reduce erodibility further.

In its original testing, the NE proved to be most accurate for soils in the medium texture range. Both the Gretna clay and the Leary sandy loam soils fall outside this texture range.

Unlike the NE, the modified Young and Mutchler equation (MYME) accounted for the influences of clay mineralogy and aggregation. The MYME value of 0.0187 for the Gretna clay was significantly lower than the NE value of 0.0273. A cool climate has caused less weathering of this soil than in those of the Southern and Central U.S. The resulting higher montmorillonite content should lead to a high degree of aggregation and subsequent low soil erodibility value. The high percentage of montmorillonite in the clay fraction of the Gretna clay (31.2) coupled with an high percent clay (50.4), produced a high value for the percent montmorillonite in the total soil of 15.7%. This high level of montmorillonite has the effect of reducing, substantially, the MYME's prediction of K. No other test soil used in the MYME's development had a clay content greater than 36%, or a montmorillonite content over 10.5%.

The aggregate index value for the Gretna clay of 0.195 was lower than 10 of the 13 soils which constituted the MYME's developmental data base. This low value was in part due to the presence of aggregates greater than 9.5 mm in the same soil samples. It may be that the rotary method of sieving used in the development of the equation was less destructive than the 15 minute mechanical shaking procedure used in this study. There was an indication that aggregate index would almost double if separation of the size fractions were conducted without mechanical agitation of the soil aggregates. If all other parameter values remained unchanged, doubling the aggregate index would approximately double the K value of the Gretna clay soil.

The average dispersion ratio for the Gretna clay was greater than all but one soil used in the equation's development. This was because the average suspension percentage (15.01), the numerator of the ratio, was nearly twice the highest value of the test soils (7.94). One would expect the dispersion ratio to be low in a well-aggregated soil with a high organic matter content such as the Gretna clay. It would appear that the Gretna clay was susceptible to severe aggregate destruction upon quick-wetting due to processes of slaking and differential expansion. Like percent montmorillonite, the relatively high dispersion ratio had the effect of substantially reducing the K value for this soil.

It would appear that caution was needed when applying the MYME to the Gretna clay as it was outside the range of soils from which the equation was derived. The Gretna clay soil had a clay content, estimated montmorillonite content, and suspension ratio greater than all 13 soils used in deriving the equation. Also, it had a very low aggregate index and a very high dispersion ratio.

The MYME value of 0.0291 for the Leary sandy loam was slightly higher than that predicted by the NE. The estimated percent montmorillonite in the clay fraction and in the total were both within the test soils' range, as were bulk density and percent silt plus percent very fine sand.

The aggregate index for the Leary sandy loam was very low, probably for the same reasons outlined for the Gretna clay. The aggregate index was lower than the Gretna clay value due to its lower structure grade (strength). This very low aggregate index value would greatly reduce the predicted K value.

As was the case with the Gretna clay, the Leary sandy loam dispersion ratio value was high; however, the reasons were probably different. The average suspension percentage for Leary sandy loam was low at 3.19%, due in part to the high sand content. For the same reason, the denominator - percent silt plus percent clay - was also small. The combination resulted in a very high dispersion ratio, giving the false impression that the Leary sandy loam had a low K value because it was poorly aggregated.

The deceptively high dispersion ratio and the possible underestimation of the aggregate index suggested that the MYME's predicted K value may be slightly low for Leary sandy loam.

4.4.2 Observed K values

K values were determined for both sites for each soil loss occurrence and for the operating period. For individual storms, K was determined by dividing the soil loss from fallow by the erosion index (EI) for the storm. To determine the overall average value of K for the entire operating period, the total soil loss from fallow during the period was divided by the cumulative EI for all rainfalls greater than 3.8 mm. The soil loss and EI values for the August 17th storm were excluded, due to their ambiguity as discussed in section 4.1.

Variablity between storms was great, and K values ranged from 0 to 0.103 for the Gretna clay and 0 to 0.095 for the Leary sandy loam. The former had a very low operating period average of 0.0022. This value more than doubled to 0.0043 when the August 5th storm data - questionable for reasons previously mentioned - was excluded. The Leary sandy loam had a much higher operating period average of 0.0199. The effects of large storms can be seen when including the results of the August 17th storm. For that storm the K value was >0.031 for Gretna clay and >0.082 for Leary sandy loam. The storm's inclusion increased the operating period K value of the Gretna clay and Leary sandy loam to over 0.014 and 0.041, respectively.

As previously discussed, the literature specifies the type of fallow plot management that was to take place if soil loss measurements from them was to be used for determining soil loss ratios. These same requirements applied to fallow plots that were to be used in the determination of soil erodibility values. For reasons outlined in the earlier discussion, the existing deviations from the literature specifications may have affected the soil loss from the fallow plots and therefore the observed K values of the soils.

4.4.3 Comparison of K values

The very low observed K values for Gretna clay suggest that the prediction equations are grossly overestimating the soil erodibility. The high NE value may be due to the equation's inability to account for the soil's high montmorillonite level and its effect on aggregation and clay expansion. The high MYME value may be due to the equation's inability to directly account for the Gretna clay's high organic matter content. In all probability, the discrepancies lie with the inclusion of the August 5 storm, which underestimated K, and the exclusion of the August 17 storm, which would have increased the observed K values beyond the predicted levels.

Observed K for the Leary sandy loam was slightly lower than the predicted values. The exclusion of the large August 17 storm and the short data collection period may have been factors in the observed K's low value.

Comparison of the observed K values with those predicted by the NE and MYME, is at best, a preliminary evaluation. Too little data was available to have confidence in an observed K value for the soils. The presence of impure fallow conditions and the exclusion from the data base of large storm events in 1985 served to hinder the determination of each soil's true K value. Antecedent moisture and tillage conditions and storm characteristics may also be contributing to the variability of K from storm to storm. Many plot years of soil loss and rainfall data would need to be collected before the actual K could be determined, or prediction equations such as the NE or MYME could be verified.

Chapter V

SUMMARY AND CONCLUSIONS

The results for 1985 proved to be inconclusive in determining the applicability of the USLE under Manitoba conditions, for many reasons.

Poor crop development and the absence of directly comparable crop-management systems hindered the comparison of soil loss ratios and the evaluation of the C factor.

Observed K values were variable and too often affected by equipment failure to permit adequate comparison with the nomograph equation (NE) and modified Young and Mutchler equation (MYME) predicted values. Whether or not NE needs modification to account for soils with organic matter levels over 4% was not determined as neither experimental soil had significantly more than 4% organic matter. Many soil property values of the Gretna clay and Leary sandy loam were outside the range of values of the soils used in the MYME's derivation. Both experimental soils were on the fringe of the texture range of soils that constituted the bulk of each prediction equation's developmental base.

Other aspects of the study that hindered proper USLE factor evaluation included the absence of appropriate fallow conditions, and the intermittent failure of the equipment to sample and collect 1% of the runoff.

The limiting factor in this study was its short duration. The R, K, and C values for individual storms showed extreme variability. The fact that definite factor values were not determined after one (1) year of study is not surprising, since the USLE is based on a 22 year rainfall cycle.

Before the applicability of the USLE in Manitoba can be determined, some conditions will need to be met. Better crop growth will need to take place in order for evaluation of soil loss ratios for all crop stage periods to occur. New soils, with a wide range of soil property values, including some with organic matter levels well over 4% will need to be added to the data base, to facilitate the evaluation of the NE and MYME. Fallow conditions that meet the literature specifications will need to exist for accurate comparison of soil loss ratios and K values to take place. Finally, many plot-years of data will be needed to substantiate the use or modification of the USLE in Manitoba.

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Appendix A

CONVERSION OF THE USLE TO THE INTERNATIONAL SYSTEM OF UNITS (SI)

The conversion of the USLE from its original British units to SI units can be accomplished in two ways. When the rainfall, soil loss and slope length data are measured in in/h, tons/acre and ft, the factor values may be calculated using the original formulas, then multiplied by a conversion factor to put them into SI units.

To convert from:	British units	multiply by:	to obtain SI units
Rainfall erosivity, R	$\frac{\text{hundreds of ft-tonf in}}{\text{acre h}}$	17.02*	$\frac{\text{MJ mm}}{\text{ha h y}}$
Soil erodibility, K	$\frac{\text{ton acre h}}{\text{hundreds of acre ft tonf in}}$	0.1317	$\frac{\text{t ha h}}{\text{ha MJ mm}}$
Soil loss, A	$\frac{\text{ton}}{\text{acre}}$	2.242	$\frac{\text{t}}{\text{ha}}$

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*Conversion factors after Foster et al. (1981).

C, LS, and P are dimensionless ratios that require no conversion.

When the collected data is in metric units - mm/h, t/ha, m - the formulas for calculating some factor values must be altered. The kinetic energy per unit of rainfall (E) is calculated using the formula:

$$E = 0.119 + 0.0873 \log_{10} I$$

$$\text{for } I \leq 76 \text{ mm/h}$$

where E has units of MJ mm ha^{-1} h^{-1}. E equals 28.3 for all I values greater than 76 mm/h.

Even though the topographical factor is dimensionless, the slope length portion (λ) needs adjustment when measured in meters. Dividing λ by 0.3048 converts it back to feet. LS is then calculated using the original formula. Slope gradient, measured in percent, will be immune to any changes in systems.

Soil erodibility, K, will automatically take on the units of A and R. As dimensionless ratios, C and P are once again unaffected by a change in the system.

Appendix B

MULTIPLE LINEAR REGRESSION VARIABLES USED BY YOUNG AND MUTCHLER (1977)

Soil	K Measured	Aggregate Index	% Montmorillonite	Bulk Density	% Silt + v. f. sand	Dispersion Ratio
Barnes l	0.27	0.37	3.75	1.20	39.4	10.00
Hamerly l	0.27	0.35	4.77	1.14	44.6	8.55
Waukon s l	0.14	0.00	2.45	1.40	33.7	19.56
Rockwood s l	0.33	0.43	1.50	1.41	36.8	16.03
Nebish s l	0.25	0.37	1.12	1.37	28.9	14.38
Sioux s l	0.35	0.43	4.51	1.60	23.2	5.28
Flak s l	0.32	0.19	neg.	1.61	46.2	9.36
Sverdrup l s	0.11	0.00	9.67	1.46	11.2	16.74
Kranzburg c l	0.33	0.47	6.42	1.22	49.7	9.22
Rothsay c l	0.41	0.54	5.73	1.42	39.8	9.86
Forman c l	0.23	0.54	10.48	1.25	38.8	8.75
Clarion s c l	0.35	0.59	6.49	1.42	27.9	8.23
Storden s c l	0.36	0.54	6.25	1.37	30.4	8.02

Appendix C

SOIL PROPERTY VALUES FOR EACH GRID POSITION

Grid No.	% silt + v.f.sand	% silt + sand	% Organic Matter	Structure Code	Permeability Class	Aggregate Index	% Montmorillonite	Bulk Density (g/cm^3)	Suspension Percentage	Dispersion Ratio	Soil Erodibility K ($t\ h/MJ\ mm \times 10^2$) NE†	MYME†
GRETNA CLAY												
1	30.10	63.22	4.00	4	6	0.184	11.48	1.37	15.51	23.97	3.06	1.71
2	31.17	61.44	5.51	4	6	0.167	12.03	1.43	15.78	23.14	2.83	1.84
3	31.55	55.18	4.71	4	6	0.149	13.98	1.50	8.79	11.82	2.84	2.35
4	27.44	44.47	4.33	4	6	0.314	17.33	1.46	17.43	21.35	2.54	2.15
5	25.50	44.19	4.29	4	6	0.184	17.41	1.42	16.82	21.13	2.48	1.42
6	28.87	43.45	4.31	4	6	0.173	17.64	1.46	15.00	17.84	2.57	1.71
7	30.92	40.19	3.04	4	6	0.251	18.66	1.50	18.55	20.57	2.68	2.01
8	34.52	48.84	3.10	4	6	0.157	15.96	1.43	13.34	15.78	3.02	1.92
9	30.82	45.30	5.20	4	6	0.158	17.07	1.44	13.91	16.49	2.57	1.74
LEARY SANDY LOAM												
1	23.24	89.35	0.53	4	2	0.189	3.32	1.52	3.71	15.67	2.45	3.01
2	23.01	88.44	0.95	4	2	0.114	3.61	1.54	3.33	13.51	2.33	2.81
3	22.16	87.57	0.75	4	2	0.086	3.88	1.55	3.87	15.69	2.27	2.58
4	24.67	91.43	0.84	4	2	0.042	2.67	1.58	2.87	12.96	2.58	2.76
5	21.53	91.03	1.05	4	2	0.041	2.80	1.62	3.72	19.03	2.24	2.50
6	22.91	89.97	0.95	4	2	0.076	3.13	1.56	2.80	11.85	2.36	2.83
7	25.89	87.76	0.78	4	2	0.231	3.82	1.50	2.47	8.62	2.61	3.49
8	25.08	86.95	0.62	4	2	0.135	4.07	1.51	3.28	10.94	2.54	3.17
9	28.84	88.03	1.15	4	2	0.070	3.73	1.55	2.65	8.58	2.81	3.02

†NE = K calculated from Wischmeier et al. (1971) nomograph equation.
MYME = K calculated from modified Young and Mutchler (1977) equation.

Appendix D

PARTICLE SIZE ANALYSIS FOR EACH GRID POSITION

Grid No.	% Gravel†	% Sand‡					% Silt‡	% Clay‡
		v.coarse	coarse	medium	fine	v.fine		
GRETNA CLAY								
1	1.86	1.65	2.34	5.79	23.34	2.17	27.92	36.78
2	2.24	1.39	2.84	5.78	20.26	1.76	29.41	38.56
3	3.03	1.79	3.10	5.09	13.65	1.79	29.76	44.82
4	1.08	1.28	1.88	3.66	10.20	1.38	26.06	55.53
5	1.12	1.00	1.36	3.75	12.58	1.57	23.92	55.81
6	0.43	0.83	1.13	2.91	9.72	1.47	27.40	56.55
7	0.26	0.32	0.79	2.01	6.15	0.58	30.33	59.81
8	0.58	0.95	1.37	2.91	9.09	1.11	33.42	51.16
9	0.36	0.79	1.26	2.79	9.63	1.26	29.56	54.70
LEARY SANDY LOAM								
1	5.29	1.95	6.76	26.28	31.11	9.40	13.84	10.65
2	3.89	2.68	8.65	23.50	30.60	9.89	13.12	11.56
3	3.00	2.24	5.04	28.09	30.04	9.45	12.72	12.43
4	3.78	1.56	8.87	26.32	30.00	11.28	13.40	8.57
5	3.74	1.62	8.41	27.83	31.63	10.59	10.94	8.97
6	3.59	1.74	7.21	27.09	31.01	9.34	13.57	10.03
7	2.81	2.35	7.82	24.90	26.79	9.46	16.43	12.24
8	2.45	1.52	8.09	25.64	26.63	8.14	16.94	13.05
9	2.91	2.63	8.06	23.86	24.65	9.32	19.52	11.97

*Canadian classification system.
†Percentage of whole soil.
‡Percentage of soil excluding particles >2.0 mm.

Appendix E

SUMMARY OF RUNOFF CHARACTERISTICS FROM ALL SOIL LOSS EVENTS IN 1985

	Alfalfa		Wheat		Corn		Summerfallow	
Date of Storm	max flow rate (L/s)	tot. run-off (L)	max flow rate (L/s)	tot. run-off (L)	max flow rate (L/s)	tot. run-off (L)	max flow rate (L/s)	tot. run-off (L)
GRETNA CLAY								
May 12	0.17	7450	0.13	6445	0.25	11065	0.05	1910
May 29	-	-	0.07	1825	0.03	95	0.04	1950
May 31	-	-	0.06	1585	0.04	3320	0.36	4030
June 8	-	-	0.11	1400	0.04	840	0.31	1035
June 25	0.01	455	0.27	3705	0.42	8385	0.16	5555
June 28	-	-	0.23	1765	0.20	4140	0.03	3075
July 16	0.03	875	0.06	745	0.04	640	0.03	2205
July 20	0.03	495	0.01	45	0.03	1685	0.03	3680
Aug. 5	0.17	4745	0.16	8625	0.23	10065	0.04	5520
Aug. 12	0.03	1800	0.14	3105	0.04	6415	0.03	3070
Aug. 17	1.83	24700	1.95	27465	4.22	31520	4.05	28125
Sept.20	0.06	2625	0.14	7860	0.03	2030	0.05	120
Oct. 23	0.21	7300	0.16	4495	0.06	3860	0.11	1840
LEARY SANDY LOAM								
June 25	0.08	5445	0.03	310	0.04	2725	0.04	1590
July 20	3.65	600	2.33	420	0.53	150	0.13	95
Aug. 5	8.63	7135	6.27	4490	1.84	1360	4.47	13970
Aug. 12	0.68	3285	-	-	-	-	0.85	7960
Aug. 17	1.62	12595	1.27	6545	1.16	18410	0.41	10510
Aug. 23	-	-	-	-	-	-	0.12	120
Sept.20	0.07	2715	0.04	1255	0.04	525	-	-
Oct. 23	0.07	985	0.04	845	0.04	1040	0.06	640

Appendix F

LISTING OF COMPUTER PROGRAMS

Program used in calculating rainfall erosivity values from rainfall intensity data.

```
//WPAULS JOB ',,'
// EXEC PASCCG
//PASC.SYSIN DD *
PROGRAM RAINPROG(INPUT,OUTPUT);

   (*** THIS PROGRAM CALCULATES THE RAINFALL CHARACTERISTICS
        THE FIRST RECORD IN THE DATA FILE IS THE LOCATION
        CARD AND THE FIRST 8 CHARACTERS ARE TAKEN AS THE
        SITE NAME.
        THIS PROGRAM WAS WRITTEN BY JOY L. PAULS FOR USE
        BY W. PAULS GRADUATE STUDENT - M.SC.                  ***)

CONST
   CLOCKHR = 24;
   MAXIPM = 5000;
   SITELEN = 8;
   MAXLINES = 60;

TYPE
   TIMEREC = RECORD
      HR : INTEGER;
      MIN : INTEGER;
   END;
   IPMARRAY = RECORD
      LAST : 0..MAXIPM;
      ARR : ARRAY [1..MAXIPM] OF REAL;
   END;

VAR
   LINECT,MINS,IND,DATEIN,DATESV:INTEGER;
   STTIME,ENDTIME:TIMEREC;
   SITE : STRING(SITELEN);
   CH : CHAR;
   AMTIN,INTENS,EPM,EPI,TOTAMT,TOTEPI:REAL;
   IPMTAB : IPMARRAY;

PROCEDURE HDGRTN(CONST SITE:STRING(SITELEN);
                 VAR LINECT,DATESV : INTEGER);

      (* PRINT THE HEADINGS *)

   BEGIN
```

```
   PAGE;
   WRITELN;
   WRITELN(' ':18,'SITE: ':6,SITE:SITELEN,' ':18,'DATE: ',DATESV:6);
   WRITELN;
   WRITELN;
   WRITELN(' ':12,'TIME':4,' ':19,'STORM INCREMENTS':16,' ':15,
         'ENERGY':6);
   WRITELN('---------------------------',' ':6,'-------------------',
           ' ':7,'---------------------');
   WRITELN('START      END      ELAPSED',' ':6,'AMOUNT    ',
           'INTENSITY',' ':9,'PER      PER');
   WRITELN(' ':21,'(MIN)',' ':8,'(MM)',' ':6,'(MM/H)',' ':12,
           'MM',' ':6,'INCREMENT');
   WRITELN('---------------------------',' ':6,'-------------------',
           ' ':7,'---------------------');
   WRITELN;
   LINECT := 10;
   END;
               (* END HEADING ROUTINE *)


FUNCTION MINCALC (OLDT,NEWT:TIMEREC):INTEGER;

   (* CALCULATE ELAPSED MINUTES FROM THE TWO GIVEN TIMES *)

   BEGIN
   IF NEWT.HR >=OLDT.HR THEN BEGIN
      IF NEWT.MIN >= OLDT.MIN THEN
         MINCALC := ((NEWT.HR - OLDT.HR)*60) + (NEWT.MIN - OLDT.MIN)
      ELSE
         MINCALC := (((NEWT.HR - OLDT.HR) - 1) * 60)
                    + ((60 - OLDT.MIN) + NEWT.MIN)
   END ELSE BEGIN
      IF NEWT.MIN >= OLDT.MIN THEN
         MINCALC := (((CLOCKHR - OLDT.HR) + NEWT.HR) * 60)
                  + (NEWT.MIN - OLDT.MIN)
      ELSE
         MINCALC := ((((CLOCKHR - OLDT.HR) + NEWT.HR) - 1) * 60)
   END;
   END;
                     (* END OF MINUTES CALCULATION *)


PROCEDURE INTPERMIN (VAR IPMTAB:IPMARRAY; MIN:INTEGER; AMT:REAL);

   (* THIS PROCEDURE INPUTS THE INTENSITY PER MINUTE FOR EACH *)
   (* MINUTE IN THE GIVEN INTERVAL, INTO THE IPM TABLE *)

   VAR
      I : INTEGER;
      IPMWK : REAL;

   BEGIN
   IPMWK := AMT / MIN;
   IF (IPMTAB.LAST + I) > MAXIPM THEN
      WRITELN('*** INTENSITY TABLE NEEDS SIZE INCREASE ***')
   ELSE BEGIN
```

```
      FOR I := 1 TO MIN DO
         IPMTAB.ARR[IPMTAB.LAST+I] := IPMWK;
      IPMTAB.LAST := IPMTAB.LAST + MIN;
      END;
   END;
            (* END INTENSITY TABLE INSERTION *)


FUNCTION  MAXINT (VAR IPMTAB:IPMARRAY):REAL;

         (* CALCULATE THE 30 MINUTE PERIOD OF MAXIMUM *)
          (* INTENSITY RAINFALL *)

VAR
   MAX,SUM:REAL;
   I : INTEGER;

   BEGIN
   WITH IPMTAB DO BEGIN
      IF LAST < 30 THEN
         BEGIN
         WRITELN('*** RAINFALL PERIOD OF INSUFFICIENT LENGTH *** - ',
                 LAST:3,' MINUTES');
         MAX := 0.0;
         FOR I := 1 TO LAST DO
            MAX := MAX + ARR[I];
         END    (* IF *)
      ELSE BEGIN
         MAX := 0.0;
         FOR I := 1 TO 30 DO
            MAX := MAX + ARR[I];
         I := 1;
         SUM := MAX;
         WHILE ((I + 30) <= LAST) DO
            BEGIN
            SUM := SUM - ARR[I] + ARR[I + 30];
            IF SUM > MAX THEN
               MAX := SUM;
            I := I + 1;
            END;   (* WHILE *)
         END;   (* ELSE *)
      MAXINT := MAX;
      END;   (* WITH *)
   END;

      (* END OF MAXIMUM INTENSITY CALCULATION *)


PROCEDURE DATEDATA(TOTEPI,TOTAMT:REAL);

   (* PRINT OUT DATA FOR RAINFALL AS PER DATE *)

   VAR
      MAXI30, MAXDBL, MAXMLT, TOTDIV : REAL;

   BEGIN
   WRITELN;
```

```
   WRITELN(' ':5,'TOTAL',' ':23,TOTAMT:5:1,' ':33,TOTEPI:7:2);
   WRITELN;
   TOTDIV := TOTEPI/100.0;
   WRITELN(' ':5,'KINETIC ENERGY = ',TOTEPI:7:2,' /100 = ',
          TOTDIV:7:2,' MJ/ha');
   WRITELN;
   MAXI30 := MAXINT(IPMTAB);
   MAXDBL := MAXI30 * 2;
   WRITELN(' ':5,'MAX. RAIN IN 30 MINUTES = ',MAXI30:5:1,
          ' mm',' ':9,'I30 = ',MAXI30:5:1,' *2  = ',
          MAXDBL:5:1,' mm/h');
   WRITELN;
   MAXMLT := TOTDIV * MAXDBL;
   WRITELN('     EI = ',TOTDIV:7:2,' * ',MAXDBL:5:1,
            ' = ',MAXMLT:7:2,' MJ mm/ha h');
   END;

   (** END OF DATE DATA PRINT AND CALCULATIONS *)


PROCEDURE DATECH(VAR TOTEPI,TOTAMT:REAL);

   (* CHANGE OF RAINFALL , PRINT AND RESET VALUES *)

   BEGIN
   DATEDATA(TOTEPI,TOTAMT);
   DATESV := DATEIN;
   STTIME := ENDTIME;
   READLN(DATEIN,ENDTIME.HR,ENDTIME.MIN,AMTIN);
   IPMTAB.LAST := 0;
   TOTAMT := 0.0;
   TOTEPI := 0.0;
   HDGRTN (SITE,LINECT,DATESV);
   END;

   (* END OF DATE OF RAINFALL CHANGE *)


BEGIN   (* MAINLINE *)
IF NOT EOF THEN
   BEGIN
   SITE := '';
   FOR IND := 1 TO SITELEN DO
      BEGIN
      READ(CH);
      SITE := SITE || STR(CH);
      END;   (* FOR *)
   READLN;
   READLN(DATEIN,STTIME.HR,STTIME.MIN,AMTIN);
   DATESV := DATEIN;
   HDGRTN(SITE,LINECT,DATESV);
   IPMTAB.LAST := 0;
   TOTEPI := 0.0;
   TOTAMT := 0.0;
   WHILE (NOT EOF) DO
      BEGIN
      READLN(DATEIN,ENDTIME.HR,ENDTIME.MIN,AMTIN);
```

```
      IF (DATEIN <> DATESV) THEN
         DATECH(TOTEPI,TOTAMT);
      IF (LINECT > MAXLINES) THEN
         HDGRTN(SITE,LINECT,DATESV);
      MINS := MINCALC(STTIME,ENDTIME);
      INTPERMIN(IPMTAB,MINS,AMTIN);
      TOTAMT := TOTAMT + AMTIN;
      INTENS := (AMTIN * 60) / MINS;
      IF AMTIN = 0.0 THEN
         EPM := 0.0
      ELSE
         IF INTENS > 76 THEN
            EPM := 28.3
         ELSE
            EPM := 11.9 + (8.73 * ((LN(INTENS))/(LN(10))));
      IF EPM < 0.0 THEN
         EPM := 0.0;
      EPI := AMTIN * EPM;
      TOTEPI := TOTEPI + EPI;
      IF (STTIME.MIN=0) AND (ENDTIME.MIN=0) THEN
         WRITELN(STTIME.HR:2,' ','00':2,' ':5,ENDTIME.HR:2,
                 ' ','00':2,' ':6,MINS:4,' ':9,AMTIN:4:1,
                ' ':6,INTENS:6:2,' ':9,EPM:7:2,' ':6,EPI:6:2)
      ELSE
      IF STTIME.MIN = 0 THEN
         WRITELN(STTIME.HR:2,' ','00':2,' ':5,ENDTIME.HR:2,
                 ' ',ENDTIME.MIN:2,' ':6,MINS:4,' ':9,AMTIN:4:1,
                ' ':6,INTENS:6:2,' ':9,EPM:7:2,' ':6,EPI:6:2)
      ELSE
         IF ENDTIME.MIN = 0 THEN
         WRITELN(STTIME.HR:2,' ',STTIME.MIN:2,' ':5,ENDTIME.HR:2,
                 ' ','00':2,' ':6,MINS:4,' ':9,AMTIN:4:1,
                ' ':6,INTENS:6:2,' ':9,EPM:7:2,' ':6,EPI:6:2)
      ELSE
         WRITELN(STTIME.HR:2,' ',STTIME.MIN:2,' ':5,ENDTIME.HR:2,
                 ' ',ENDTIME.MIN:2,' ':6,MINS:4,' ':9,AMTIN:4:1,
                ' ':6,INTENS:6:2,' ':9,EPM:7:2,' ':6,EPI:6:2);
      LINECT := LINECT + 1;
      STTIME := ENDTIME;
      END;   (* WHILE *)
   DATEDATA(TOTEPI,TOTAMT);
   PAGE;
   END;   (* IF *)
END.
//GO.INPUT DD *
```

Program for calculating soil loss from each plot.

```
//WPAULS  JOB ',,'
//        EXEC WATFIV
//FT05F001  DD  *
$JOB
C THIS PROGRAM CALCULATES THE SOIL LOSS.  IT ACCEPTS A DATA
C FILE WHOSE FIRST RECORD CONTAINS THE NAME OF THE LOCATION
C OF THE RESEARCH PLOT IN THE FIRST 10 SPACES OF THE RECORD.
C THE FIRST FILE IT ACCEPTS CONTAINS THE JAR WEIGHTS.  AT
C PRESENT THERE ARE 250 JARS IN THE FILE.  THIS IS HARD CODED
C INTO THE PROGRAM. PLEASE UPDATE AS NECESSARY.
C THE DATA FILE CONTAINS THE WEIGHT OF THE SOIL PLUS THE JAR.
C IT ALSO CONTAINS THE DATE, PLOT CODE, JAR NUMBER, WEIGHT,
C AND AN INDICATOR (0 OR 1) AS TO WHETHER THIS IS A 1% SAMPLE
C (IE. 1 = 1% SAMPLE, 0 = 100% SAMPLE).
      INTEGER NUMJAR/250/,PGNUM/1/,LC/70/,DATEIN,DATESV,
     *       MULTIN,JARIN,IND
      LOGICAL  CIND/F/,SIND/F/,WIND/F/,AIND/F/,EOF/F/,EOW/F/
      REAL  JARWT(250), WGHTIN
       REAL*8  WEIGHT,WRK,STOT/0.0D0/,WTOT/0.0D0/,CTOT/0.0D0/,
     *        ATOT/0.0D0/,FINS/0.0D0/,FINW/0.0D0/,FINC/0.0D0/,
     *         FINA/0.0D0/
       CHARACTER  PLOTIN,PLOTSV,CROP*5,NAMEIN*10,CORN/'C'/,
     *           WHEAT/'W'/,ALFALF/'A'/,SMRFLL/'S'/
C   START PROGRAM
      EXECUTE INITWT
      READ(5,10,END=100) NAMEIN
      EXECUTE READCD
      IF (EOF) GO TO 100
      DATESV = DATEIN
      EXECUTE PLTSET
80    CONTINUE
      IF (DATEIN .NE. DATESV) THEN DO
        EXECUTE DATECH
        EXECUTE PLTSET
      ENDIF
      IF (PLOTSV .NE. PLOTIN) THEN DO
        EXECUTE PLTSET
      ENDIF
      WGHTIN = WGHTIN - (JARWT(JARIN))
      IF (MULTIN .EQ. 1) THEN DO
        WEIGHT = WGHTIN * 100.0D0
      ELSE DO
        WEIGHT = WGHTIN * 1.0D0
      ENDIF
      EXECUTE ADDPLT
      EXECUTE READCD
      IF (EOF) GO TO 90
      GO TO 80
90    CONTINUE
      EXECUTE DATECH
      EXECUTE FINTOT
100     CONTINUE
      STOP
```

```
10    FORMAT (A10)
C   INITIALIZE CONTAINER WEIGHTS TABLE
      REMOTE BLOCK INITWT
        DO 140 IND=1,NUMJAR,1
          JARWT(IND) = 0.0
140   CONTINUE
145   CONTINUE
        READ 150,JARIN,WGHTIN
          AT END
            EOW = .TRUE.
          END AT END
        IF (JARIN .EQ.000) THEN DO
          EOW = .TRUE.
        ELSE DO
          JARWT(JARIN) = WGHTIN
        ENDIF
        IF (.NOT. EOW) GO TO 145
150   FORMAT (I3,F6.2)
      END BLOCK
C
C READ INPUT DATA CARD
C
      REMOTE BLOCK READCD
        READ 120,DATEIN,PLOTIN,JARIN,WGHTIN,MULTIN
          AT END
          EOF = .TRUE.
          END AT END
120   FORMAT (I6,A1,I3,F6.2,I1)
      END BLOCK
C
C SET THE CORRECT PLOT INDICATOR ON, TO INDICATE ACTUAL DATA
C IS PRESENT FOR A PARTICULAR DATE FOR THAT CROP
C
      REMOTE BLOCK PLTSET
        PLOTSV = PLOTIN
        IF (PLOTIN .EQ. CORN) THEN DO
          CIND = .TRUE.
        ELSE DO
          IF (PLOTIN .EQ. WHEAT) THEN DO
            WIND = .TRUE.
          ELSE DO
            IF (PLOTIN .EQ. SMRFLL) THEN DO
              SIND = .TRUE.
            ELSE DO
              IF (PLOTIN .EQ. ALFALF) THEN DO
                AIND = .TRUE.
              ELSE DO
                PRINT 130,PLOTIN
              ENDIF
            ENDIF
          ENDIF
        ENDIF
130     FORMAT ('0','*** INVALID PLOT CODE ',A1)
      END BLOCK
C
C CHANGE IN DATE, PRINT OUT FOUR LINES OF DATA, ADD TO FINAL
C ACCUMULATORS, AND RESET ALL ACCUMULATEORS, INDICATORS AND
```

```
C SAVE AREAS.  CHECK FOR HEADINGS TO BE PRINTED. PRINT 'NEG'
C IF NO DATA HAS BEEN COLLECTED FOR A PLOT ON A PARTICULAR DATE.
C
      REMOTE BLOCK DATECH
        IF (LC .GT. 60) THEN DO
          EXECUTE HDGRTN
        ENDIF
        CROP = 'ALFA '
        IF (AIND) THEN DO
          WRK = ATOT * 0.0001D0
          PRINT 200, DATESV,CROP,ATOT,WRK
          FINA = FINA + ATOT
        ELSE DO
          PRINT 205,DATESV,CROP
        ENDIF
        CROP = 'WHEAT'
        IF (WIND) THEN DO
          WRK = WTOT * 0.0001D0
          PRINT 220,CROP,WTOT,WRK
          FINW = FINW + WTOT
        ELSE DO
          PRINT 210,CROP
        ENDIF
        CROP = 'CORN '
        IF (CIND) THEN DO
          WRK = CTOT * 0.0001D0
          PRINT 220,CROP,CTOT,WRK
          FINC = FINC + CTOT
        ELSE DO
          PRINT 210,CROP
        ENDIF
        CROP = 'SMFW '
        IF (SIND) THEN DO
          WRK = STOT * 0.0001D0
          PRINT 220,CROP,STOT,WRK
          FINS = FINS + STOT
        ELSE DO
          PRINT 210, CROP
        ENDIF
        ATOT = 0.0D0
        WTOT = 0.0D0
        CTOT = 0.0D0
        STOT = 0.0D0
        AIND = .FALSE.
        WIND = .FALSE.
        CIND = .FALSE.
        SIND = .FALSE.
        LC = LC + 5
        DATESV = DATEIN
200   FORMAT('0',15X,I6,9X,A5,8X,F9.2,8X,F5.2)
205   FORMAT('0',15X,I6,9X,A5,11X,'NEG.',11X,'NEG.')
210   FORMAT (' ',30X,A5,11X,'NEG.',11X,'NEG.')
220   FORMAT (' ',30X,A5,8X,F9.2,8X,F5.2)
      END BLOCK
C
C  HEADING ROUTINE
C
```

```
      REMOTE BLOCK HDGRTN
        PRINT 300,NAMEIN,PGNUM
        PRINT 310
        PRINT 320
        PRINT 325
        PRINT 330
        PRINT 335
        LC = 10
        PGNUM = PGNUM + 1
300   FORMAT('1',27X,A10,' SOIL LOSS DATA',15X,'PAGE: ',I2)
310   FORMAT(' ',27X,'-------------------------')
320   FORMAT('-',45X,'S O I L  L O S S')
325   FORMAT (' ',45X,'------------------')
330   FORMAT ('0',16X,'DATE',10X,'CROP',11X,'G/PLOT',10X,'T/HA')
335   FORMAT (' ',16X,'----',10X,'----',11X,'------',10X,'----')
        END BLOCK
C
C ADD THE WEIGHT TO THE APPROPRIATE WEIGHT FOR PLOT ACCUMULATOR
C
      REMOTE BLOCK ADDPLT
        IF (PLOTSV .EQ. CORN) THEN DO
          CTOT = CTOT + WEIGHT
        ELSE DO
          IF (PLOTSV .EQ. WHEAT) THEN DO
            WTOT = WTOT + WEIGHT
          ELSE DO
            IF (PLOTSV .EQ. SMRFLL) THEN DO
              STOT = STOT + WEIGHT
            ELSE DO
              ATOT = ATOT + WEIGHT
            ENDIF
          ENDIF
        ENDIF
      END BLOCK
C
C PRINT THE FINAL TOTALS
C
      REMOTE BLOCK FINTOT
        WRK = FINA * 0.0001D0
        CROP = 'ALFA '
        PRINT 400,CROP,FINA,WRK
        WRK = FINW * 0.0001D0
        CROP = 'WHEAT'
        PRINT 410, CROP,FINW,WRK
        WRK = FINC * 0.0001D0
        CROP = 'CORN '
        PRINT 410,CROP,FINC,WRK
        WRK = FINS * 0.0001D0
        CROP = 'SMFW '
        PRINT 410,CROP,FINS,WRK
        PRINT 430
400   FORMAT('-',15X,'TOTAL',10X,A5,7X,F10.2,7X,F6.2)
410   FORMAT (' ',30X,A5,7X,F10.2,7X,F6.2)
430   FORMAT('-',31X,'* END OF PROCESSING *',/,'1')
      END BLOCK
      END
$ENTRY
```

Program to calculate flow rate of runoff from
water level recorder charts.

```
//WPAULS JOB ',,'
// EXEC PASCCG
//PASC.SYSIN DD *
PROGRAM WATLEVPROG(INPUT,OUTPUT);
   (*** THIS PROGRAM EVALUATES THE WATER LEVEL RECORDER DATA. IT
   EVALUATES THE MAXIMUM FLOW RATE BY PUTTING THE MAXIMUM NUMBER
   OF DIVISIONS FROM THE CHART THROUGH AN EQUATION BASED ON THE
   SPECIFIC PLOT.  IT ALSO CALCULATES THE TOTAL RUNOFF VOLUME, BY
   SUMMING THE VOLUMES FOR EACH 4 HOUR PERIOD AS GIVEN BY THE CHART.
   THE INPUT CONSISTS OF 2 TYPES OF INPUT RECORDS.  THE 1ST COLUMN
   CONTAINS A TYPE CODE.  A 1 CARD CONTAINS THE DATE, A PLOT CODE, AND
   THE MAXIMUM NUMBER OF DIVISIONS FOR THAT RAINFALL.  MULTIPLE NUMBER
   #2 CARDS FOLLOW EACH NUMBER 1 CARD.  EACH CONTAINS THE END DIVVAL  FOR
  A CONSTANT SLOPE ON THE GRAPH AND THEN THE TIME IN MINUTES OF THE
  CONSTANT SLOPE.  THE START DIV VAL IS TAKEN FROM THE PREVIOUS #2
   RECORD.  DATA IS PRINTED OUT WHEN THE
   DATE CHANGES FOR ALL 4 PLOT TYPES.  THE 1ST INPUT CARD CONTAINS THE
   SITE NAME IN THE 1ST 8 CHARACTERS.   ***)

CONST
   SITELEN = 8;
   MAXCON  = 99.9;
   SECCON  = 60;

VAR
   DATEIN,DATESV,LC,CODEIN,IND:INTEGER;
   PLOTCD,CH:CHAR;
   TOTA,TOTW,TOTC,TOTS,MAXA,MAXC,MAXW,MAXS,MAXD,STVAL:REAL;
   EDVAL:REAL;
   TIMEIN:INTEGER;
   SITE:STRING(SITELEN);

PROCEDURE HDGS(CONST SITE:STRING(SITELEN);
               VAR LC,DATESV:INTEGER);

          (* PRINT HEADINGS *)

   BEGIN
   PAGE;
   WRITELN(' ':56,SITE:SITELEN,' FLOW RATE DATA');
   WRITELN;
   WRITELN(' ':18,'ALFALFA',' ':25,'WHEAT',' ':26,'CORN',' ':27,
            'SMFLLW');
   WRITELN(' ':10,'MAX. FLOW   TOT. RUNOFF',' ':8,
         'MAX. FLOW   TOT. RUNOFF',' ':8,'MAX. FLOW   TOT. RUNOFF',
         ' ':8,'MAX. FLOW   TOT. RUNOFF');
   WRITELN(' DATE  ','RATE (L/S)    VOL. (L) ':26,' ':8,'RATE (L/S)',
         '    VOL. (L) ','RATE (L/S)    VOL. (L) ':31,
         'RATE (L/S)    VOL. (L) ':31);
   WRITELN;
   LC := 7;
   END;
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        (* END OF HEADING ROUTINE *)

PROCEDURE DATECH(VAR TOTA,TOTW,TOTC,TOTS,MAXA,MAXW,MAXC,MAXS:REAL;
                  VAR DATESV:INTEGER);

        (* PRINT OUT THE INFORMATION FOR THE DATE*)
        (* IF NO RECORDS PROCESSED FOR ANY ONE PLOT, THEN *)
        (* -99.9 WILL BE PRINTED ON THE OUTPUT *)

BEGIN
   IF LC > 60 THEN
      HDGS (SITE,LC,DATESV);
   IF TOTA = 0 THEN TOTA := -MAXCON;
   IF TOTW = 0 THEN TOTW := -MAXCON;
   IF TOTC = 0 THEN TOTC := -MAXCON;
   IF TOTS = 0 THEN TOTS := -MAXCON;
   WRITELN(' ',DATESV:6,' ':5,MAXA:5:2,' ':7,TOTA:7:1,' ':12,
      MAXW:5:2,' ':5,TOTW:7:1,' ':12,MAXC:5:2,' ':5,TOTC:7:1,
      ' ':12,MAXS:5:2,' ':5,TOTS:7:1);
   TOTA:=0;  TOTW:=0;   TOTC :=0;   TOTS:=0;
   MAXA:=-MAXCON;   MAXW:=-MAXCON;  MAXC:=-MAXCON;  MAXS:=-MAXCON;
   DATESV:=DATEIN;
   LC := LC +1;
   STVAL :=0;
   END;    (* END OF DATE CHANGE *)

PROCEDURE READRTN;

   (*  READ THE APPROPRIATE INPUT RECORD BASED ON THE TYPE CODE *)

   BEGIN
   READ(CODEIN);
   CASE CODEIN OF
      1:READLN(DATEIN,PLOTCD,MAXD);
      2:READLN(EDVAL,TIMEIN);
   END;  (* CASE *)
   END;       (* END OF READ PROCEDURE *)

PROCEDURE CALCMAX (MAXD:REAL);

   (* CALCULATE THE MAXIMUM FLOW RATE FOR THE PLOT, USING THE
     APPROPRIATE EQUATION *)

   BEGIN
   IF SITE = 'ROSEISLE' THEN
      BEGIN
      CASE PLOTCD OF
         'A':MAXA:=(0.1315 - 0.0537*(MAXD) + 0.0109*SQR(MAXD));
         'W':MAXW:=(0.0488 - 0.018*(MAXD) + 0.0053*SQR(MAXD));
         'C':MAXC:=(0.0542 - 0.0186*(MAXD) + 0.0052*SQR(MAXD));
         'S':MAXS:=(0.0454 - 0.0102*(MAXD) + 0.0047*SQR(MAXD));
      END    (* CASE *)
   END ELSE BEGIN
      CASE PLOTCD OF
         'A':MAXA:=(0.0128 + 0.0041*(MAXD) + 0.0035*SQR(MAXD));
         'W':MAXW:=((-0.0072) + 0.016*(MAXD) + 0.0021*SQR(MAXD));
         'C':MAXC:=(0.0273 - 0.0054*(MAXD) + 0.0037*SQR(MAXD));
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          'S':MAXS:=(0.0362 - 0.0098*(MAXD) + 0.0041*SQR(MAXD));
       END   (* CASE *)
    END   (* IF *)
    END;   (* PROCEDURE CALCULATE MAXIMUM *)

PROCEDURE SUMDIV (SVAL,EVAL:REAL; TM:INTEGER);

   (* SUM THE VOLUME FOR THE AVERAGE NUMBER OF DIVISIONS USING THE *)
   (* CORRECT EQUATION *)
  VAR
     SECS:INTEGER;
     AVG:REAL;

   BEGIN
   SECS := TM*SECCON;
   AVG:= (SVAL + EVAL)/2;
   IF SITE = 'ROSEISLE' THEN
      BEGIN
      CASE PLOTCD OF
         'A':TOTA:=TOTA + ((0.1315 - 0.0537*AVG
              + 0.0109*SQR(AVG))*SECS);
         'W':TOTW:=TOTW + ((0.0488 - 0.018*AVG
              + 0.0053*SQR(AVG))*SECS);
         'C':TOTC:=TOTC + ((0.0542 - 0.0186*AVG
              + 0.0052*SQR(AVG))*SECS);
         'S':TOTS:=TOTS + ((0.0454 - 0.0102*AVG
              + 0.0047*SQR(AVG))*SECS);
      END   (* CASE *)
   END ELSE BEGIN
      CASE PLOTCD OF
         'A':TOTA:=TOTA + ((0.0128 + 0.0041*AVG
              + 0.0035*SQR(AVG))*SECS);
         'W':TOTW:=TOTW + (((-0.0072) + 0.016*AVG
              + 0.0021*SQR(AVG))*SECS);
         'C':TOTC:=TOTC + ((0.0273 - 0.0054*AVG
              + 0.0037*SQR(AVG))*SECS);
         'S':TOTS:=TOTS + ((0.0362 - 0.0098*AVG
              + 0.0041*SQR(AVG))*SECS);
      END   (* CASE *)
   END   (* IF *)
   END;   (* PROCEDURE SUM VOLUMES *)

BEGIN   (***********M A I N L I N E  *************)
LC := 65;
IF NOT EOF THEN1 1127/5
   BEGIN
   SITE := '';
   FOR IND:=1 TO SITELEN DO
      BEGIN
      READ(CH);
      SITE:=SITE||STR(CH);
      END;   (* FOR *)
   READLN;
   (* READ IN SITE NAME *)
   READRTN;   (* READ 1ST RECORD *)
   DATESV := DATEIN;
   STVAL := 0;
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   MAXC := -MAXCON;   MAXA := -MAXCON;  MAXW:=-MAXCON; MAXS:=-MAXCON;
   TOTA:=0;  TOTW:=0;  TOTC:=0;  TOTS:=0;
         (* INITIALIZE ACCUMULATORS AND SAVES *)

   WHILE (NOT EOF) DO
      BEGIN
      IF DATEIN <> DATESV THEN
         DATECH(TOTA,TOTW,TOTC,TOTS,MAXA,MAXW,MAXC,MAXS,DATESV);
      CASE CODEIN OF
         1: BEGIN
              CALCMAX(MAXD);
              END;   (* CASE 1 *)
         2: BEGIN
              SUMDIV(STVAL,EDVAL,TIMEIN);
              STVAL:=EDVAL;
              END  (*  CASE 2 *)
         END;   (* CASE *)
      READRTN
      END;   (* WHILE *)
   DATECH(TOTA,TOTW,TOTC,TOTS,MAXA,MAXW,MAXC,MAXS,DATESV)
   END   (* IF *)
END.
//GO.INPUT DD *
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